UNIVERSITY OF GHANA-LEGON

EFFECT OF POSTHARVEST WAXING TREATMENTS, YAM VARIETY AND TUBER SIZE ON SHELF LIFE OF WHITE YAM (*Dioscorea rotundata* Poir)

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL CROP SCIENCE DEGREE

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DECLARATION

I certify that this study was carried out by me, Yusuf Dramani, of Crop Science Department, University of Ghana-Legon at Apiakura in the Volta Region of Ghana and also at Nuguchi Memorial Research Institute of the University of Ghana-Legon. I further testify that this thesis has never been presented on any occasion at any university for the award of a degree and that any literature cited has been acknowledged.

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ABSTRACT

A significant quantity of yam tubers gets deteriorated in storage due to sprouting, weight loss, and rotting. There was, therefore, the need to identify cost effective ways of extending postharvest life of yam tubers without compromising with the health of consumers. Therefore, field research was conducted to explore the effect of shea butter & palm kernel oil waxing, yam variety, and tuber size on postharvest shelf life of Puna, Asana, and Punjo varieties of white yam (*Dioscorea rotundata).* Laboratory experiment was also carried out to find out the possible sensory quality changes that might have occurred as a result of shea butter and palm kernel oil waxing. The field experiment was conducted using the farmers' own storage facilities at Apiakura located along the Jasikan-Abotoase trunk road in the Volta Region of Ghana. The variable factors used in the field experiment were waxing, yam variety and tuber size while the fixed factors were similar storage facilities, and constant ambient conditions (temperature, relative humidity, and wind speed in and around the storage facilities). The waxing comprised shea butter, palm kernel oil waxing and unwaxed tubers (control). Yam varieties used were Puna, Asana, and Punjo, whilst tuber sizes used were smaller tuber size (with surface factor 1.1 ±1), medium tuber size (with surface factor (1.4 ±1) and bigger tuber size (with surface factor 1.7 ±1). The experimental design used was a 3 x 3 x 3 factorial in randomized complete block design. Four storage facilities were used. Each storage facility was used as an experimental block, and they were located at different farms. Each block contained 27 treatment combinations. Data collected were weight loss (%), sprouting (%), and rotting (%) at 2 weeks intervals. The sensory evaluation was conducted in the Home Economics Food Laboratory at Bueman Senior High School at Jasikan using 20 trained sensory panellists. Sensory qualities evaluated were; taste, flavour, texture, attractiveness (appearance) of the cooked, and acceptability to consumers. Food tests were carried out at the Nuguchi Memorial Research Institute to monitor the moisture contents and the levels of reducing sugars in the stored yam to verify the occurrence of sprouting and weight loss. The results from the study indicated that shea butter and palm kernel oil waxing reduced weight loss, sprouting, and rotting significantly ($p < 0.05$) for up to three months. Yam variety and tuber size were also found to affect weight loss significantly ($p < 0.05$). There were interaction effects among the three factors (waxing materials, tuber size, and yam variety) used. In addition, waxing, yam variety, and tuber size were also found to affect taste, texture, and flavour of the yam tubers. However, these treatments did not affect attractiveness and acceptability. Shea butter and palm kernel oil waxing reduced weight loss, sprouting, and rotting. Generally, the result showed great potential for yam farmers and exporters whose income is being affected by high tuber weight loss (desiccation), sprouting, and rotting. This discovery, will also boast food security situation in Ghana.

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DEDICATION

I dedicate this work to my beloved mother (Ms. Abiba-Tani Akosua Daru) and my wife (Ms. Sherifatu Abubakar Mustapha) for their endless supplications and words of encouragement that have brought me this far.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Yam (*Dioscorea spp.*) is a major staple food crop in Ghana and in other parts of the world especially West- and East-Africa, Caribbean, and Asia-Pacific regions where the crop is largely cultivated. Annual yam production globally is about 30.3 million metric tons (Bancroft, 2000). Edible yams are major food security crop in the diet of over 60 million people in the world (FAO, 2002). Apart from its high calorie content (381 kCal per 100 g), yam has good amount of protein (4.94 g per 100 g), vitamin (64 mg per 100 g), fibre (13.23 g per 100 g), and minerals (2.97 g per 100 g) (Jonathan *et al.,* 2011). Yam is the second most important tuber crop in West Africa after cassava (*Manihot utilisima*) in terms of tonnage of production and in food security terms (Robertson & Lupien, 2008).

The main cultivated species of yam are white yam (*Dioscorea rotundata*), yellow yam (*D. cayenensis),* water yam *(D. alata),* cush-cush yam *(D. trifida),* and air potato *(D. bulbifera)* (Asiedu & Alieu, 2010). In Ghana, greater quantity of yam is produced in the Northern, Volta, Upper West, Brong-Ahafo, and Ashanti regions (Sagoe, 2006). Many farmers in Ghana are yam farmers (Aidoo, 2009), and annual rate of yam consumption in Ghana is estimated to be 42.3 kg/caput (Sagoe, 2006). The most preferred forms of consuming yam in Ghana are pounded yam (*fufu*), boiled yam slices (*busa*), and fried yam (*koliko*). Greater profit is made from selling yam in tuber form than in processed forms (e.g. yam flour) (Robertson & Lupien, 2008; and Aidoo, 2009). White yam consists of about 80% of total global production of yam per annum (ITTA, 2009 and Beckford *et al*., 2011).

Postharvest losses of yam have been a major challenge for farmers in Ghana (Alhassan, 1994). The level of yam tuber perishability at postharvest is causing farmers to lose high amount of income (Akoroda & Hahn, 1995 and GTZ, 1995). It was revealed that 10-12% of yams get rotten in the first 3 months of storage and 30-60% after 6 months of storage (FAO, 2003). Farmers prefer to store greater part of harvested yams for a minimum period of three months to enable them make much profit (Alhassan, 1994 and Kleih *et al,* 1994). Postharvest yam losses are caused by physiological and pathological factors (Osunde, 2008). Physiological causes lead to tuber weight loss (desiccation) and loss in nutritive quality while pathological losses are mainly rotting (decay) caused by fungi, bacteria and parasitic nematode (Ravi & Aked, 1996; FAO, 1998; Osunde, 2008). Market survey conducted in Ghana by the researcher prior to this study revealed that prices of yam tubers do increase towards the lean season (beginning from February each year) and, therefore, farmers who have yam tubers, especially white yam tubers (e.g. Puna), during the lean season period (February to June), make much profit.

Interaction with yam farmers at Apiakura in the Biakoye District of Volta Region in Ghana by the researcher prior to this study revealed that there were high postharvest losses of yam tubers, and that had produced disincentive for yam cultivation at Apiakuro and its adjoining communities, thereby, leading to high rate of poverty and food insecurity among the people. There was, therefore, the need to identify cost effective means of reducing postharvest losses of stored yam tubers to increase food security and also maximize farmers' income.

1.2 Rationale and Justification

Extending shelf life of yam tubers is very necessary since higher profit margins are realised when fresh tubers are marketed instead of processed yam products (Robertson & Lupien, 2008 and Aidoo, 2009). Rees (2012) asserted, when given the needed husbandry and postharvest storage attention, yam can help alleviate food security concern in Ghana. In addition, Bancroft (2000) explained that as a result of the importance of yam as a major food security crop, the National Agricultural Research Strategy Plan for Ghana included yam as a priority crop for research and development in 1994, and this is the main reason why effort is being made to reduce postharvest losses estimated at 20%. Socio-economic status of yam farmers will significantly be improved if very appropriate and cost effective method of storing yam for longer period of time is identified or developed (Robertson & Lupien, 2008 and Aidoo, 2009).

Extending shelf life of yam tubers will help farmers improve their living standard since they could store their harvested tubers to meet the time of good market price (Aidoo, 2009). Most farmers in West Africa could not store their tubers for more than two months due to poor storage infrastructure (FAO, 2003) and are, therefore, compelled to dispose of their harvested tubers at the time when market is glutted with yam. This situation creates low market price per unit of tuber (Robertson & Lupien, 2008). Extending the shelf life of yam tubers will increase the availability of yam tubers all year round.

Another reason why this study is justified is that Ghana's foreign exchange earnings from roots and tubers will also be increased. For example, while agriculture contributed about 75% of Ghana's export earnings in 2002, root and tuber crops alone contribute about 40% of the total agricultural gross domestic product (MOFA, 2003). Sagoe (2006) also reported that Ghana's root and tuber exports generate about 75% of Government earnings and offers about 70% employment for the population. Postharvest crop losses in general are having serious repercussion on global food security. It is noted that 75% of countries in Africa are in serious food crisis (Maplecroft (2012), hence the need to work to prevent or reduce postharvest losses of staples such as yam (FAO (2012).

It was discovered that sheabutter waxing could extend green life of plantain by 10 days (from 11 to 21 days) (Sugri & Johnson, 2009). Waxing yam tubers with epolene (E10) improves appearance quality (attractiveness) but there is no effect on the levels of fungal infection and weight loss (Akihisa *et al,* 2010). Sheabutter (SBO) and palm kernel oil (PKO) were used in this research study because both contain high amount of lauric acid which are known to inhibit weight loss in living organisms (Akihisa *et al.,* 2010). Palm kernel oil also has antimicrobial properties, and this implied that microbial (pathogenic) causes of yam rot could be reduced. Shea butter and palm kernel oil waxing are relatively cheap compared to using other storage method such as refrigeration and irradiation. Furthermore, since SBO and PKO are natural (organic) edible waxes, health problems associated with the used of inorganic chemicals for postharvest treatments would be avoided since inorganic chemicals leave toxic residues in yam tubers making the tubers unwholesome for consumption (Marcotte *et al*., 2005; Osunde, 2008; Babalola & Apata, 2011; Imeh *et al*., 2012). Thus, the use of shea butter and palm kernel oil for waxing of tubers would ensure safety of consumers since SBO and PKO are edible fat and oil from natural food sources and have no known negative health effects on consumers (Babalola & Apata, 2011).

In this research, effect of yam tuber size on postharvest shelf life was also studied. This is because size of tuber was found to affect the rate of moisture loss (Ezeike, 1984); therefore, there was the need to find out what tuber size would better extend postharvest shelf life. Effect of yam variety on postharvest losses was also studied to confirm the effect of yam variety on postharvest losses. Many of the farmers interviewed prior to this study complained that among the three major white yam varieties (Puna, Asana, and Punjo), Puna is highly perishable.

The interactions among the waxing materials (SBO and PKO), tuber size and tuber variety were studied to know whether the application of these three factors could result in postharvest shelf life extension of tubers when they (these factors) are combined. Effect of SBO and PKO waxing on nutritional composition and sensory qualities of stored yam tubers were also considered in the study because some waxes are likely to produce undesirable sensory qualities in the yam tubers that could affect marketability (Chiedozie et. al., 2003).

1.3 Objectives

The research was aimed at assessing the effect of shea butter and palm kernel oil waxing, variety and tuber size on postharvest shelf life of Puna Asana, and Punjo varieties of white yam (*Dioscorea rotundata*). The specific objectives of the study were to determine:

1. effect of the two waxing treatments (shea butter and palm kernel oil) on weight loss, sprouting, rotting in white yam tubers.
2. whether potential interactions among waxing material, tuber size, and yam variety on sprouting, weight loss, and tuber rotting exist.
3. effect of the waxing material on the nutritional composition and sensory qualities of cooked white yam tubers

CHAPTER 2

2.0 LITERATURE REVIEW

In this chapter, various relevant literatures concerning yam production, importance of yam, postharvest losses, effect of sprouting, effect of dormancy in yam storability, effect of pathogens on quality of yam tuber, sensory qualities of yam tubers, biochemical changes occurring during yam storage, methods of storing yam tubers, waxing of fresh agricultural produce, effect of waxing (on weight loss, decay, and attractiveness of tubers), physico-chemical properties of shea butter and palm kernel oil, and effect of surface factor on weight loss have been reviewed in separate subheadings.

2.1 Yam Production in Ghana

Yams (*Dioscorea spp.*) are starchy large tuberous staple food crop produced by annual and perennial vines (IITA, 2009). Roots and tubers especially cassava and yam are cultivated and consumed respectively by about 500 million and 700 million people in tropical and subtropical regions of the world (Ravi & Aked, 1996). Ghana is the third largest yam producing country in the world with annual tonnage production of 4 million (MIDA, 2010). Several varieties of white yams are cultivated throughout the country but predominantly in the Northern and Brong Ahafo Regions, and the northern part of the Volta Region. Some of the varieties of white yam (*Dioscorea rotundata)* are Puna, Dente (Punjo), Asana (Mpuanu), and Orlondor (also called Nigeria) with Puna being the most preferred variety due to its early maturing, high yielding, and sweetness (high sugar content) but is highly perishable (MIDA, 2010). Though Ghana is the third leading producer of yam, it is the largest yam exporter in the world (IITA, 2009 and MIDA, 2010). Ghana's annual yam export is more than 21, 000 metric tonnes (MIDA, 2010).

2.2 Economic Importance of Yam

It has been reported that more than two-thirds of annual yam production in West Africa is sold out as fresh tubers with only small fraction sold in processed form such as yam flour, chips, and flakes (MIDA, 2010). Additionally, only a small fraction of annual yam production is processed into industrial starch (MIDA, 2010). The crop is very valuable in the local commerce in West Africa and accounts for nearly 32% of farm revenue (Chukwu & Ikwelle, 2000). In urban centres, yam constitutes close to 13% of household budget in Ghana (Aidoo, *et al.* 2009). It contributes significantly to the foreign exchange earnings (Ohene-Yankyera *et al.,* 2011), and is utilized as raw materials for starch manufacturing and pharmaceutical products (Amanze *et al.,* 2011). The production and marketing of yam provide great prospects for income generation since large number of people are involved in yam business ranging from farmers, distributers, transporters, processors to consumers.

2.3 Socio-cultural Importance of Yam

Socio-culturally, yam is a very important food crop for many ethnic groups in Ghana and in many other parts of the world. Many festivals are celebrated with the onset of new yam. In Ghana, for instance, *Tedudu-za* (Yam Festival) is celebrated by the Asorgli people of Ho in the Volta Region (Nortey, 2012). TwinsYam festival is also celebrated by the Gas during the celebration of another festival called *Homowo* (Nortey, 2012) where yam is used to prepare food in honour of twins. In addition, Okeke *et al*. (2008) stated that in Niger state in Nigeria, yam harvest is celebrated where everyone contributes a fowl. The Yorubas of Nigeria celebrate Yam festival at the onset of harvest to bring people together to make merry and contribute towards the development of their area. In Fiji, great feasts are celebrated at first harvest of new yam where tubers are presented to ancestral spirits. This serves as a way of commemorating and remembering important events in history. Mbiti (1990) asserted that festivals of these kind bring people together, thus, solidifying their unity and cohesion. Socio-culturally, yam is an important part of bride price among some tribes or ethnic groups in West Africa (Osunde, 2008). The Nchumurus of Ghana especially those in Grubi, Akaniem, Lentemanso, Chinderi, and Borae in the northern part of Volta Region used bigger yam tubers as part of the pride price (Nortey, 2012). Yam is also a calendar crop around which the season of farming and yearly festivals revolved (Okeke *et al*., 2008).

2.4 Medicinal Values of Yam

Yam is sometimes regarded as health food instead of staple food in oriental countries (Liu *et al.,* 1995). Recently, lots of health benefit of yam were identified and presented in literature (Hou *et al*., 2001). For example, literature of Traditional Chinese herbal medicine reports that yam has anti-aging activity (Hou *et al*., 2001). Significant anti-oxidative activity and modified serum lipid levels were identified in humans fed with yam extracts (Araghiniknam, *et al*., 1996). Yam flour has been used to protect rats against chemical-induced toxicity (Farombi, *et al*., 1997) and purified storage protein of yam called dioscorine was found to contain scavenging properties against free radicals (Hou *et al*., 2001). Consumption of yam may, therefore, reduce the rate of aging in humans. Some yam varieties have been utilized in traditional herbal medicines for centuries. It is used predominantly to promote proper functioning of the renal and the endocrine system in female (Hou *et al*., 2001). For instance, the roots of the yam have traditionally been given to lactating women, but there is no distinct proof as to whether indeed yam root facilitate milk secretion in lactating mothers. Studies are on-going to find a connection between diosgenins (a chemical substance found in yam) and the endocrine functioning of female. Additionally, yam also helps to reduce water retention and nausea at pregnancy (Liu *et al*., 1995). Yams contain high amount of vitamin B6, a good supplement for women under depression as a result of premenstrual syndrome (Liu *et al*., 1995). Regular consumption of vitamin B6 is known to be very beneficial against some heart related diseases and stroke (Benzie, 2000). Yam tubers help in breaking down some chemical substances known as homocysteine (Liu *et al*., 1995) which raptures walls of blood vessels resulting in some health problems (Benzie, 2000). The complex carbohydrate and fibre in yam convert into sugar at a very slow rate, thereby, slowing the rate of absorption into the blood stream (Hou *et al*., 2001) to lower or maintain blood sugar level. Furthermore, based on the high fibre content of the yam, it helps distribute weight uniformly without heaping extra weight to the hip or the waistline (Benzie, 2000). It contains good amount of manganese that is needed in metabolic activities of carbohydrate and antioxidant defences (Araghiniknam, *et al*., 1996). Additionally, manganese is a co-factor in some enzymes that are involved in energy production. The crop provides essential elements for optimum functioning of the glandular to benefits the urinary, respiratory, and nervous systems (Benzie, 2000). Yam helps in controlling hypertension (Benzie, 2000) by supplying good amount of potassium. It is identified that yam also facilitate digestion process by dilating vessels and stimulating the flow of bile (Liu *et al*. 1995).

2.5 Nutritional Values (Importance) of Yam

Yam tubers are composed of a high moisture content (55-75%) and dry matter. The dry matter is predominantly composed of carbohydrates (65-80%), vitamins (ascorbic acid, carotene and riboflavin), protein (1-2%, fresh weight), in addition to sugars and minerals (iron, calcium, phosphorous and ash) (Olayiwola & Okhiria, 2012). Yams in Ghana have good amount of ascorbic acid (vitamin C) levels (Okwu & Ndu, 2006). Natural vitamin C levels of most yam varieties is between 6.5 and 11 mg per 100g of tuber, but some are found to contain as small as 4.5 mg and as much as 21.5 mg/100g. Loss of vitamin C in yam tubers over storage for the first 4 months was relatively less in undamaged yam tubers; however, loss of vitamin C was high in tubers which are either damaged or bruised prior to storage. The quantity of yam consumed by households in West Africa is enough to supply all the vitamin C requirements per consumer. Yam contains some vitamin B6 which is found to be very good for human health in diverse ways (Osunde, 2008).

Yam is an important source of calories and many other nutrients in the diet of many people. It was even further asserted that yam provides much protein than is often appreciated (Osunde & Orhevba, 2009). The crude protein content of white yam was found to be between 6.40–9.64 g/100g (Mbome-Lape & Treche 1994 and Agbor-Egbe & Trenche, 1995). This is why white yam is regarded as a good source of nutrients for people. Nutritionally, yam is very important than cassava which is widely grown in all regions in Ghana. This is because yam generally has higher protein than the 1.70 g/100 g reported for cassava (Osunde & Orhevba, 2009). Studies conducted by Osunde (2008) revealed that the carbohydrate proportion of yam tubers constitutes about three-quarters of its total dry weight. This indicates that yam is indeed a good source of energy or calories to people and, therefore, a good staple food crop. Yam holds good amount of minerals. For instance, the concentration of phosphorus is 16.1 mg/100 g, and iron is 10.0 mg/100 g (Afoakwa& Sefa-Dedeh, 2001). Yam has been identified to contain phosphorous and vitamins such as thiamine, riboflavin, niacin and ascorbic acid (Knoth, 1993).

2.6 Yam as an Important Food Security Crop (Dietary Importance)

Yams are important staple foods in many tropical countries (Akanbi et al., 1996). It is widely accepted staple food West Africa sub-region which provide adequate among of calories, dietary fibre and protein (MIDA, 2010) and serves as one of the main food security crops in tropical and sub-tropical regions of the world (IITA, 2009). More than 60 million people in West Africa live on Yam in daily basis (IITA, 2009). It is one of the crops identified to provide multiple opportunities for poverty alleviation and nourishment for people in Ghana. Yam production, however, is stagnating and for that matter threatening rural livelihoods and urban food security (Asumugha *et al*., 2009). It could be predicted that the crop will remain the most preferred starchy staple for many people in West Africa for many years to come. The tuber is currently the most expensive tuber crops in market partly because large amount of the crop deteriorate during storage. There is, therefore, the need to explore other cost effective ways of keeping the tubers for a longer period after harvest. According to Nweke, *et al*. (1991) and FAO (1999), yam will continue to be a major food security crop for about 300 million low income people in food deficit countries in the tropics by providing them with nearly 200 dietary calories per day.

Nutritionally, yam is said to be far better than cassava based on the fact that yam provides higher amount of vitamin C which is between 40-120 mg/g edible portion and crude protein of 40-140g/kg dry matter contents. It also does not contain cynogenic compounds as it is in cassava (FAO, 1999). They also concluded that about 4.6% of net dietary protein and calorie exists in yam as compared to4.7% in maize (MIDA, 2010). Yam, according to IITA (2009), is very important crop for both domestic and export markets serving as a great source of income and vital staple crop for food security. Knoth (1993) noted that yam meal could provide 100% total energy and protein requirement of male adult including about 13% and 80% calcium and iron respectively. As a result of high postharvest losses, farmers are compelled to sell the tubers just after harvest in order to avoid postharvest losses and so end up selling their produce at a much reduced price, thereby, having significant effect on their overall profit, and also having serious food security implication during the lean season (Okigbo & Ikediugwu, 2002 and Aidoo, 2007).

2.7 Post-Harvest Losses of Yam in Ghana

Yam tubers are perishable produce (Alhassan, 1994). It was observed that large quantities of yams are lost annually to the detriment of producers, distributors, and consumers. Though agriculturists generally believed that tubers of yam store well, that is not the case since candid observations showed that postharvest losses are heavy (Asiedu & Alieu, 2010). The bulkiness of yam tuber, its chemical composition and moderately high water content predispose it to degradation during long-term storage (Asiedu & Alieu, 2010). Losses occurring during storage of yam could be classified into quantitative and qualitative losses. Quantitative losses of yam include weight loss which is mostly due to moisture loss through transpiration and, thereby, leading to desiccation. Qualitative losses include dry matter losses (loss of nutrient content as a result of sprouting and respiration) and loss of nutritive quality. Available statistics indicate that weight loss after 3 months of storage ranges between 10-20% and 50% after 6 months of storage (Robertson & Lupien, 2008)

2.7.1 Causes of Post-Harvest Losses of Yam

The storage of fresh yam tubers has been confronted with a major problem over the years. The factors that contribute to yam losses in storage are physiological and pathological (Ravi & Aked, 1996; Kader, 2005; Imeh *et al*., 2012). Physiological activities in yam that lead to postharvest losses are transpiration and respiration which in turn contribute to weight loss, sprouting (turning of edible tuber carbohydrates to inedible sprout), and desiccation (Marcotte *et al*., 2005; Osunde, 2008; Imeh *et al*., 2012) Pathogenic causes of postharvest yam deterioration include moulding (fungal growth) and bacterial infection (Green &

Simons, 1994 and Dumont, 1995). Physiological activities taking place in yam tubers in storage bring about some changes in their internal composition, thereby, resulting in loss of nutritional qualities (Serge & Agbor-Egbe, 1996; Afoakwa & Sefa-Dedeh, 2001; Osunde, 2008), and under normal storage condition can cause 10% losses within 3 months and up to 25% losses in 5 months (Robertson & Lupien (2008). Major causes of postharvest losses, according to (Ezeh, 1995), are weight loss, insect attack, microbial, and sprouting. Sprouts development, according to Osunde (2008), is a major cause of storage losses. Weight loss is greatly influenced by respiration and transpiration where the latter is accelerated by sprouting (IITA, 1995 and Kader, 2005). Yams exported to EU market from Ghana are usually characterized by rotting at the point of arrival with a wastage rate of 10 to 50% (Asante, 2002) and 25-50% losses globally (Anon, 1993).During the early stages of storage, yam tubers do experience low rate of respiration which is followed by high respiration rate which coincides with sprouting (PH, 2004c). Furthermore, there is a close relationship between the amount of CO_2 produced and dry weight losses in yam tubers (Afoakwa & Sefa-Dedeh, 2001).

2.7.2 Weight Loss and Yam Tuber Quality

Depending on the cultivar, the moisture content of yams ranges between 60 - 80% (Asiedu and Alieu, 2010). The moisture content of fresh yam reduces steadily at storage. Water loss from the tubers is sometimes difficult to notice during the first weeks of postharvest, and in some cases, there could be slight moisture rise (Asiedu & Alieu, 2010). After this phase, moisture loss continues to increase. Thus, weight loss in yam occurs when tubers lose moisture (water). This usually occurs because transpiration and respiration processes take place in living tubers (Ravi & Aked, 1996). The higher the moisture loss, the higher the weight loss (Aidoo, 2007). This implies that the size of yam tubers reduces as a result of weight loss (moisture loss) leading to loss of revenue since price of yam tubers depend on sizes or weight (in EU and US markets price of a yam tuber depends on its weight). Qualitatively, the greater the moisture loss, the more wrinkled and unattractive the tubers become to buyers (De Waal & Nadine, 2005). Within the first five months of storage, weight loss due to transpiration was estimated to be about 20% (Osunde, 2008). During storage, yam moisture and starch contents decrease whiles sugar content increases. The polysaccharide constituents of the cell wall which comprises lignin, cellulose, acid and fibres, and hemicelluloses are found to increase at storage, thereby, resulting in hardening of tubers leading to loss of quality (Afoakwa & Sefa-Dedeh, 2001). It was noted that the rate of quality change greatly depend on the condition and duration of storage (Afoakwa & Sefa-Dedeh, 2001). Osunde (2008) reported that nutritional value of yam tubers is affected by weight loss due to respiration but not transpiration. He further reiterated that weight loss due to transpiration is not desired since it causes viability loss and shrinkage, thereby, resulting in tuber unattractiveness and flavour loss

2.7.3 Effect of Sprouting on the Quality of Yam Tubers

Tubers of yam are living organs and, therefore, continue to respire. For the continuation of this process, energy (carbohydrate) stored in the tubers are used up. During this process, carbon (IV) oxide (CO_2) and water (H_2O) are released into the atmosphere. The difference between transpiration and respiration in this instance is that while transpiration only causes water loss, respiration causes the stored energy in the tubers to be used up, thereby, reducing the amount of food available for human consumption. For instance, at dormancy, one kilogramme (1 Kg) of yam tuber stored at of 25^0C lost the equivalent of 3 ml of CO_2 per hour (Afoakwa & Sefa-Dedeh, 2001). Increased respiration is the consequence of sprouting. Sprouting of yams that are meant for consumption is unacceptable because the process result in loss of carbohydrate, sugar, and other nutrient contents in the yam tubers (Afoakwa & Sefa-Dedeh, 2001). The more the nutrients such as carbohydrates are lost, the smaller the yam becomes in terms of size, and less the price of the yam respiration (Ravi and Aked, 1996). This affects the income level of yam exporters and farmers in Ghana. Sprouting is accelerated by respiration (Ravi and Aked, 1996). All tubers of a cultivar are found to sprout at about the same period after storage. This assertion is true for *D. rotundata*, *D. alata,* and *D. esculenta* planted within the same period and stored under similar conditions (Elsie, 2011). When sprouts are removed regularly on monthly intervals, it helps reduce the amount of weight loss and at the same time increase useful storage life (Osunde *et al.* 2003). Sprouts removal at monthly intervals reduces fresh tuber weight loss within5-month storage period by 11% in *D. rotundata* and *D. alata* tubers (Osunde *et al.* 2003). Furthermore, Osunde (2006) reiterated that removing sprout in tubers reduces weight loss while those whose sprouts are not removed experience high weight loss. This implies that if sprouting can be prevented, it will enhance farmers' economic gain.

2.7.4 Effect of Dormancy in Yam Storability

Yam tuber dormancy is an indication of a state of rest when metabolic activities such as respiration, starch and sugar metabolism, and enzymatic activity are low or indicate the presence of endogenous growth inhibiting substances (Elsie, 2011). Thus, the period of dormancy is a period when fresh tubers of yam are unable to sprout (germinate) which is largely due to internal and external factors. The ability to extend the dormancy period of yam tubers will be largely beneficial to both farmers and marketers or yam traders. This is because the onset of sprouting in yams that are meant for the market (consumption), seriously affect their market value. The ideal (optimum) temperature for sprouting among tropical species is between 25 and 30 ^{0}C (Osunde, 2008). The exposure to a higher temperature of 35^{0}C was found to cause about 85% sprouting of yam tubers after 95 days of storage (Asiedu & Alieu, 2010). Besides, low temperatures between 15 to 16^{0}C were found to extend dormancy but temperature below 10 ^{0}C causes chilling injury (Osunde, 2008). In yam-barn storage condition, sprouting takes place steadily or progressively earlier during warmer conditions until it reaches the optimum. This is because of the fact that temperature in yam barns fluctuates (Elsie, 2011).

2.7.5 Effect of Pathogens on Quality of Yam Tuber

Pathogens (microbes) such as fungi, bacteria, and nematodes cause postharvest losses of yam tubers through rotting. Yam tuber rot is mostly caused by pathogenic fungi. These fungi include *Aspergillus flavus, Aspergillus niger, Botryodiplodia theobromae, Fusarium oxysporum, Fusarium solani, Penicillium chrysogenum, Rhizoctonia* spp.*, Rhizopus nodosus Penicillium oxalicum,* and *Trichoderma viride* (Okigbo & Ikediugwu, 2002 and Aidoo, 2007). Normally, fungi that do cause rot are lesion pathogens, thus, they depend on the lesions or wounds to enable them penetrate the tubers to cause rot (Okigbo & Emoghene, 2004). Yam rot can be classed into three namely, dry, watery, and soft rot (Aidoo, 2007 and Lebo, 2009). Dry rot is usually not observed externally. Rottenness causes quality attributes such as consistency and flavour to be lost or rendering the tuber unwholesome for consumption, thereby, causing huge loss in market value. Even though bacteria do cause yam to rot, they are not economically important as mould fungi. There are numerous species of mould fungi which infest yam tubers but often these are only of regional importance (Jonathan *et al*. 2011)

2.7.6 Biochemical Changes Occurring During Yam Storage

Yam tubers are living organs and for that matter undergo some biochemical changes with time. These changes take place as a result of respiration and transpiration processes taking place in the living tissues of the yam tubers. These biological processes are greatly influenced by ambient condition of the yam tubers dictated by temperature, relative humidity, and duration of storage (Afoakwa & Sefa-Dedeh, 2001). For instance, when white yam (*D. rotundata*) is stored for 110 days (nearly 4 months) under normal storage condition (28 ^{0}C), the rate of moisture loss was found to be 31% (Serge & Agbor-Egbe,1996). This shows that yam tubers undergo quite rapid dehydration at postharvest possibly leading to cell wall polysaccharides to shrink and allowing maximum interactions of hydrogen bonding and Van der Waals forces; this increase cell rigidity at storage (Afoakwa & Sefa-Dedeh, 2001).

Furthermore, starch content of yam tubers decreases with the duration of storage, temperature, and the cultivar of storage (Afoakwa & Sefa-Dedeh, 2001). This means that decrease in starch content in yam tubers varies from one cultivar to another provided they are all treated alike at storage. This is why it is believed that metabolic activities taking place in yam tubers contribute significantly in post-harvest quality changes of the tuber. However, total alcohol-soluble sugars and reducing sugars increase with storage time, temperature, and the cultivar under storage. It is suspected that the rise in sugar level in tubers during storage is as a result of the breakdown and subsequent hydrolysis of starches into sugars at postharvest (Agbor-Egbe & Treche, 1995; and Panneerselvam & Abdul Jaleel, 2008).

It is also known that acid and neutral detergent fibre contents of yam tubers are greatly affected by storage condition, cultivar, and storage time, thus, during prolonged storage, fibre content increases (Afoakwa & Sefa-Dedeh, 2001). Studies conducted by Goodwin & Mercer

(1992) revealed that, generally, there had been some increases in the cellulose, lignin, and hemicellulose contents with storage time. It further explained that with the exception of lignin, other yam constituents such as cellulose and hemicellulose are affected by cultivar, storage condition and storage time of tubers. Both mature and immature tubers have starch as the most abundant carbohydrate (FAO, 1998), and this starch get used up or deteriorated with time through the processes of respiration and sprouting (ITTA, 2011). High temperature raises the level of enzymatic catalysis leading to biochemical breakdown of fresh produce compound (Osunde & Orhevba, 2009).A research conducted on the physical, chemical and sensory changes taking place in white yams and yellow yams stored for 150 days in traditional barns showed some losses in moisture, crude protein, dry matter, and ascorbic acid contents of yam tubers at the end of 120-day storage period (Osunde & Orhevba, 2009.Osunde*et al.* (2003) conducted a similar research in which they reported a weight loss of 17 – 22%, 30 – 50% loss in crude protein, and 38-49 % appreciation in sugar content of yam stored in barn. This is why Osunde & Orhevba (2009) stated that stored tuber do experience losses in weight, starch, crude protein, and mineral content but with some appreciation in sugar and fibre contents

2.7.7 Methods of Storing Yam Tubers in Ghana

Farmers in Ghana prefer to store harvested yam tubers for a while before selling to achieve good market price. However, farmers tend to encounter high storage losses and this in tend has caused an increase in the prices of yam tubers, thereby, compelling yam lovers to resort to the consumption of cassava as a substitute (Tetteh & Saakwa, 1991).

Harvested yam tubers are generally stored in traditional barns, cribs and heaps, and in ditches. Cold storage, irradiation and use of sprout inhibitors are also used to preserve yam tubers (Gyamfi, 2002).Cold storage as another method of storing yam, usually results in chilling injury when stored at temperatures below 13 ^{0}C (Henckes *et al*., 1995; Girardin *et al*, 1996; PH, 2004a; Osunde, 2008). Even the use of cold storage is costly considering the cost of electricity and the fact that most major yam producing areas in Ghana do not have electricity. Though yam can effectively be preserved using radiation or cold storage at temperature of 15 ^{0} C, its high cost of operation makes it inaccessible to farmers who are often located at places where electricity is non-available (Gyamfi, 2002). Farmers prefer to store most of their tubers after harvest because the most preferred form of consuming yam is in fresh tuber form which is used for *fufu* (yam dough or pounded yam), *busa* (boiled yam in form of slices) and *koliko* (fried yam in the form of slices). This means that better financial return is accrued from the sale of yam as fresh tubers than as processed yam flour.

Fresh yam tubers are treated in various ways before storage (Osunde, 2008); e.g. of the treatments include use of postharvest fungicides, palm wine, plant extracts and gamma irradiation while storage techniques include the use of yam barns, cold storage, and improved underground storage (Osunde, 008). This research in this thesis looks at treatment of yam tubers using waxing. It seeks to investigate how waxing can be used to extend the shelf life of yam tubers. Though waxing seems to be a promising alternative storage treatment for yams, much research about it has not been done.

2.8 Sensory Qualities of Yam Tubers

Consumers or buyers want tubers that have good looking skin and sometime a bit slimmer. Yam tubers are generally and naturally preferred when they have cylindrical shape (Osunde, 2008). Consumers' acceptability of boiled yam usually depends on the following sensory qualities: mealiness, colour (appearance), wetness, softness (texture), flavour, and taste, while that of pounded yam (*fufu*) is judged based on consistency, colour, sheen, smoothness, stickiness, and elasticity; these attributes are usually rated using hedonic scales (Chiedozie, *et al*., 2003). They further stressed that for boiled yam, mealiness, colour and taste are considered most important while for *fufu* consistency, colour and stickiness are most preferred.

2.9 Waxing of Fresh Agricultural Produce

Waxing is an act of coating fresh produce with food-based waxes which in turn slows down transpiration and improves their appearance by impacting an attractive lustre to the skin. Waxing creates a modified atmosphere in the products; thereby, extending the produce shelf life (Baldwin *et al.,* 1994 and Hu *et al*., 2011). Modified atmosphere occurred when the oxygen, which is much needed for respiration, is reduced around the product's ambient environment while the content of carbon (IV) oxide, which retards respiration, is increased. This condition is found to reduce the rate of respiration which eventually extends the shelf life of the product. Commercial waxes include carnauba wax, paraffin, and shellac (PH, 2004b). Waxing in cassava has been found to extend shelf life from a maximum of three days to one month by averting vascular tissue discoloration (PH, 2004b). Though waxing has been identified as a means of preventing excessive transpiration (PH, 2004b), its actual effects on most popular yam cultivars against sprouting, weight loss, nutrient degeneration, and microbial (pathogenic) attacks have not been thoroughly investigated.

Waxing yam tubers with epolene (E10) improves appearance quality but has no effect on the levels of fungal infection, and its effect on weight loss of tuber is inconsistent (Thompson & Bancroft, 1996; Osunde & Orhevba, 2009; Akihisa *et al,* (2010). In any case, the wax they used was epolene (E10) and not shea butter or palm kernel oil both of which have different biochemical properties compared to epolene (E10).Some of the differences in the properties of shea butter and palm kernel oil are: shea butter contains high amount of lauric acid which serves as a moisturizer and as anti-oxidant (Babalola & Apata, 2011) but epolene (E10) does not contain lauric acid, also shea butter is a natural wax (Pranut *et. al*., 2012), epolene (E10) is a synthetic wax (Akihisa *et. al.,* 2010). In addition, shea butter is not affected by moisture (Emenike, 2010) as compared to epolene (E10) which is negatively affected by moisture (Pranut *et al.,* 2012). In terms of cost, both shea butter (kariate butter) and palm kernel oil are less expensive and readily available in all the selected yam farming communities in Ghana. It is expected that this study, concerning the use of shea butter and palm kernel oil waxing, in Apiakura in the Volta Region will help in clarifying the situation.

2.10 Effect of Waxing on Weight Loss, Decay, and Attractiveness of Tubers

Waxing reduced weight loss slightly in potatoes as compared to un-waxed ones but had little commercial value (Serra *et al*., 2010). Transcontinental shipment test conducted on waxed and non-waxed potatoes revealed that more of the waxed potatoes experienced decay, especially from lenticels type infection and that consumer preferred the waxed potatoes to the un-waxed ones (Hardenburg *et al*., 1959). The researchers did not use shea butter or palm kernel oil which perhaps, might have revealed a different result. Besides, potato is quite different from yam and, therefore, conducting a research on yam using shea butter and palm kernel oil could be a useful trial. Waxed tubers are observed to have lustrous and attractive appearance. It is usually used in some countries in South America and Europe to improve market quality of tubers (PH, 2004a). Sheabutter waxing was used to extend shelf life of plantain from a maximum of 11 days to 21 days (3 weeks) (Sugri & Johnson, 2009). It was also reported that weight loss in cassava was reduced by 30 to 40% through Paraffin and carnauba waxing (PH, 2004b).

2.11 Physico-Chemical Properties of Shea butter (SBO) and Palm Kernel oil (PKO)

Physically, traditional shea butter is a white or somewhat yellow. It is semi-solid and waxy substance which melts at about 30-35°C. Texturally, shea butter is smooth and soft, but as it ages, it appears stiffer but still. It is very viscous and fatty (Emenike, 2010). Both shea butter (SBO) and palm kernel oil (PKO) are known to contain fatty acids, and they also have antimicrobial properties (Akihisa *et al.,* 2010). Palm kernel oil is noted to contain about 50% of lauric acid while no other major oil contains more than 3% of it (Codex Alimentariu Commission, 1999). Lauric acid is one of the important fatty acids, and it is found to be high in both PKO and SBO but comparatively higher in PKO than SBO (Babalola & Apata, 2011). According to Maranz *et. al* (2003), Shea butter characteristically has the property of moisturizing and protecting human skin against drying or moisture loss. It may do same to yam tubers when the tubers are waxed with it. Furthermore, shea butter has some phenols which include catechin, gallic acid, epicatechin, gallocatechin, epicatechingallate, and epigallocatechingallate plus trans-cinnamic acid and quercetin. The main fatty acids in shea butter are triglycerides predominated with oleic, linoleic, and stearic acids (Emenike, 2010). PKO also has high saturated fatty acid content which is mainly lauric acid (Babalola & Apata, 2011).

Antimicrobial studies of PKO revealed that it was active against *Escherichiacoli*, alpha and beta hemolytic streptococci, *Aspergillus fumigatus* and *Staphylococcus aureus* (Ekpa and Ebana, 1996). However, though PKO inhibited growth of *Escherichia coli,* it did not do same against *Pseudomonas aeruginosa, Staphylococcus aureus, Candida albicans* and *Asperigillus niger* (Ekwenye & Ijeomah, (2005). *Asperigillus niger* is one of the fungi that causes yam tuber rot (Bancroft, 2000). Okullo *et al.* (2010) and Tano-Debrah & Ohta (1994) also revealed that shea butter oil contain fatty acids such as palmitic, stearic, oleic, linoleic and arachidic fatty acids with the following value ranges: 6.52-8.12%, 28.65-30.94%, 54.99-57.72%,6.18-7.79% , and 0.65 - 0.90% respectively. They further stated that shea butter oil has beta-carotene and tocopherols (vitamin E). Tocopherol is an anti-oxidant and, therefore, an anti-cell aging. The assumption is that since shea butter contains fatty acids known to prevent moisture loss, then it is likely that it can helps prevent moisture loss in yam tubers if it is used to waxed the tubers. Another assumption is that since it contains tocopherol, when the oil is used to wax tubers, the rate of aging of living cells in yam tubers could be reduced since tocopherol is an antioxidant.

2.12 Effect of Surface Factor on Weight Loss

Solid materials such as yam tubers of different varieties and sizes have different geometric characteristics which may affect the rate of moisture loss to their surrounding environment depending on the prevailing ambient condition. This situation is better explained using the surface factor (SF) of the yam tubers concerned. Surface factor of a yam tuber relates to the total surface area of the yam tuber, thus, it is noted that the greater the values of the surface factor of a tuber, the higher the surface area available for the transfer of moisture and vice versa (Ezeike, 1984). The implication is that tubers with higher surface factor (SF) tend to lose much moisture than those with lower SF. SF influences weight loss because it affects water retention and movement in solid material. This may imply that SF of solid material could affect the rate at which moisture is lost from them. Also, solid of the same length but of different sizes are more likely to have different values for the SF. The above assertion implied that bigger solid materials have high value for surface factor.

CHAPTER 3

3.0 MATERIALS AND METHODS

The research was conducted in the field and the laboratory. The field work was conducted on the farmers' fields at Apiakora located in Biakoye District in the northern part of Volta Region using their own storage facilities (yam barns). The community is about 8 km from Jasikan along the Jasikan-Abotoase trunk road where yam cultivation is a major occupation. In the course of the research, both variable and non-variable factors were considered. The variable factors of the experiment were yam varieties (V), types of waxing materials (T), and different sizes of yam tuber (S). The non-variable (fixed) factors were similar storage structures and uniform environmental conditions (temperature, relative humidity, and wind speed) at the storage sites. The temperature (ambient and inside the storage barn) was 31±2 ^{0}C. The relative humidity was 75±3%. The humidity was determined by using hygrometer. Wind speed around the storage barn was found to be around 9km/h using hand held anemometer.

3.1 Assessment of the Effect of Sheabutter and Palm Kernel Oil Waxing, Yam Variety, and Tuber Size on the Shelf Life of White Yam Tubers

3.1.1 Experimental Design and Data Collection

A 3x3x3 factorial experiment in a randomized complete block design (RCBD) was used. Factor-A consisted of three (3) varieties of yam and were denoted as follows: $V_0 \rightarrow$ Puna, $V_1 \rightarrow$ Asana (Mpuano), and $V_2 \rightarrow$ Punjo; factor-B consisted of different waxing treatments indicated as follows: $T_0 \rightarrow$ no waxing (control), $T_1 \rightarrow$ waxing with shea butter oil (SBO), $T_2 \rightarrow$ waxing with palm kernel oil (PKO) and factor-C comprised of 3 different sizes of yam tubers denoted as follows: $S_0 \rightarrow$smaller tuber size (with a surface factor of 1.1±1), $S_1 \rightarrow$

medium tuber size (with a surface factor of 1.4±1), and $S_2 \rightarrow$ larger tuber size (with a surface factor of 1.7±1). In all, there were twenty-seven (27) treatment combinations forming a block as indicated in the table (3.1) below. The yam tubers used were carefully selected to avoid the use of diseased and bruised tubers. Only freshly harvested tubers were used for the study. These tubers were then labelled using the labelling of the treatment combinations stated in Table 3.1. These treatment combinations were represented in each of four blocks (replicates) with each block representing a different farmer's storage facility. These storage facilities were similar in terms of structure, ambient temperature, relative humidity, and wind speed. The selected tubers were used for the experiment on the fourth day after harvest. The storage period lasted for five months, from December, 2012 and to May, 2013.

Table 3.1: Factorial Treatment Combinations Used for the Study

			Factor A	
Factor B	**Factor C**	**V_0**	**V_1**	**V_2**
T_0	S_0	$V_0T_0S_0$	$V_1T_0S_0$	$V_2T_0S_0$
T_0	S_1	$V_0T_0S_1$	$V_1T_0S_1$	$V_2T_0S_1$
T_0	S_2	$V_0T_0S_2$	$V_1T_0S_2$	$V_2T_0S_2$
T_1	S_0	$V_0T_1S_0$	$V_1T_1S_0$	$V_2T_1S_0$
T_1	S_1	$V_0T_1S_1$	$V_1T_1S_1$	$V_2T_1S_1$
T_1	S_2	$V_0T_1S_2$	$V_1T_1S_2$	$V_2T_1S_2$
T_2	S_0	$V_0T_2S_0$	$V_1T_2S_0$	$V_2T_2S_0$
T_2	S_1	$V_0T_2S_1$	$V_1T_2S_1$	$V_2T_2S_1$
T_2	S_2	$V_0T_2S_2$	$V_1T_2S_2$	$V_2T_2S_2$

* *V_0 = Puna, V_1 = Asana (Mpuano), V_2 = Punjo, T_0 = no waxing, T_1 = waxing with shea butter oil, T_2 = waxing with palm kernel oil, S_0 = smaller tuber size (with a surface factor of 1.1±1), S_1 = medium tuber size (with a surface factor of 1.4±1), and S_2 = larger tuber size (with a surface factor of 1.7±1)*

3.1.2 Selection of Yam Tubers for Study

The soil particles on the selected tubers were removed by gently brushing the surfaces of the tubers using painter's brush (flat brush) in such a way that the skins of the tubers were not damaged in the process.

3.1.3 Determination of the Surface Factor of Yam Tubers

Surface factor (SF) had been found to influence the rate of moisture loss (evaporation) in yam tubers of different geometric characteristics. It should be noted that while volume increases with tuber weight (mass), the surface area per unit weight (specific surface area) decreases with increasing tuber weight. Thus, the greater the value of surface factor, the higher the surface area available for the movement of moisture from the tuber and vice versa (Ezeike, 1984). For the purpose of this experiment, three different sizes of tubers for each of all the three varieties based on the value of their SF were obtained and used for the experiment to identify if tuber size has effect on the rate of weight loss on Puna, Asana, and Punjo yam varieties. To determine the surface factor of the yam tubers, the following relation was used:

$$SF = \frac{L}{\sqrt[3]{(D_1 D_2 D_3)}}$$

Where L= the length of the axis of the tuber, and D_1, D_2 and D_3 are major diameters with D_1 being the diameter of the proximal part of the yam tuber, D_2 being that of the mid portion, and D_3 being the diameter of the distal part of the tuber. These measurements were taken at the start of the storage period. The length, L, of a tuber was determined by using a tape measure. To determine the proximal diameter (D_1), the following relation was used:

$$D_1 = \frac{C_1}{\pi}$$

Where 'C_1' = the circumference of the yam tuber at the proximal part (the head portion) while π = 3.14 or 22/7. To get the value of 'C_1' in the equation above, a tape measure was used to go round the tuber at its proximal portion. The same procedure was used to obtain the values for D_2 and D_3. This resulted in the following three sizes of yam tubers that were used in the experiment based on their surface factor as follow: small tuber size (with SF = 1.1±1), medium tuber size (with SF = 1.4±1), and large tuber size (with SF = 1.7±1). This implied that each of Puna, Asana, and Punjo yam varieties had all the above stated tuber sizes for the experiment.

3.1.4 Application of the Waxes on the Tubers

Flat brushes were used to apply the waxes: shea butter oil (SBO) and palm kernel (PKO) on designated yam tubers. The application was done by dipping the brush in the SBO oil and applied on tubers. The same process was also used for tubers designated for PKO but at this time using a different flat brush. Both the shea butter and palm kernel oil were obtained directly from shea butter and palm kernel oil processors in Abotoase, three kilometres from the research site. That is, tubers with the following labels: [$V_0T_1S_0$], [$V_1T_1S_0$], [$V_2T_1S_0$], [$V_0T_1S_1$], [$V_1T_1S_1$], [$V_2T_1S_1$], [$V_0T_1S_2$], [$V_1T_1S_2$], and [$V_2T_1S_2$] were waxed with SBO while those labelled as [$V_0T_2S_0$], [$V_1T_2S_0$], [$V_2T_2S_0$], [$V_0T_2S_1$], [$V_1T_2S_1$], [$V_2T_2S_1$], [$V_0T_2S_2$], [$V_1T_2S_2$] and [$V_2T_2S_2$] were waxed with PKO. But those labelled as [$V_0T_0S_0$], [$V_1T_0S_0$], [$V_2T_0S_0$], [$V_0T_0S_1$], [$V_1T_0S_1$], [$V_2T_0S_1$], [$V_0T_0S_1$], [$V_1T_0S_2$] and [$V_2T_0S_2$] were unwaxed tubers used as control in the experiment. About 500 ml each of the waxes was used for 20 tubers that have surface factor 1.1±1 or 1.4±1 and rags were used to mob up excess waxes on the tubers. This approach was adopted because it was more convenient for the farmers. In all, $1dm^3$ of either shea butter or palm kernel oil was used for 30 tubers that have surface factor of 1.7.

3.1.5 Determination of Weight Loss of Yam Tubers

Prior to waxing, the weights (kg) of the tubers were determined using a top pan balance (the top pan balance was sensitive to 0.1Kg). The weights of the tubers were taken. These initial masses (or weight) of the tubers were denoted by the letter 'W'. While in storage, the weights of the tubers were determined fortnightly and recorded as 'W_1'. These weights were used to calculate for the cumulative weight loss (% W_L) at each point of storage period by using the relation: $\%W_L = \left(\frac{W - W1}{W}\right) \times 100\%$ (Ezeike, 1984). The data obtained as the cumulative weight loss of all the yam varieties were used to draw graphs to illustrate the trend in weight loss among the various treatments studied.

3.1.6 Determination of Sprouted (%) Yam Tubers

Stored yam tubers were carefully observed two-weekly throughout the five-month storage period for the presence of sprout buds to consider the tuber sprouted. The number of tubers that sprouted per each subsequent fortnight was determined by counting, and the number was added to the previously recorded number of sprouted yam tubers under each waxing treatments. The percentage (%) of sprouted tubers under each type of waxing was estimated using the following formula:

$$\%\ \text{sprouted tubers} = \frac{\text{Weekly cumulative number of sprouted tubers for each waxing type}}{\text{Initial total number of tubers for each waxing type}} \times 100\%$$

The values obtained for the percentage (%) of sprouted tubers were used to draw a graph to illustrate the trend of the sprouting as affected by waxing.

3.1.7 Determination of Rotten Tubers (%)

The tubers of each variety were carefully observed fortnightly for the occurrence of soft spots and wet surfaces. The percentage of rotten tubers was determined using the formula below. The values obtained were used to draw the cumulative graph for the rate of soft spots occurrence.

$$\% \text{ rotten tubers} = \frac{\text{Weekly cumulative number of tubers with soft spot for each waxing type} \times 100}{\text{Initial total number of yam tubers for each waxing type}}$$

3.1.8 Statistical Analysis of Data

The data obtained for the cumulative weight loss, sprouting, and rotting in tubers were statistically analysed using the Analysis of Variance (ANOVA). Prior to the analysis, the raw data obtained for the %weight loss, %sprouting, and %rotting were transformed by subjecting the data to a reciprocal square root transformation (Osborne, 2002). The relation used for reciprocal square root transformation was $y = \frac{1}{\sqrt{x}}$ where x = original data and y = transformed data. The y-values were subjected to analysis of variance (ANOVA) using GenStat statistical software package (version 9.2). Mean separation was done using the Least Significant Difference (LSD 5%).

3.2 Assessment of the Effect of Waxing Treatments on Organoleptic and Physico-chemical Properties of White Yam

In this experiment, moisture content (to monitor the rate of weight loss) and reducing sugars (to monitor the rate of sprouting) of the yam samples and also the sensory parameters (such as taste, texture, flavour, appearance, and overall acceptability) of cooked and roasted forms of the yam samples were determined. It should be noted that extra tubers were marked prior to the storage period to be used for sensory evaluation and also for the determination of moisture contents and the level of reducing sugars.

3.2.1 Sensory Test

Sensory (organoleptic) properties of yam tubers affect the overall patronage by consumers. For this reason, sensory evaluation was conducted on the treated and stored yam tubers to ascertain the extent to which the sensory qualities of the tubers were affected during the storage duration. The sensory tests were conducted on both cooked and roasted yam tubers. Cooked tubers were used because that was the commonest method by which most people in Ghana process yam for consumption. Roasted yam was also used because the process does not involve addition of water or any other ingredient which could interfere or influence the data of the actual sensory qualities of the yam tubers. The sensory data were collected on flavour, texture, taste, appearance, and overall acceptability. This attributes were considered because they are the key qualities that consumers usually looked out for. Several tests were conducted: at the beginning of the storage period and then on monthly bases throughout the storage period (from December 2012 to May 2013).

Hedonic scale type of sensory analysis questionnaires was used (appendix 4). Twenty (20) trained panellists between the ages of 17 and 40 years were involved. The panellists were trained on how to evaluate the targeted food attributes. For example, they were trained to score a given food attribute base on their own preference for any given food attribute by placing the codes of the given cooked yam samples on the hedonic scale that has been structured from 1 to 10 where 1 means “dislike greatly’’ and 10 means “like greatly’’. The codes of all the given food samples for sensory evaluation were placed on each scale of a given food attribute on the sensory ballot. The values on which the codes of the food samples were placed on the scale denote the preference of the sensory panellists. As part of the sensory evaluation training, they (sensory panellists) were advised to take a bite of the cracker given them and to also take a sip of water or rinse their mouths after every tasting to prevent misjudgement due to taste interference. The attributes to be evaluated were also explained to them to avoid any possible ambiguity of meaning. Booths type of sensory panel room were used to prevent panellists from interacting with each other since by doing so they could be distracted and as a result produce biased evaluation. The testing area was well lit and well ventilated to make things in the room more visible and also make room free of foreign odour since that could also interfere with their assessments. The evaluation took place in Bueman Senior High School Food and Nutrition Laboratory. The school is located in Jasikan in the Volta Region closer to the study site.

The data obtained from the sensory test were subjected to analysis of variance to statistically determine the level of significance among the various food samples provided with respect to the given food attributes namely, taste, flavour, appearance (colour), texture, and overall acceptability. A bar charts was drawn out of the sensory data gathered to graphically illustrate the level of preference for each attribute in a given food sample

3.2.2 Determination of Moisture Content and Reducing Sugars

The key parameters of the study from the onset of the research were the effects of the various treatments in reducing weight loss (moisture loss), sprouting, and occurrence of tuber rot. Moisture content and the level of reducing sugars in the stored tubers were monitored on monthly basis.

3.2.2.1 Moisture Determination

The moisture contents of the tubers were determined by using the autoclave where chopped up yam samples were weighed at 100 g and placed in an oven at a 100 ^{0}C for 24 hours. After the 24 hours, the dried tubers were removed and reweighed a constant weight was obtained. The moisture content was then determined using the following relation.

$$\%Moisture = \frac{M_{initial} - M_{dried}}{M_{initial}} \times 100\%$$

Where $M_{initial}$ = mass of tuber before drying, and M_{dried} = mass of tuber after drying in the oven.

In order to identify the level of significance between the moisture content of waxed tubers and un-waxed tubers, analysis of variance was performed on the data collected for moisture contents of waxed and un-waxed tubers. These data were first transformed using base ten logarithms {$Log_{10}(x+1)$} (Thompson *et al.,* 1977) to normalise the data obtained. This method of data transformation was used because the standard deviation was proportional to mean (Osborne, 2002). The transformed data were subjected to analysis of variance. Mean separation was done using the Least Significant Difference (LSD 5%).

3.2.2.2 Reducing Sugar Determination

The determination of the quantities of reducing sugars in stored tuber samples was estimated using the Nelson-Somogyi method (Nelson, 1944; Somogyi, 1952). To estimate the quantity of reducing sugars in the stored yam sample, alcohol extracts of the samples of the yam tissues were made by homogenising 200 mg of the yam tissue in 80 % (v/v) ethyl alcohol using a glass mortar and pestle and carefully transferring the homogenate into a round bottomed flask fitted with water condenser. This was refluxed over a steam bath for 4 hours. After cooling, the extract was transferred into centrifuge tubes and was centrifuged 4000 x g for ten minutes and supernatant liquid collected into a boiling tube. The residue was again homogenised at 80% (v/v) ethanol and refluxed for one hour and the extracted clarified using centrifugation. The supernatant was collected and added to the original one and dried in an evaporating china dish. The residue left in the china dish after the evaporation, was dissolved in a known volume of distilled water, and aliquot was then taken from this estimation. The aliquot from the extract prepared was then subjected to the Nelson-Somogyi method. The Nelson-Somogyi method required that Somogyi's copper reagent and Nelson's Arsenomolybdate reagent are freshly prepared.

The protocol for preparing Somogyi's reagent required that you dissolve 24 g of anhydrous form of sodium carbonate and 12 g of sodium potassium tartrate (Rochelle salt) in 0.25 dm^3 of distilled water. A 10 % (w/v) solution of a 4 g of copper sulphate was incorporated into the solution and mixed after which 16 g of sodium bicarbonate was also added. In addition, 180 g of sodium sulphate was dissolved in a 0.5 dm^3 of distilled water and boiled to remove air from the water. After cooling, the two solution was mixed and volume was made up to 1 dm^3 (Somogyi, 1952). This reagent was prepared by dissolving 25 g of ammonium heptamolybdate in 0.45 dm^3 of distilled water. After this, 0.021 dm^3 of tetraoxosulphate (VI) acid was added and shake to mix well. Also, a solution was prepared by dissolving 3.0 g of disodium hydrogen arsenate in 0.025 dm^3 of distilled water. This solution was added to the mixture of ammonium heptamolybdate and tetraoxosulphate (VI) acid prepared earlier. This new mixture (solution) was thoroughly mixed and incubated for 24 hours at 37 ^{0}C (Nelson, 1944). A known volume of aliquot prepared from the yam samples was pipetted out and was made up to 1.0 ml using distilled water. A 1.0 ml of Somogyi's copper reagent was added to this solution, and the mixture was placed on a bath of boiling water and heated for 20 minutes. After it has been allowed to cool under a tap water, 1.0 ml of the Nelson's arsenomolybdate reagent was added with immediate mixing until the stoppage of the effervescence. The colour intensity was then measured after proper dilution at 540 nm using a Photochem Digital Calorimeter. D-Glucose was used as the standard.

CHAPTER 4

4.0 RESULTS

4.1 Effect of Sheabutter and Palm Kernel Oil Waxing, Yam Variety, and Tuber Size on Shelf Life of White Yam Tubers

4.1.1 Effect of Sheabutter and Palm Kernel Oil Waxing on Weight Loss, Sprouting, and Rotting of Stored Yam Tubers

Stored white yam tubers (Puna, Asana and Punjo) waxed with sheabutter and palm kernel oil showed significant ($p<0.05$) reduction in weight loss within the first 14 weeks of storage compared to unwaxed tubers, however, from 14th week to 20th week of storage, weight loss began to increase significantly ($p<0.05$) (Fig.4.1, Fig. 4.2, and Fig. 4.3). Weight loss in white yam tubers waxed with sheabutter was significantly ($p<0.05$) lower than yam tubers waxed with palm kernel oil (Fig.4.1, Fig. 4.2 and Fig. 4.3). Likewise yam tubers waxed with palm kernel oil exhibited significantly ($p<0.05$) less weight loss compared to unwaxed tubers.

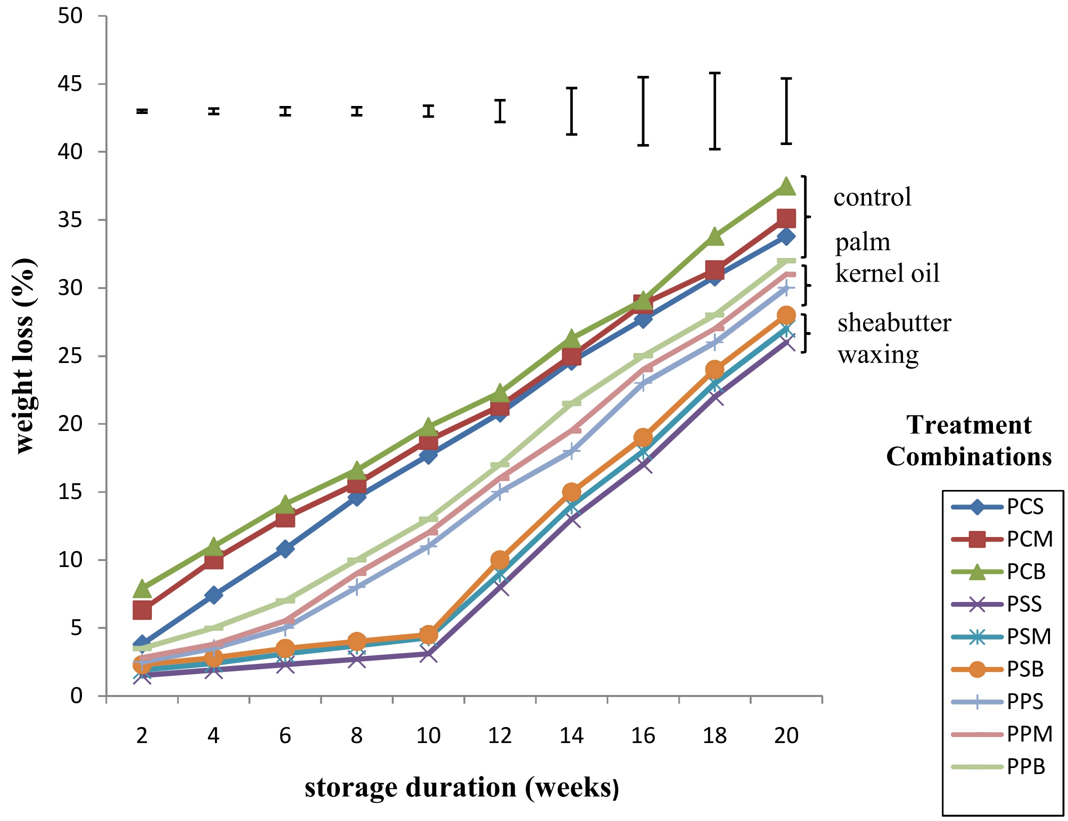

Fig. 4.1: Effect of waxing materials and size of tuber on the weight loss of Puna variety of white yam tubers stored at 31±1 ^{0}C and 75±3% RH

*vertical bars indicate LSD values at 5% level of significance

PCS = small size of Puna without waxing, **PCM** = medium size of Puna without waxing, **PCB** = bigger size of Puna without waxing, **PSS** = small size of Puna with sheabutter waxing, **PSM** = mediun size of Puna with sheabutter waxing, **PSB**= bigger size of Puna with sheabutter waxing, **PPS** = small size of Puna with palm kernel oil waxing, **PPM**= medium size of Puna with palm kernel oil waxing, **PPB** = bigger size of Puna with palm kernel oil waxing

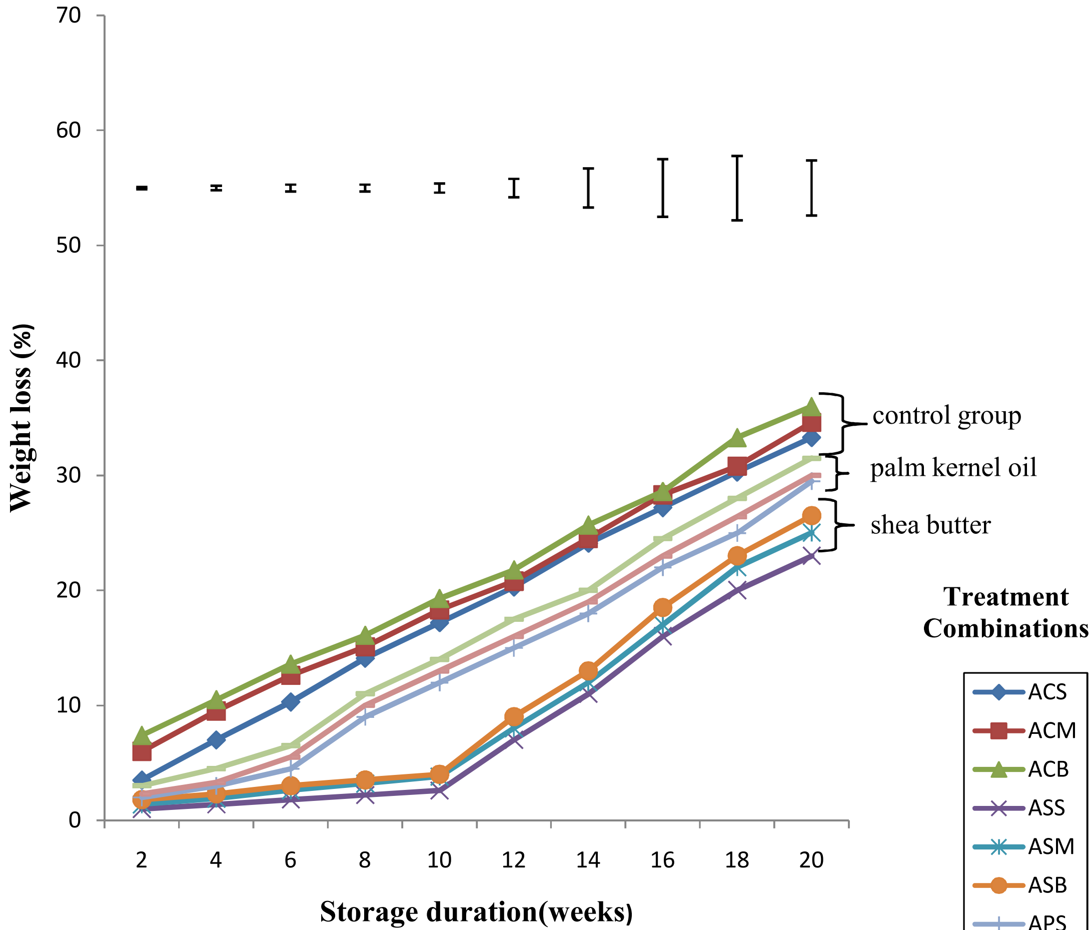

Fig. 4.2: Effect of waxing materials and size of tuber on the weight loss of Asana variety of white yam tubers stored at 31±1 ^{0}C and 75±3% RH

*vertical bars indicate LSD bars at 5% level of significance

ACS= small size of Asana without waxing, **ACM** = medium size of Asana without waxing, **ACB** = bigger size of Asana without waxing, **ASS** = small size of Asana with sheabutter waxing, **ASM** = mediun size of Asana with sheabutter waxing, **ASB**= bigger size of Asana with sheabutter waxing, **APS** = small size of Asana with palm kernel oil waxing, **APM**= medium size of Asana with palm kernel oil waxing, **APB** = bigger size of Asana with palm kernel oil waxing

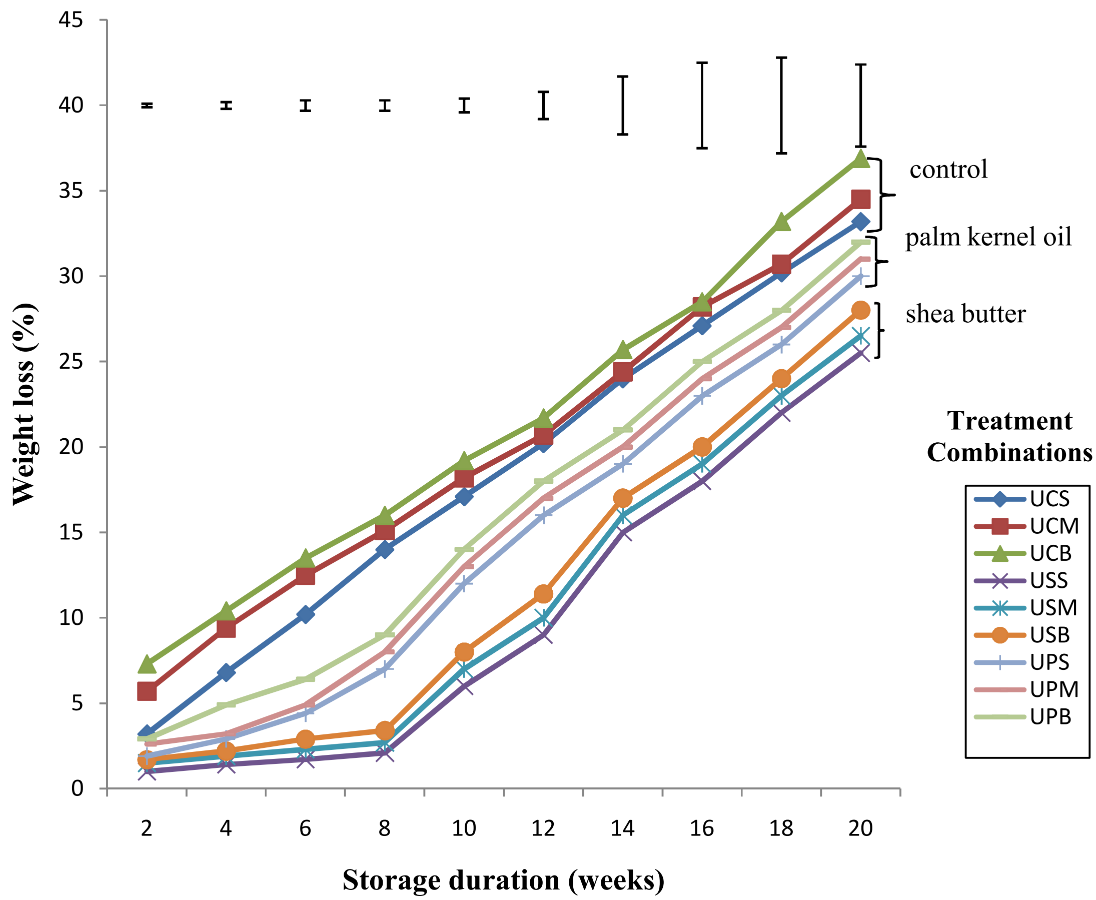

Fig. 4.3: Effect of waxing materials and size of tuber on the weight loss of Punjo variety of white yam tubers stored at 31±1 ^{0}C and 75±3% RH

*vertical bars indicate LSD values at 5% level of significance

UCS= small size of Punjo without waxing, **UCM** = medium size of Punjo without waxing, **UCB** = bigger size of Punjo without waxing, **USS** = small size of Punjo with sheabutter waxing, **USM** = mediun size of Punjo with sheabutter waxing, **USB**= bigger size of Punjo with sheabutter waxing, **UPS** = small size of Punjo with palm kernel oil waxing, **UPM**= medium size of Punjo with palm kernel oil waxing, **UPB** = bigger size of Punjo with palm kernel oil waxing

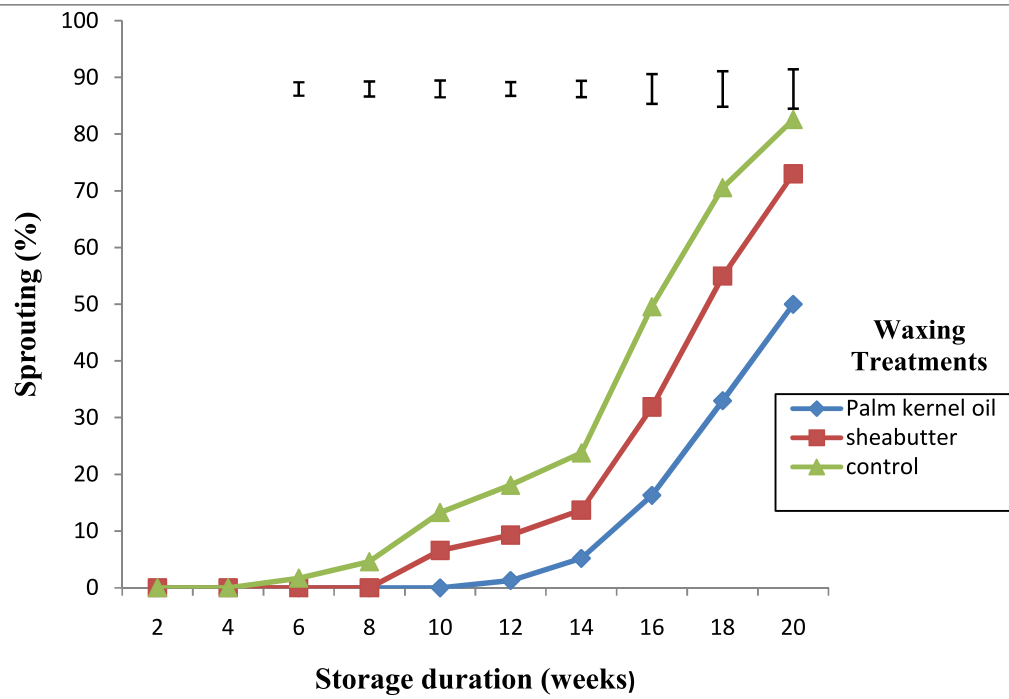

Fig. 4.4: Effect of shea butter and palm kernel oil waxing on sprouting in either Puna, Asana or Punjo variety of white yam stored at 31±1 ^{0}C and 75±3 % RH

*vertical bars indicate LSD values at 5% level of significance

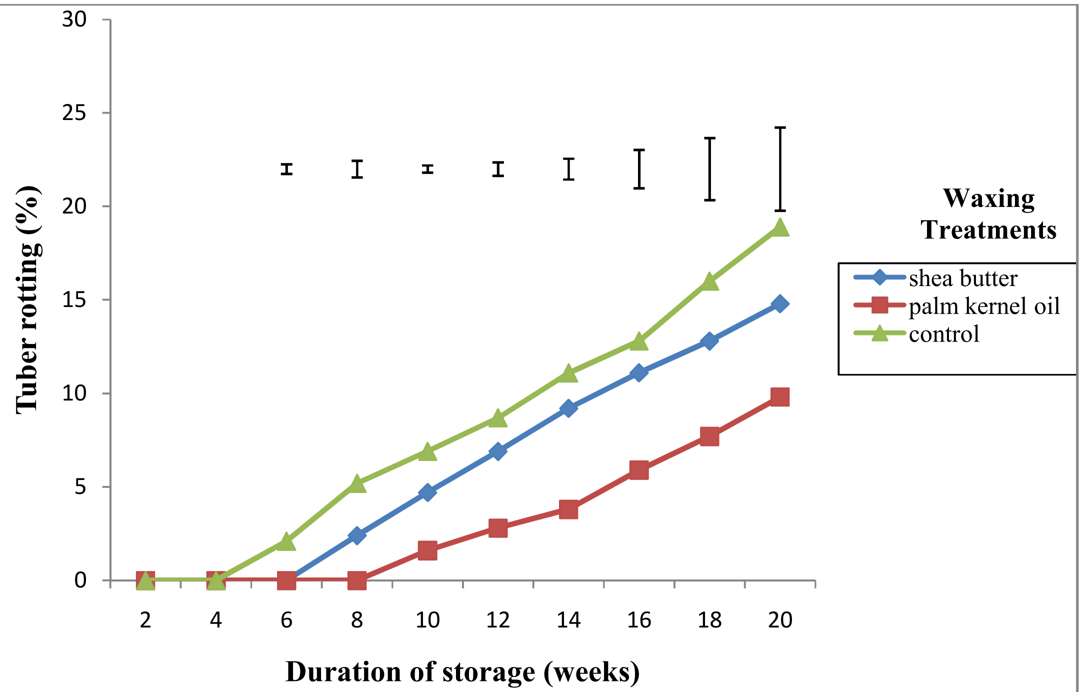

Fig. 4.5: Effect of shea butter and palm kernel oil waxing on rotting in Puna, Asana and Punjo varieties of white yam stored at 31±1 ^{0}C and 75±3 % RH

*vertical bars indicate LSD values at 5% level of significance

At the end of the 20 weeks of storage period, rotting in all tubers treated with palm kernel oil was 9.8% whereas tubers waxed with shea butter had 14.8% rotten tubers and the unwaxed tubers had 18.9% rotten tubers (Fig. 4.5). Thus, the performance of palm kernel oil against soft spot formation was significant ($p < 0.05$) than the application of shea butter and that of the control group.It was also observed that yam variety also influenced the rate of soft spots occurrence; the influence was significant ($p < 0.05$). That is, the number of tubers of Puna variety that rotted was higher than the number of tubers of Asana variety that rotted, and also more than the number that sprouted in Punjo variety.

4.1.2 Effect of Yam Variety and Tuber Size on Weight Loss in Stored White Yam Tubers

Yam variety affected weight loss in stored white yam tubers. Weight loss in Puna was significantly ($p<0.05$) higher than weight loss in Asana, so also was weight loss in Asana higher than that of Punjo (Table 4.1), e.g. on the 14th week of storage, weight loss in Puna was 12.82% compared to Asana (11.51%) and Punjo (11.21%) (Table 4.1). Tuber size was also found to significantly ($p < 0.05$) influence weight loss in yam tuber (Table 4.1). Tubers of smaller size (SF = 1.1 ±1) were found to lose less weight compared to weight loss in medium sized tubers (SF = 1.4 ±1) and bigger sized tubers (SF = 1.7 ±1), e.g. in 14 weeks of storage, the average weight loss in smaller tubers (SF = 1.1 ±1) was 10.46% compared to 11.34% weight loss in medium sized tubers (SF = 1.4 ±1) and 12.42% weight loss in bigger sized tubers (SF = 1.7 ±1) (table 4.1). The interaction between yam tuber size and variety on reduction of weight loss was positive and significant ($p < 0.05$) (Table 4.1).

Table 4.1: Effect of yam tuber size and variety on weight loss (%) of white yam tubers stored at 31±1 ^{0}C and 75±3 % RH for 14 weeks

Yam Tuber Size	Yam Variety			Mean weight loss for Tuber size
	Puna	Asana	Punjo	
Small size (SF=1.1±1)	11.20 (0.2988)	10.34 (0.3110)	9.83 (0.3190)	**10.46 (0.3092)**
Medium size (SF=1.4±1)	12.88 (0.2786)	11.28 (0.2977)	11.34 (0.2970)	**11.34 (0.2970)**
Large size (1.7±1)	14.39 (02636)	12.90 (0.2784)	12.46 (0.2833)	**13.25 (0.2747)**
Mean weight loss for Yam Variety	**12.82 (0.2793)**	**11.51 (0.2948)**	**11.21 (0.2987)**	

*LSD ($p < 0.05$) for tuber size = 0.0026, yam variety = 0.0026, variety x tuber size = 0.00033
*values in parenthesis are transformed values

4.1.3 Effect of Yam Variety and Tuber Size on Sprouting of Stored White Yam Tubers

Yam variety and tuber size had no significant ($p < 0.05$) effect on sprouting in yam tubers, thus, even though the number sprouted Puna tubers was higher than sprouted tubers of Asana and Punjo, the difference was not significant ($p < 0.05$) (Table 4.2). There is also no interaction effect between yam tuber size and variety on sprouting (Table 4.2).

Table 4.2: Effect of tuber size and variety on sprouting in white yam varieties stored at 31±1 ^{0}C and 75±3 % RH for 14 weeks

Variety of White Yam	Tuber size			Mean weight loss for yam variety
	Small size (SF=1.1±1)	Medium size (SF=1.4±1)	Large size (1.7±1)	
Puna	12.23 (0.2860)	11.55 (0.2942)	11.67 (0.2927)	**11.81 (0.2910)**
Asana	8.01 (0.3534)	8.41 (0.3449)	11.91 (0.2898)	**9.22 (0.3294)**
Punjo	11.45 (0.2955)	10.61 (0.3070)	12.69 (0.2807)	**11.54 (0.2944)**
Mean weight loss for tuber size	**10.30 (0.3116)**	**10.05 (0.3154)**	**12.07 (0.2878)**	

*LSD ($p < 0.05$): Tuber size = 0.042, Variety = 0.042, and Tuber size x Variety = 0.073
*Values in parenthesis are transformed values

4.1.4 Effect of Yam Variety on Rotting of Stored White Yam Tubers

Yam variety had no significant ($p < 0.05$) effect on rotting of stored tubers, e.g. in a storage period of 14 weeks, 7.32% of Puna tubers rotted, Asana (6.71%) and Punjo (6.64%) (Table 4.3).

Table 4.3: Effect of Tuber size and variety on rotting in white yam varieties stored at 31±1 ^{0}C and 75±3 % RH for 14 weeks

Yam variety	%Tuber rotted
Puna	7.32 (0.3695)
Asana	6.71 (0.3860)
Punjo	6.64 (0.3882)

*LSD ($p < 0.05$) for variety = 0.023 *Values in parenthesis are transformed values

4.2 Effect of Sheabutter and Palm Kernel oil Waxing, and Yam Variety on Organoleptic (sensory) and Physico-Chemical Properties of White Yam

4.2.1 Sensory Evaluation

Sensory evaluation was conducted on waxed Puna, Asana, and Punjo yam varieties to collect information on taste, flavour, texture, attractiveness and acceptability. There was no significant ($p< 0.05$) difference in attractiveness and acceptability of cooked tubers treated with sheabutter and palm kernel oil as well as the unwaxed tubers (Table 4.4), however, there was significant difference in texture and flavour among tubers waxed with sheabutter and palm kernel oil, and the unwaxed tubers (Table 4.4). Majority of the sensory panellists indicated their preference for the taste and texture of yam tubers waxed with sheabutter followed by the taste and texture of yam tubers waxed with palm kernel oil.

Table 4.4: Effect of shea butter and palm kernel oil waxing on sensory qualities of cooked white yam

Type of waxing	Sensory scores due to effect of waxing				
	Taste	Texture	Flavour	Attractiveness	Acceptability
Shea butter	8.67[a]	9.17[a1]	8.33[b2]	9.33	8.33
Palm kernel oil	7.29[b]	7.79[b1]	8.08[b2]	9.33	8.33
Unwaxed	6.33[c]	6.83[c1]	9.00[a2]	9.33	8.33
LSD (p< 0.05)	**0.0702**	**0.0702**	**0.332**	**NS**	**NS**

*NS= not significant

Further analysis of sensory data revealed that varietal differences had significantly ($p < 0.05$) affected the sensory properties of the yam tubers evaluated for taste, flavour, and texture. Attractiveness and acceptability of cooked tubers were not significantly ($p < 0.05$) affected by variety, thus there was significant difference ($p < 0.05$) between Puna and other two varieties (Asana and Punjo) in terms of taste, texture, and flavour, however, there was no significant ($p < 0.05$) difference among the three yam varieties in terms of attractiveness and overall acceptability even though more consumers showed acceptability preference for Puna compared to Punjo and Asana (Table 4.5).

Table 4. 5: Effect of yam variety on the sensory qualities of yam tubers

Variety	Sensory scores due to varietal differences				
	Taste	Texture	Flavour	Attractiveness	Acceptability
Puna	8.00[a]	9.25[a1]	9.25[a2]	9.00	9.00
Asana	7.29[b]	8.92[b1]	8.08[b2]	10.00	8.00
Punjo	7.00[c]	8.17[c1]	8.08[b2]	9.00	8.00
LSD (p< 0.05)	**0.070**	**0.124**	**0.332**	**NS**	**NS**

*NS = Not significant

Furthermore, there were no significant differences ($p < 0.05$) between Asana and Punjo varieties in terms of flavour, appearance, and overall acceptability, but there was significant difference between Asana and Punjo in term taste and flavour just as there was significant ($p < 0.05$) difference between Puna and these two varieties (Asana and Punjo yam varieties) (Table 4.5).

4.2.2 Moisture Contents of the Stored White Yam Tubers

The moisture content of waxed yam tubers was significantly ($p < 0.05$) higher than un-waxed yam tubers (Table 4.6). Moisture content in tubers waxed with shea butter was significantly ($p < 0.05$) higher than yam tubers waxed with palm kernel oil as well as the moisture content in unwaxed tubers (Table 4.6), e.g. at the end of the 5-month storage period, the moisture content in sheabutter waxed yam tubers was 63.2 %, moisture content in palm kernel oil waxed tubers was 57.8% while moisture content in unwaxed tubers was 53.7% (Table 4.6).

Table 4.6: Effect of shea butter and palm kernel oil waxing on moisture content of white yams stored for five months at 31±1 ^{0}C and 75 ±3 % RH

Type of waxing material	Moisture content (%) of stored yam tubers (Storage duration in months)				
	1	2	3	4	5
Shea butter waxed tubers	74.1 (1.870)	71.1 (1.852^{a})	68.7 (1.837^{a1})	64.7 (1.811^{a2})	63.2 (1.801^{a3})
Palm kernel oil waxed tubers	72.6 (1.861)	66.7 (1.834^{b})	64.3 (1.808^{b1})	59.3 (1.773^{b2})	57.8 (1.762^{b3})
Unwaxed Tubers	72.1 (1.858)	66.7 (1.824^{c})	61.7 (1.790^{c1})	55.2 (1.742^{c2})	53.7 (1.730^{c3})
LSD ($p < 0.05$)	**NS**	**0.0088**	**0.0093**	**0.0101**	**0.0104**

*NS = not significant *Figures in parenthesis are transformed values

4.2.3 Effect of Sheabutter and Palm Kernel Oil Waxing on the Level of Reducing Sugars in Yam Tubers Stored for Five Months

The reducing sugars content (level) in the stored yam tubers were found to be increasing greatly throughout the five-month storage. The increment of the level of reducing sugars was found to be higher in tubers that were not waxed than those that were waxed. Similarly, tubers waxed with sheabutter produced higher level of reducing sugars than those that were waxed with palm kernel oil (Table 4.7).

Table 4.7: Level of reducing sugars in Puna, Asana, and Punjo varieties of white yams waxed with sheabutter and palm kernel oil and stored for a period of five months

Storage Duration	Tuber Variety	Waxing material		
		Palm kernel oil	Sheabutter	No waxing (control)
1st month of storage	Puna	3.85	3.87	4.36
	Asana	3.83	3.84	4.01
	Punjo	3.82	3.82	4.03
3rd month of storage	Puna	3.98	4.27	6.63
	Asana	3.97	4.25	6.44
	Punjo	3.95	4.23	6.46
5th month of storage	Puna	4.21	6.55	8.34
	Asana	4.19	6.52	8.31
	Punjo	4.18	6.49	8.30

*Values are expressed in $mg.g^{-1}$ dry weight *More sprouting was observed in tubers with no waxing followed by tubers waxed with sheabutter and tubers waxed with palm kernel oil in that order.

The levels of reducing sugars were high in tubers that were sprouting than those that were not sprouting. There were also varietal influences in the levels of reducing sugars in the stored tubers.

CHAPTER 5

5.0 DISCUSSIONS

5.1 Effect of Shea Butter and Palm kernel Oil Waxing on Weight Loss, Sprouting, and Rotting in White Yams

The results obtained from postharvest waxing of white yam varieties of Puna, Asana, and Punjo using shea butter and palm kernel oil revealed that sheabutter and palm kernel oil were effective in reducing weight loss in yam tubers for a period of three months and two months respectively. Sheabutter has the property of moisturizing and protecting skin against drying or moisture loss; at the same time, it reduces the rate of gaseous exchange between the tuber and its ambient environment (Maranz *et. al,* 2003). Reducing the rate of gaseous exchange between the tuber and its external environment, implies that the rate of oxygen (O_2) absorption is reduced, and that reduces the rate of respiration which eventually reduces the rate of moisture and dry matter loss (Osunde, 2008).

Shea butter reduces the rate of respiration and moisture loss because it has great amount of lauric acid, beta-carotene and tocopherols (vitamin E) which are known to serve as anti-moisture loss agents (Maranz *et. al* 2003). It is important to note that lauric acid and tocopherols contained in sheabutter are anti-oxidants (Codex Alimentariu Commission, 1999) and for that matter reduces the rate of oxidation (respiration) that takes place in the tubers, and by so doing reducing aging which, therefore, contribute to the extension of shelf life of the tubers in storage. This explains why sheabutter was more effective in moisture retention in tubers than palm kernel oil. Furthermore, regular application of sheabutter on the yam tubers, at two months intervals, enabled tubers retain much moisture throughout the entire storage period of five months. The finding is in line with the findings of Sugri & Johnson

(2009) who reported that shea butter waxing was effective in extending the shelf life of plantain from 11 days to three weeks, and it was also in line with the report that waxing was effective in reducing weight loss in cassava by 40% and by so doing extending the shelf life of cassava from a maximum of three days to one month (PH, 2004b). Furthermore, the finding was similar to the findings of Hardenburg *et al.* (1959) who reported that waxing reduced weight loss in potatoes as compared to un-waxed ones. Akihisa *et al* (2010) used epolene (E10) to waxed yam, but reported that weight loss reduction was inconsistent. In any case, it should be noted that shea butter is different from epolene (E10) because while shea butter contained good amount of lauric acid and tocopherols (Babalola & Apata, 2011)which serve as anti-oxidants and moisturisers, epolene (E10) does not contained lauric acid and tocopherols (Emenike, 2010). Moreover, sheabutter is not negatively affected by moisture (Emenike, 2010) as compared to epolene (E10) which is negatively affected by moisture (Emenike, 2010). Waxing can be used to create modified atmosphere (a condition where oxygen level in the produce is reduced and carbon (IV) oxide level is increased) around a produce to reduce the rate of moisture loss by reducing the rate of respiration and transpiration (Liu *et al*., 1995 and Baldwin *et. al* (1994). Waxing is used to prevent excessive transpiration in farm vegetables (PH, 2004a).

This study revealed that waxing yam tubers with palm kernel oil effectively reduced the occurrence of soft tuber rots. Thus, the study results revealed that the rotting was reduced when palm kernel oil was applied to yam tubers before storage. This was contrary to the findings of Hardenburg *et al. (*1959) who reported that waxed potatoes developed decay especially from lenticel type of infection. The ability of palm kernel oil to reduce pathogen infections that caused tuber rot could be due to its anti-microbial properties (Akihisa *et al.,* 2010). This assertion has been emphasized by Ekpa and Ebana (1996) and Bancroft (2000) when they reported that palm kernel oil was active against *Escherichia coli*, alpha and beta hemolytic streptococci, *Aspergillus fumigates*, *Staphylococcus aureus and Asperigillus niger* some of which caused serious yam tuber rot.

Waxing was also found to reduce sprouting or shoot and root development of yam tubers during storage. Sprouting is tied to increased moisture loss and increased level of reducing sugars in the tuber. During sprouting, much of the carbohydrate stored in the tubers was used for respiration (Baldwin *et. al.*, 1994). Waxing yam tubers was found to reduce sprouting in yam tubers because the rate of moisture loss through transpiration and metabolic activities such as respiration was reduced. Waxing creates a kind of modified atmosphere around the yam tuber which in turn reduced the level of gaseous exchange between the yam tuber and its ambient environment. In normal circumstances, much oxygen gas (O_2) is absorbed into the cells of the tuber whiles carbon (IV) oxide (CO_2) is released into the atmosphere (i.e. respiration) but in the modified atmosphere created by waxing, less oxygen is allowed in and little carbon (IV) is allowed out of tubers. Respiration is a catabolic process, thus sprouting causes the breakdown of complex carbohydrate in tubers. The pores on the skin of the tuber through which gaseous exchanged occurred were block by the wax coating (Liu *et al*., 1995).

Not all waxes have the ability to significantly control the amount of gaseous exchange. This is why not all waxes can be used in this regard. Shea butter, however, contained high amount of lauric acid (Codex Alimentariu Commission, 1999) which served as moisturiser for living cells and, therefore, prevented moisture loss in great quantity. This also implied that the rate of metabolic activities that led to moisture loss had been reduced. Furthermore, waxes such as palm kernel oil have antimicrobial property (Baldwin *et. al.,* 1994) and this implied that palm kernel oil when applied to yam tubers can be lethal to the buds on the tubers. This could explain why tubers that were waxed with palm kernel oil had very low % sprouting. This observation was especially in tubers whose pre-tuber has been well smeared with the palm kernel oil. Palm kernel oil could well serve as sprout-suppressant in yam production industry where sprouting causes serious postharvest losses and some traders and farmers resorting to using chemical sprout-suppressant which might leave some residues in tubers and pose health hazard to consumers. However, it was observed that excessive application of palm kernel oil on the yam tubers could kill the periderm of tubers. It is, therefore, advisable to mob up the excess oil on the tubers during waxing.

5.2 Effect of Tuber Size and Yam Variety on Sprouting, Weight Loss, and Rotting in White Yam

The results obtained from the study indicated that weight loss in yam tubers was affected by the tuber size, the type of waxing used, and the variety of the tuber. For instance, bigger tubers of Puna, Asana, and Punjo varieties did lose much weight during storage than those with smaller tuber sizes. This finding reaffirmed the findings of Ezeike (1984) who stated that the greater the surface factors of solid objects (such as produce), the greater the surface area available for the transfer of moisture and vice versa. This means that bigger tubers have bigger surface area which provides larger medium for moisture transfer from the tuber to the environment.

Among some of the findings made during this study is that varieties of yam tubers affect the rate of weight loss. This might be due to varietal differences in the physico-chemical properties of the yam tubers. Emenike (2010), reported that with the exception of lignin, other yam constituents such as cellulose and hemicelluloses were affected by tuber variety.

Similarly, it is reported that during prolonged storage, fibre content increases, but the rate of increase depended on the tuber variety (Afoakwa and Sefa-Dedeh, 2001).

Yam variety was found to play insignificant role in the occurrence of rotting on the yam tubers at postharvest. This is may explain why greater number of tubers of Puna variety rotted as compared to Asana or Punjo varieties. This observation supports that of MIDA (2010) which observed that most preferred tubers are most perishable with Puna being among the most preferred and most perishable. The high perishability of Puna compared to Asana and Punjo might be due to its high sugar content.

Varietal differences were also found to affect the rate of sprouting in yam tubers. It has been noted that postharvest losses such as rotting and sprouting are caused by pathological and physiological factors. The pathological factors include fungi, bacteria and parasitic nematode which cause tuber rot while physiological factors include increased transpiration and rate of respiration which eventually lead to increased sprouting, desiccation and weight loss (Ravi and Aked, 1996 and Osunde, 2008).

When white yam (*D. rotundata*) is stored for 110 days (nearly 4 months) under normal storage condition (28 ^{0}C), the rate of moisture loss was found to be 31% (Serge and Agbor-Egbe,1996). This shows that yam tubers undergo quite rapid dehydration in storage leading to cell wall polysaccharides to shrink and allowing maximum interactions of hydrogen bonding and Van der Waals forces, thereby, increasing cell rigidity at storage (Afoakwa and Sefa-Dedeh, 2001). Moreover the starch content of the tubers decreases with the duration of storage, temperature, and the variety of yam under storage. This means that decrease in starch content in yam tubers varies from one variety to another provided they are all treated alike at storage, therefore, metabolic activities in yam tubers contribute significantly in post-harvest quality changes of the tuber

5.3 Effect of Shea Butter and Palm Kernel Oil Waxing on the Nutritional Composition and Sensory Qualities of White Yam

The sensory qualities of yam tubers that were studied are taste, texture, flavour, appearance, and overall acceptability. These qualities were considered to be among the most preferred qualities of yam tubers that consumers looked out for when buying yam tubers (Chiedozie, *et al*., 2003). The results obtained from this study revealed that waxing yam tubers with shea butter and palm kernel oil affected some of these sensory qualities positively. The taste of waxed tubers was found to be significantly preferred to unwaxed tubers. Analysis revealed that most of the un-waxed tubers sprouted. In this case the finding was in line the report that sprouting of yams results in loss of carbohydrate, sugar, and other nutrient contents in the yam tubers (Afoakwa & Sefa-Dedeh, 2001).

Furthermore, the texture of the waxed tubers was also preferred to those that were not waxed. This consistent with the finding of Goodwin & Mercer (1992) where aging of plant produce increases the level and stiffness of cellulose, lignin, and hemicellulose in the tubers. Since shea butter and palm kernel oil contain anti-aging properties (lauric acid and tocopherols) (Codex Alimentariu Commission, 1999), it implies the rate of lignification and stiffness of cellulose and hemi-cellulose in them (tubers) will be less than un-waxed tubers. The texture in the waxed tubers will, therefore, be much softer than un-waxed tubers. However, the flavour of un-waxed tubers was much preferred to tubers waxed with shea butter and palm kernel oil. The reason for this phenomenon could not be explained and, therefore, future research should investigate into the reason why unwaxed tubers that were not waxed with shea butter or palm kernel had better flavour than those that were waxed whereas in normal circumstances, it is expected that the waxed tubers should have better flavour than tubers that were not waxed. This is because according to Kader (2005) weight loss through transpiration causes viability loss and flavour loss. In any case, tubers that were waxed underwent relatively low weight loss as compared to un-waxed tubers which had undergone much moisture loss (weight loss).

Other qualities such as attractiveness and acceptability evaluated for tubers waxed with shea butter and un-waxed tubers indicated that there was no significant difference between both the shea butter waxed and un-waxed tubers. The implication was that waxing yam tubers with shea butter does not adversely affect the choices of consumers in terms of attractiveness and acceptability of the tubers by consumers. Palm kernel oil waxing did not also affect negatively the attractiveness and acceptability of tubers.

The study conducted revealed that the variety of yam also influenced its sensory qualities. Consumers' choice of yam depended on the variety of the yam tuber. It was identified that taste, flavour, and texture were the major attributes of yam variety. For instance, very large number of consumers preferred Puna to other varieties probably because of its excellent taste (sweetness), flavour, and texture. Consumers purchase yam based on whether it is good for *fufu* (pounded yam) or *busa* (boiled yam slices for consumption). This was probably because the major forms of consuming yam in Ghana are pounded form (fufu) and boiled yam slices (busa) (Chiedozie, *et al*., 2003). The high preference of Puna to other varieties may be based on these attributes. The level of reducing sugars in waxed tubers was found to be lower compared to those tubers that were not waxed. This is because the level of reducing sugars increases in tubers that are sprouting (Panneerselvam & Abdul Jaleel, 2008). Moisture content of yam tubers contributes significantly to its weight. Yam tubers that lose much water might have relatively less weight. For instance, when white yam (*D. rotundata*) was stored for 110 days (nearly 4 months) under normal storage condition (28 ^{0}C), the rate of moisture loss was 31% (Serge and Agbor-Egbe,1996).

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- In this study it was revealed that waxing of Puna, Asana, and Punjo varieties of white yam (*Dioscorea rotundata* Poir) with shea butter reduced their weight loss for a storage period of three months while palm kernel oil reduced weight loss during two months storage. Sheabutter waxing delayed sprouting for at least eight weeks in storage while palm kernel oil delayed sprouting by 10 weeks in storage. Palm kernel oil resulted in significantly lower number of rotting tubers compared to sheabutter. At the end of the storage period (week 20), % rotting in tubers waxed with palm kernel oil was 9.8 % whereas % rotting in sheabutter waxed and unwaxed tubers were 14.8 % and 18.9 % respectively.
- Weight loss in tubers of smaller sizes was significantly lower than those of medium and bigger tuber sizes. Tuber size had no effect on sprouting and rotting of yam tubers. Weight loss in Puna variety was 12.82% and weight loss in Punjo and Asana were 11.21% and 11.51% respectively; thus, % weight loss in Puna was greater than Punjo and Asana.

- There were interactions among yam variety, tuber size and waxing materials against weight loss, but there were no interactions among yam variety, tuber size and waxing materials against sprouting and rotting.
- Shea butter and palm kernel oil waxing had positively affected the taste of the stored yam tubers. Thus, sensory panellists were able to tell the difference in terms of taste in waxed and un-waxed tubers of the same variety. There is no significant difference in attractiveness (appearance) of cooked tubers that were waxed and those that were not waxed. Sensory panellists showed preference to tubers of the variety that were not waxed. However, there was no significant difference in acceptability of waxed and un-waxed tubers of the same variety.

6.2 Recommendations

It is recommended that:

- Farmers, retailers and exporters of Puna, Asana, and Punjo varieties of yam can use shea butter waxing to significantly reduce the rate of tuber weight loss for a period of three months after harvest. In addition, farmers and marketers of yam tubers can use palm kernel oil waxing to reduce sprouting and rotting in yam tubers to significantly extend their shelf life for a period of five months.

- Furthermore, farmers and exporters who are into organic farm produce marketing can use shea butter and palm kernel oil waxing as weight loss, rot, and sprout suppressants instead of inorganic chemicals.

- For effective inhibition of weight loss during storage, smaller size of tubers with surface factor of 1.1 or less than 1.7 should be treated with shea butter waxing; this is because tubers of smaller sizes do not undergo high rate of weight loss compared to those of bigger tuber size.

- Future research should look at cost effectiveness of using shea butter and palm kernel oil waxing to extend shelf life of stored white yam tubers. Also a research into why the flavour of shea butter and palm kernel oil waxed tubers are not much preferred compared to the flavour of unwaxed tubers.

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APPENDICES

Appendix 1: ANOVA of the Effect of Variety, Waxing, and Tuber size on Weight Loss (%) of Puna, Asana, and Punjo

Week 2

Variate: Transform_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.821E-05	6.071E-06	1.69	
Block.*Units* stratum					
Variety_V	2	1.286E-01	6.428E-02	17926.51	<.001
waxing_T	2	1.792E+00	8.962E-01	2.499E+05	<.001
Size_S	2	8.367E-01	4.184E-01	1.167E+05	<.001
Variety_V.waxing_T	4	9.884E-03	2.471E-03	689.13	<.001
Variety_V.Size_S	4	2.998E-02	7.494E-03	2090.05	<.001
waxing_T.Size_S	4	4.231E-02	1.058E-02	2950.18	<.001
Variety_V.waxing_T.Size_S	8	1.822E-02	2.278E-03	635.18	<.001
Residual	78	2.797E-04	3.586E-06		
Total	107	2.858E+00			

Week 4

Variate: Transform_4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4.833E-06	1.611E-06	1.93	
Block.*Units* stratum					
Variety_V	2	5.360E-02	2.680E-02	32093.13	<.001
waxing_T	2	1.270E+00	6.350E-01	7.605E+05	<.001
Size_S	2	3.923E-01	1.962E-01	2.349E+05	<.001
Variety_V.waxing_T	4	3.359E-03	8.398E-04	1005.66	<.001
Variety_V.Size_S	4	1.051E-02	2.629E-03	3147.86	<.001
waxing_T.Size_S	4	6.353E-02	1.588E-02	19019.23	<.001
Variety_V.waxing_T.Size_S	8	6.542E-03	8.178E-04	979.28	<.001
Residual	78	6.514E-05	8.351E-07		
Total	107	1.800E+00			

Week 6

Variate: Transform_6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2.962E-06	9.873E-07	0.58	
Block.*Units* stratum					
Variety_V	2	3.370E-02	1.685E-02	9916.79	<.001
waxing_T	2	8.630E-01	4.315E-01	2.540E+05	<.001
Size_S	2	1.373E-01	6.864E-02	40399.37	<.001
Variety_V.waxing_T	4	2.878E-03	7.194E-04	423.42	<.001
Variety_V.Size_S	4	1.083E-03	2.706E-04	159.28	<.001
waxing_T.Size_S	4	4.570E-02	1.142E-02	6723.73	<.001
Variety_V.waxing_T.Size_S	8	3.425E-03	4.282E-04	251.98	<.001
Residual	78	1.325E-04	1.699E-06		
Total	107	1.087E+00			

Week 8

Variate: Transform_8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3.664E-06	1.221E-06	1.26	
Block.*Units* stratum					
Variety_V	2	3.550E-02	1.775E-02	18268.57	<.001
waxing_T	2	6.855E-01	3.428E-01	3.528E+05	<.001
Size_S	2	1.030E-01	5.152E-02	53026.49	<.001
Variety_V.waxing_T	4	1.612E-02	4.031E-03	4148.80	<.001
Variety_V.Size_S	4	1.988E-03	4.971E-04	511.64	<.001
waxing_T.Size_S	4	5.525E-02	1.381E-02	14216.90	<.001
Variety_V.waxing_T.Size_S	8	1.139E-02	1.424E-03	1465.64	<.001
Residual	78	7.578E-05	9.715E-07		
Total	107	9.089E-01			

Week 10

Variate: Transform_10

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00119845	0.00039948	24.34	
Block.*Units* stratum					
Variety_V	2	0.01116773	0.00558386	340.26	<.001
waxing_T	2	0.29822687	0.14911344	9086.44	<.001
Size_S	2	0.04506773	0.02253387	1373.13	<.001
Variety_V.waxing_T	4	0.00143518	0.00035880	21.86	<.001
Variety_V.Size_S	4	0.00070457	0.00017614	10.73	<.001
waxing_T.Size_S	4	0.01727487	0.00431872	263.17	<.001
Variety_V.waxing_T.Size_S	8	0.00382434	0.00047804	29.13	<.001
Residual	78	0.00128002	0.00001641		
Total	107	0.38017978			

Week 12

Variate: Transform_12

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	6.996E-07	2.332E-07	1.27	
Block.*Units* stratum					
Variety_V	2	5.370E-03	2.685E-03	14598.65	<.001
waxing_T	2	1.123E-01	5.614E-02	3.052E+05	<.001
Size_S	2	1.963E-02	9.815E-03	53364.31	<.001
Variety_V.waxing_T	4	3.401E-04	8.502E-05	462.26	<.001
Variety_V.Size_S	4	2.720E-04	6.799E-05	369.68	<.001
waxing_T.Size_S	4	1.082E-02	2.704E-03	14701.20	<.001
Variety_V.waxing_T.Size_S	8	1.082E-03	1.352E-04	735.33	<.001
Residual	78	1.435E-05	1.839E-07		
Total	107	1.498E-01			

Week 14

Variate: Transform_14

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	5.303E-07	1.768E-07	1.05	
Block.*Units* stratum					
Variety_V	2	3.222E-03	1.611E-03	9585.50	<.001
waxing_T	2	6.036E-02	3.018E-02	1.796E+05	<.001
Size_S	2	1.425E-02	7.127E-03	42409.13	<.001
Variety_V.waxing_T	4	1.477E-04	3.692E-05	219.68	<.001
Variety_V.Size_S	4	1.997E-04	4.992E-05	297.03	<.001
waxing_T.Size_S	4	3.912E-03	9.781E-04	5819.76	<.001
Variety_V.waxing_T.Size_S	8	4.160E-04	5.200E-05	309.42	<.001
Residual	78	1.311E-05	1.681E-07		
Total	107	8.252E-02			

Week 16

Variate: Transform_16

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.368E-08	4.561E-09	0.42	
Block.*Units* stratum					
Variety_V	2	1.633E-03	8.164E-04	74780.19	<.001
waxing_T	2	2.588E-02	1.294E-02	1.185E+06	<.001
Size_S	2	9.288E-03	4.644E-03	4.254E+05	<.001
Variety_V.waxing_T	4	3.042E-04	7.605E-05	6965.69	<.001
Variety_V.Size_S	4	1.420E-04	3.550E-05	3251.90	<.001
waxing_T.Size_S	4	2.736E-03	6.840E-04	62653.12	<.001
Variety_V.waxing_T.Size_S	8	2.622E-04	3.278E-05	3002.12	<.001
Residual	78	8.516E-07	1.092E-08		
Total	107	4.024E-02			

Week 18

Variate: Transform_18

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.089E-07	3.631E-08	1.28	
Block.*Units* stratum					
Variety_V	2	7.541E-04	3.771E-04	13259.19	<.001
waxing_T	2	1.309E-02	6.546E-03	2.302E+05	<.001
Size_S	2	5.546E-03	2.773E-03	97504.49	<.001
Variety_V.waxing_T	4	1.588E-04	3.971E-05	1396.37	<.001
Variety_V.Size_S	4	3.218E-05	8.045E-06	282.88	<.001
waxing_T.Size_S	4	1.636E-03	4.091E-04	14384.67	<.001
Variety_V.waxing_T.Size_S	8	2.065E-04	2.581E-05	907.75	<.001
Residual	78	2.218E-06	2.844E-08		
Total	107	2.143E-02			

Week 20

Variate: Transform_20

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.312E-09	4.372E-10	1.00	
Block.*Units* stratum					
Variety_V	2	4.767E-04	2.383E-04	5.452E+05	<.001
waxing_T	2	3.427E-03	1.713E-03	3.919E+06	<.001
Size_S	2	3.992E-03	1.996E-03	4.565E+06	<.001
Variety_V.waxing_T	4	2.554E-05	6.386E-06	14605.97	<.001
Variety_V.Size_S	4	1.803E-05	4.507E-06	10309.20	<.001
waxing_T.Size_S	4	5.291E-04	1.323E-04	3.025E+05	<.001
Variety_V.waxing_T.Size_S	8	1.017E-04	1.271E-05	29062.75	<.001
Residual	78	3.410E-08	4.372E-10		
Total	107	8.570E-03			

Appendix 2: ANOVA of the Effect of Variety, Waxing, and Tuber size on %Sprouting of Puna, Asana, and Punjo:

Week 6

Variate: tansform6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.03112	0.01037	0.40	
Block.*Units* stratum					
Variety_V	2	0.11883	0.05942	2.28	0.109
Waxing_T	2	1.27322	0.63661	24.44	<.001
Size_S	2	0.05093	0.02546	0.98	0.381
Variety_V.Waxing_T	4	0.23767	0.05942	2.28	0.068
Variety_V.Size_S	4	0.03395	0.00849	0.33	0.860
Waxing_T.Size_S	4	0.10186	0.02546	0.98	0.425
Variety_V.Waxing_T.Size_S	8	0.06791	0.00849	0.33	0.954
Residual	78	2.03149	0.02604		
Total	107	3.94698			

Week 8

Variate: transform8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.02533	0.00844	0.64	
Block.*Units* stratum					
Variety_V	2	0.05938	0.02969	2.24	0.113
Waxing_T	2	6.84488	3.42244	258.06	<.001
Size_S	2	0.01252	0.00626	0.47	0.626
Variety_V.Waxing_T	4	0.11875	0.02969	2.24	0.072
Variety_V.Size_S	4	0.03956	0.00989	0.75	0.564
Waxing_T.Size_S	4	0.02503	0.00626	0.47	0.756
Variety_V.Waxing_T.Size_S	8	0.07911	0.00989	0.75	0.651
Residual	78	1.03444	0.01326		
Total	107	8.23900			

Week 10

Variate: transform10

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.041090	0.013697	2.04	
Block.*Units* stratum					
Variety_V	2	0.027349	0.013675	2.04	0.137
Waxing_T	2	10.123448	5.061724	754.78	<.001
Size_S	2	0.019407	0.009704	1.45	0.242
Variety_V.Waxing_T	4	0.064100	0.016025	2.39	0.058
Variety_V.Size_S	4	0.054894	0.013724	2.05	0.096
Waxing_T.Size_S	4	0.034658	0.008664	1.29	0.280
Variety_V.Waxing_T.Size_S	8	0.095414	0.011927	1.78	0.094
Residual	78	0.523083	0.006706		
Total	107	10.983444			

Week 12

Variate: tansform12

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.03246	0.01082	0.46	
Block.*Units* stratum					
Variety_V	2	0.00258	0.00129	0.05	0.947
Waxing_T	2	8.23642	4.11821	173.51	<.001
Size_S	2	0.05686	0.02843	1.20	0.307
Variety_V.Waxing_T	4	0.05967	0.01492	0.63	0.644
Variety_V.Size_S	4	0.05047	0.01262	0.53	0.713
Waxing_T.Size_S	4	0.10081	0.02520	1.06	0.381
Variety_V.Waxing_T.Size_S	8	0.06204	0.00775	0.33	0.953
Residual	78	1.85131	0.02373		
Total	107	10.45262			

Week 14

Variate: transform14

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.008760	0.002920	0.35	
Block.*Units* stratum					
Variety_V	2	0.032464	0.016232	1.96	0.147
Waxing_T	2	1.060689	0.530344	64.13	<.001
Size_S	2	0.016145	0.008073	0.98	0.381
Variety_V.Waxing_T	4	0.068808	0.017202	2.08	0.091
Variety_V.Size_S	4	0.017057	0.004264	0.52	0.724
Waxing_T.Size_S	4	0.015491	0.003873	0.47	0.759
Variety_V.Waxing_T.Size_S	8	0.014925	0.001866	0.23	0.985
Residual	78	0.645019	0.008269		
Total	107	1.879356			

Week 16

Variate: transform16

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.0019620	0.0006540	3.04	
Block.*Units* stratum					
Variety_V	2	0.0012347	0.0006174	2.87	0.063
Waxing_T	2	0.2083032	0.1041516	483.80	<.001
Size_S	2	0.0005121	0.0002561	1.19	0.310
Variety_V.Waxing_T	4	0.0015473	0.0003868	1.80	0.138
Variety_V.Size_S	4	0.0008225	0.0002056	0.96	0.437
Waxing_T.Size_S	4	0.0009640	0.0002410	1.12	0.353
Variety_V.Waxing_T.Size_S	8	0.0032893	0.0004112	1.91	0.070
Residual	78	0.0167917	0.0002153		
Total	107	0.2354269			

Week 18

Variate: transform_18

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00019206	0.00006402	0.91	
Block.*Units* stratum					
Variety_V	2	0.00092153	0.00046076	6.53	0.002
Waxing_T	2	0.05476077	0.02738038	388.06	<.001
Size_S	2	0.00000257	0.00000129	0.02	0.982
Variety_V.Waxing_T	4	0.00052727	0.00013182	1.87	0.124
Variety_V.Size_S	4	0.00032260	0.00008065	1.14	0.343
Waxing_T.Size_S	4	0.00013591	0.00003398	0.48	0.749
Variety_V.Waxing_T.Size_S	8	0.00024280	0.00003035	0.43	0.900
Residual	78	0.00550347	0.00007056		
Total	107	0.06260896			

Week 20

Variate: transform20

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00009284	0.00003095	0.95	
Block.*Units* stratum					
Variety_V	2	0.00045103	0.00022551	6.89	0.002
Waxing_T	2	0.02741272	0.01370636	418.64	<.001
Size_S	2	0.00000367	0.00000183	0.06	0.946
Variety_V.Waxing_T	4	0.00026116	0.00006529	1.99	0.104
Variety_V.Size_S	4	0.00015236	0.00003809	1.16	0.333
Waxing_T.Size_S	4	0.00006215	0.00001554	0.47	0.754
Variety_V.Waxing_T.Size_S	8	0.00011850	0.00001481	0.45	0.885
Residual	78	0.00255371	0.00003274		
Total	107	0.03110813			

Appendix 3: Sample of Sensory Questionnaire Used

Sensory Evaluation of Cooked and Roasted Yam Tubers of Different Cultivars (Varieties) that Have Undergone Different Postharvest Waxing Treatments

Panelist's Assigned Code ______________________ Date: / / 2013

Instruction:

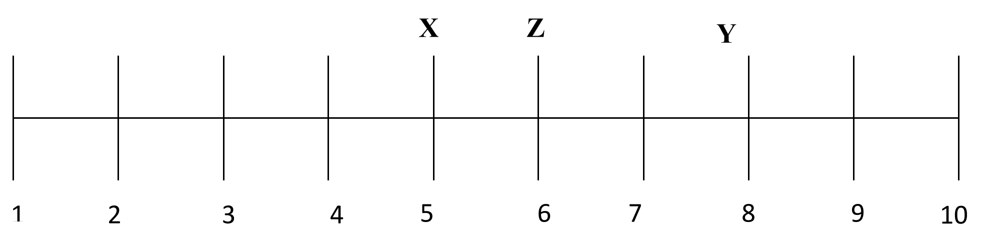
1. Please take a bite of the cracker and a sip of water to rinse your mouth before tasting the samples
2. Taste all the three samples in each given set of evaluation from left to right.
3. The values indicated on each line represent the intensity of your preference with **1** indicating that you **dislike** the attribute greatly and **10** indicating that you **like** the attribute greatly
4. Place the code of each sample provided on the value on each line that best indicate your comparison and preference of each sample according to the given attributes (see example below)
5. Feel free to add any comment in the space provided at the end of this sensory ballot

Thank you!

Example on how to use a structured interval scale:

Comparison of the degree of lightness between any given samples coded X, Y, and Z. The attribute evaluated in this example is "beauty''

Beauty



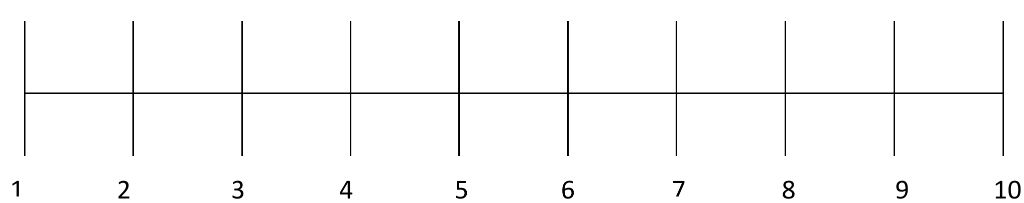
Dislike greatly **Like greatly**

IMPORTANT: If you have any question regarding the use of the given scale, PLEASE ask for assistance BEFORE starting the evaluation

---

Begin your evaluation of each stated attribute below.

Taste



Dislike greatly Like greatly

Flavour

1 2 3 4 5 6 7 8 9 10

Dislike greatly Like greatly

Appearance

1 2 3 4 5 6 7 8 9 10

Dislike greatly Like greatly

Texture

1 2 3 4 5 6 7 8 9 10

Dislike greatly Like greatly

Overall acceptability

1 2 3 4 5 6 7 8 9 10

Dislike greatly Like greatly

General comment:
………
………

Appendix 4: ANOVA of the Effect of Yam Variety and Waxing on Rate of Soft Spots Occurrence on Puna, Asana, and Punjo:

Week 6

Variate: Transform6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.010890	0.003630	0.89	
Block.*Units* stratum					
Variety	2	0.013425	0.006712	1.65	0.213
Waxing	2	0.777443	0.388721	95.48	<.001
Variety.Waxing	4	0.026850	0.006712	1.65	0.195
Residual	24	0.097707	0.004071		
Total	35	0.926315			

Week 8

Variate: Transform8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.008931	0.002977	2.68	
Block.*Units* stratum					
Variety	2	0.032585	0.016293	14.64	<.001
Waxing	2	1.903125	0.951563	855.15	<.001
Variety.Waxing	4	0.018771	0.004693	4.22	0.010
Residual	24	0.026706	0.001113		
Total	35	1.990118			

Week 10

Variate: Transform10

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.022363	0.007454	1.16	
Block.*Units* stratum					
Variety	2	0.075548	0.037774	5.86	0.008
Waxing	2	1.237201	0.618600	96.03	<.001
Variety.Waxing	4	0.012059	0.003015	0.47	0.759
Residual	24	0.154596	0.006442		
Total	35	1.501766			

Week 12

Variate: Transform12

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.006614	0.002205	1.18	
Block.*Units* stratum					
Variety	2	0.013427	0.006713	3.59	0.043
Waxing	2	0.456352	0.228176	122.14	<.001
Variety.Waxing	4	0.002303	0.000576	0.31	0.870
Residual	24	0.044835	0.001868		
Total	35	0.523531			

Week 14

Variate: Transform_14

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.0036420	0.0012140	1.60	
Block.*Units* stratum					
Variety	2	0.0025009	0.0012504	1.65	0.213
Waxing	2	0.3086531	0.1543265	203.60	<.001
Variety.Waxing	4	0.0020666	0.0005167	0.68	0.612
Residual	24	0.0181915	0.0007580		
Total	35	0.3350540			

Week 16

Variate: Transform16

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.0010386	0.0003462	1.53	
Block.*Units* stratum					
Variety	2	0.0010802	0.0005401	2.39	0.113
Waxing	2	0.1280109	0.0640054	283.73	<.001
Variety.Waxing	4	0.0009814	0.0002453	1.09	0.385
Residual	24	0.0054141	0.0002256		
Total	35	0.1365252			

Week 18

Variate: Transform18

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00043323	0.00014441	1.50	
Block.*Units* stratum					
Variety	2	0.00057769	0.00028885	2.99	0.069
Waxing	2	0.07477038	0.03738519	387.24	<.001
Variety.Waxing	4	0.00057769	0.00014442	1.50	0.235
Residual	24	0.00231701	0.00009654		
Total	35	0.07867600			

Week 20

Variate: Transform20

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00022158	0.00007386	1.47	
Block.*Units* stratum					
Variety	2	0.00035157	0.00017578	3.50	0.046
Waxing	2	0.05027135	0.02513567	500.04	<.001
Variety.Waxing	4	0.00037207	0.00009302	1.85	0.152
Residual	24	0.00120641	0.00005027		
Total	35	0.05242298			

Appendix 5: ANOVA of Yam Variety and Waxing on the Sensory Characteristics of Puna, Asana, and Punjo Varieties of White Yam Stored for 14 weeks

TASTE

Variate: Taste

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.020833	0.006944	1.00	
Block.*Units* stratum					
Variety	2	6.347222	3.173611	457.00	<.001
Waxing	2	33.013889	16.506944	2377.00	<.001
Variety.Waxing	4	2.027778	0.506944	73.00	<.001
Residual	24	0.166667	0.006944		
Total	35	41.576389			

TEXTURE

Variate: Texture

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.020833	0.006944	1.00	
Block.*Units* stratum					
Variety	2	6.347222	3.173611	457.00	<.001
Waxing	2	33.013889	16.506944	2377.00	<.001
Variety.Waxing	4	2.027778	0.506944	73.00	<.001
Residual	24	0.166667	0.006944		
Total	35	41.576389			

FLAVOUR

Variate: Flavour

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.86111	0.62037	6.23	
Block.*Units* stratum					
Variety	2	10.88889	5.44444	54.70	<.001
Waxing	2	5.38889	2.69444	27.07	<.001
Variety.Waxing	4	0.44444	0.11111	1.12	0.372
Residual	24	2.38889	0.09954		
Total	35	20.97222			

ATTRACTIVENESS

Variate: Appearance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.0	0.0		
Block.*Units* stratum					
Variety	2	8.0	4.0		
Waxing	2	0.0	0.0		
Variety.Waxing	4	0.0	0.0		
Residual	24	0.0	0.0		
Total	35	8.0			

ACCEPTABILITY

Variate: Overall_Acceptability

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.0	0.0		
Block.*Units* stratum					
Variety	2	8.0	4.0		
Waxing	2	0.0	0.0		
Variety.Waxing	4	0.0	0.0		
Residual	24	0.0	0.0		
Total	35	8.0			

Appendix 6: ANOVA of the Effect of Shea Butter and Palm Kernel Oil Waxing on Moisture Content of White Yam Stored for a Period 0f:

1st Month

Variate: Moisture, Log1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00211688	0.00070563	34.86	
Block.*Units* stratum					
Variety	2	0.00048412	0.00024206	11.96	<.001
Waxing	2	0.00091554	0.00045777	22.61	<.001
Variety.Waxing	4	0.00000006	0.00000002	0.00	1.000
Residual	24	0.00048583	0.00002024		
Total	35	0.00400243			

2nd Moth

Variate: Moisture, Log2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00239243	0.00079748	34.75	
Block.*Units* stratum					
Variety	2	0.00054702	0.00027351	11.92	<.001
Waxing	2	0.00499699	0.00249850	108.87	<.001
Variety.Waxing	4	0.00000039	0.00000010	0.00	1.000
Residual	24	0.00055080	0.00002295		
Total	35	0.00848763			

3rd Month

Variate: Moisture, Log3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00268178	0.00089393	34.52	
Block.*Units* stratum					
Variety	2	0.00061306	0.00030653	11.84	<.001
Waxing	2	0.01371746	0.00685873	264.85	<.001
Variety.Waxing	4	0.00000119	0.00000030	0.01	1.000
Residual	24	0.00062152	0.00002590		
Total	35	0.01763501			

4th Month

Variate: Moisture, Log4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00317410	0.00105803	34.11	
Block.*Units* stratum					
Variety	2	0.00072538	0.00036269	11.69	<.001
Waxing	2	0.02927675	0.01463838	471.98	<.001
Variety.Waxing	4	0.00000301	0.00000075	0.02	0.999
Residual	24	0.00074435	0.00003101		
Total	35	0.03392360			

5th Month

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00333920	0.00111307	34.07	
Block.*Units* stratum					
Variety	2	0.00076304	0.00038152	11.68	<.001
Waxing	2	0.03080507	0.01540253	471.52	<.001
Variety.Waxing	4	0.00000333	0.00000083	0.03	0.999
Residual	24	0.00078398	0.00003267		
Total	35	0.03569462			