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CURING AND HOUSEHOLD-LEVEL STORAGE METHODS AND THEIR EFFECT ON THE SHELF LIFE OF TWO ORANGE-FLESHED SWEETPOTATO [*Ipomoea batatas* (L) Lam] CULTIVARS

BY

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CANDIDATE'S DECLARATION

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

Candidate's Signature: ………………………….Date: ...……………………………..

Name: ……………………………………………………………………………….

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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

Name: …………………………………………………………………..…………..……

Head of Department

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ABSTRACT

Orange-fleshed sweetpotato (OFSP) is an important root crop capable of ameliorating vitamin A deficiency that is a public health concern in Sub Saharan Africa. However, most of the OFSP cultivars have relatively short shelf life largely due to improper pre-and post-harvest management. This study investigated the effect of two curing (field-piled and in-ground) and two household-level storage (sand box and heap) methods on the shelf life of two OFSP cultivars (Apomuden and Nane) in two successive years. The indicators for shelf life were: wound healing ability, physical and compositional root quality indices, sensory attributes and length of storage. The OFSP cultivars were either cured in-ground/dehaulming; by removing part of vines and leaving 30 cm of it from the base and allowing to cure in-ground for seven days prior to harvest or field-piled cured for seven days by covering harvested roots with fresh sweetpotato vines on the field. To create wounds, 21 roots from the two cultivar either in-ground or field-piled cured were deliberately given three wounds each using a potato peeler. The wound healing ability score was given based on the scale: *0=no lignification, 0.5=patchy lignification and 1=complete lignification*. Freshly harvested roots (uncured) together with roots that were cured for seven days from the two curing treatments were stored in either sand box or under moistened straw heap. A hedonic scale ranging *1=extremely dislike* to *5=extremely like* was used for the sensory evaluation of the boiled roots after storage in either sand box or heap. General appearance, finger-feel firmness, sweetness and overall acceptability were the sensory qualities assessed. Generally, wound healing ability of cultivars increased as curing progressed until the fifth day and levelled off. Apomuden consistently recorded significantly higher ($p < 0.05$) weight loss and rots than Nane. Roots stored in the sand box were significantly lower ($p < 0.05$) in all physical root qualities except for sprouts. The β-

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carotene content of Apomuden and Nane respectively ranged from 13.80 to 28.29 mg/100 g and 11.33 to 17.20 mg/100 g in both years. Curing did not have a significant ($p = 0.352$) influence on the β-carotene content of roots except for the second year where field –piled cured and stored roots had a significantly high (24.96 mg/100 g; $p = 0.007$) β-carotene content compared with stored roots from the dehaulmed (22.26 mg/100 g) and uncured (21.01 mg/100 g) treatments. The sand box and the heap storage methods respectively resulted in 10% and 19% decline in β-carotene after 2 months of storage. This indicates that, β-carotene retention is better in the sand box relative to the heap storage. All sensory attributes investigated in both years, had scores ranging from 3.20 to 3.93 indicating a good consumer preference for both cultivars. Storage type showed no significant difference ($p > 0.05$) in all sensory attributes in both years. Both cultivars showed good wound healing ability and could store well. Field-piled or in-ground curing could be done for a minimum of 5 days as wound healing would have been completed. The sand box storage method showed better retention of β-carotene and consumer acceptability after 2 months of storage. Sand box storage improved the storage properties of up to 2 months and should be encouraged for adoption by farmers in Ghana and the sub region.

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DEDICATION

This work is dedicated to my cherished wife Lilian Talata Aniah and our lovely kids:

Anne Ayinesune Atinpoore

And

Aaron Adolyine Atinpoore

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LIST OF ACRONYMS AND ABBREVIATIONS

AAU: Association of African Universities

ANOVA: Analysis of Variance

CAD: Cinnamyl Alcohol Dehydrogenase

CIP: International Potato Center

CRI: Crop Research Institute

CSIR: Council for Scientific and Industrial Research

ELIP: Early Light Inducible Protein

HPLC: High Performance Liquid Chromatography

ILRI: International Livestock Research Institute

LI: Lignification Index

NIRS: Near Infrared Reflectance Spectroscopy

OFDA: Office for Foreign Disaster Assistance

OFSP: Orange-Fleshed Sweetpotato

PFSP: Purple-fleshed Sweetpotato

RTIMP: Root and Tubers Improvement and Marketing Programme

SARI: Savanna Agricultural Research Institute

SASHA: Sweetpotato Action for Security and Health in Africa

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UDS: University for Development Studies

UN: United Nations

US: United States

USAID: United States Agency for International Development

USDA: United States Department of Agriculture

VAD: Vitamin A Deficiency

WFP: World Food Programme

WFSP: White-Fleshed Sweetpotato

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CHAPTER ONE

1 Introduction

The first chapter (Chapter one) gives an outline of the thesis and introduces the problem which the study seeks to address. The significance of the study as well as its objective (s) is/are also considered. The second chapter (Chapter two) contains the theoretical framework of the study which reviews relevant literature related to the study. The study focused on pre-harvest (dehaulming) and post-harvest practices (field-piled curing and storage methods) and their influence on root quality indices (weight loss, rots, weevil damage and sprout). Also, compositional and culinary properties of the stored roots have been considered. The chapter concludes with a brief summary of major issues making up the chapter. The methodology employed for the study with emphasis on the study location and experimental design, tools used and data analysis are duly considered in chapter three. Chapter four consists of all the findings and analysis of data of this investigation. Chapter five is made up of the discussions of the results on the major thematic areas: Curing, lignification, storage and their influence on the nutritional qualities of roots. Chapter six involves the conclusions drawn from the research, recommendations, area for future works to be done and the limitations of this study.

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1.1 Background

Sweetpotato (*Ipomoea batatas* (L) Lam) is globally ranked as the seventh most important food crop after wheat, rice, maize, potato, barley and cassava (Dayal, Mehra, & Scott, 1991). It is a dicot belonging to the *Convolvulaceae* or the morning glory family (Huaman, 1992; Woolfe, 1992). Over 95% of the world's sweetpotato crop is grown in the developing countries (Dayal *et al.*, 1991). United States and Japan are among the developed countries that do significant cultivation of sweetpotato (Crissman *et al.*, 2007).

Sweetpotato is a hardy, low input crop and capable of giving high yields under suitable conditions, it can also give good yield on marginal conditions (Nedunchezhiyan & Ray, 2010). Therefore, sweetpotato can serve as a food security crop in developing countries where agricultural inputs such as fertilizer and irrigation facilities are limited.

Several varieties of the sweetpotato exist, ranging from white, cream, yellow, orange and purple-fleshed (Bovell-Benjamin, 2007; Burri, 2010; Woolfe, 1992). The white and cream-fleshed sweetpotato are commonly grown and eaten in most parts of northern Ghana. The orange-fleshed sweetpotato (OFSP) is rich in β-carotene, a precursor of vitamin A (Hagenimana & Low, 2000; Low, Walker, & Hijmans, 2001), capable of improving nutrition and overall human health. For example, regular consumption of OFSP cultivars has been reported to improve the vitamin A status of young (< 5 years) South African children (van Jaarsveld *et al.*, 2005).

OFSP is being promoted in Ghana as a food-based strategy to reduce vitamin A deficiency (VAD). The prevalence of subclinical vitamin A deficiency (VAD) in Ghana is high;

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almost three-quarters of children under age five being deficient, with 35% of them classified as severe (serum retinol <10 µg/dL) (World Health Organization, 2009).

Unfortunately, the short storage life of OFSP remains a setback, limiting the availability of fresh roots for household consumption for improved food and nutrition security. The shelf life of sweetpotato has been reported to be in the ranges of 7-10 days under market conditions in developing countries (Rees *et al.*, 2003) and varies based on cultivar and the condition of storage (Ray, Ravi, Hegde, Rao, & Tomlins, 2010). However, Woolfe (1992) reported that, under regulated conditions of temperature (13-15°C) and relative humidity (90%) sweetpotato stores up to a year.

Curing is one crucial practice that improves the shelf life of sweetpotato. Curing is a post-harvest practice whereby roots are held under moderate temperature (29-33°C) and high relative humidity (90-95%) for about a week prior to storage (Edmunds *et al.*, 2008). It promotes wound healing by replacing damaged periderm (Woolfe, 1992). However, in the tropics, curing is rarely practiced by farmers but may occur naturally because tropical ambient conditions are similar to commercial curing conditions (Ravi, Aked, & Balagopalan, 1996; Woolfe, 1992).

1.2 Justification

The main constraint that limits the use of sweetpotato as a food and nutrition security crop is the short shelf life. Therefore pre- and post-harvest practices such as dehaulming, field-piled curing and appropriate storage options that have the potential to extend the shelf life of sweetpotato roots, particularly of OFSP cultivars is worth investigating. This study is therefore carried out to find appropriate alternative curing processes and storage options that could significantly improve the storability without compromising nutritional quality for improved health.

1.3 Significance of study

The short shelf life of sweetpotato does not offer rural households the opportunity to consume and/or market sweetpotato for an extended period of time after harvest. The significant contribution this study seeks to make, if successful, is for sweetpotato to be stored in a low cost, easy to use sand box at the rural communities up to 2 months after harvesting for household consumption.

1.4 Main objective

The main objective of the study is to promote nutrition in rural households by extending the shelf life of two β-carotene rich sweetpotato cultivars (Apomuden and Nane).

1.4.1 Specific objectives

- To study responses of Apomuden and Nane to wound healing when subjected to in-ground/dehaulming and field-piled curing methods.
- To compare the shelf lives of Apomuden and Nane under the sand box and heap methods.
- To study the effect of storage methods on the β-carotene and sensory qualities of Apomuden and Nane.

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CHAPTER TWO

2 Literature review

2.1 Origin and distribution of sweetpotato

Sweetpotato [*Ipomoea batatas* (L) Lam] belongs to the family Convolvulaceae or morning glory (Huaman, 1992; Woolfe, 1992). Different researchers have suggested the Americans as the origin for sweetpotato: Central America (Abd El-Baky, Ahmed, Abd El-Aal, & Salman, 2009) and North Western South America (Huaman, 1992) Although the specific location where sweetpotato originated remains unknown, it is thought to have come from America (Dayal *et al.*, 1991). Sweetpotato started to spread to other continents (Asia, Africa and Latin America) in the 17th-18th centuries because of its hardy nature and easy adaptability (Dayal *et al.*, 1991).

In the global food system, particularly that of developing countries, the contribution of roots and tubers cannot be under estimated (Kenyon, Anandajayasekeram, & Ochieng, 2006). Considering the annual volumes of production; cassava, potato and sweetpotato are among the top 10 food crops produced in third world countries (Scott, Rosegrant, & Ringler, 2000). In the tropical and sub-tropical regions, root and tuber crops such as cassava, sweetpotato and yam are primarily the important crops (Crissman *et al.*, 2007). Scott *et al*. (2000) reported the total use of roots and tubers in developing countries is expected to go up by 58% (232 million tons to 367 million tons) between 1993 and 2020. Cassava, potato and sweetpotato are expected to increase by 44, 29 and 27% respectively. As the volume of production is expected to increase, research on post-harvest losses and

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techniques to reduce these losses becomes apparently important. The current research takes a critical look at some of the factors responsible for post-harvest losses in sweetpotato and possible ways to minimize them with specific focus on pre- and post-harvest procedures.

2.2 Sweetpotato flesh colour

There are several varieties of sweetpotato with a range of flesh colours from white cream, yellow, orange, to purple (Bovell-Benjamin, 2007; Burri, 2010; Woolfe, 1992). The white-fleshed sweetpotato (WFSP) cultivars (Plate 2.1) are most commonly grown and eaten in most parts of northern Ghana.

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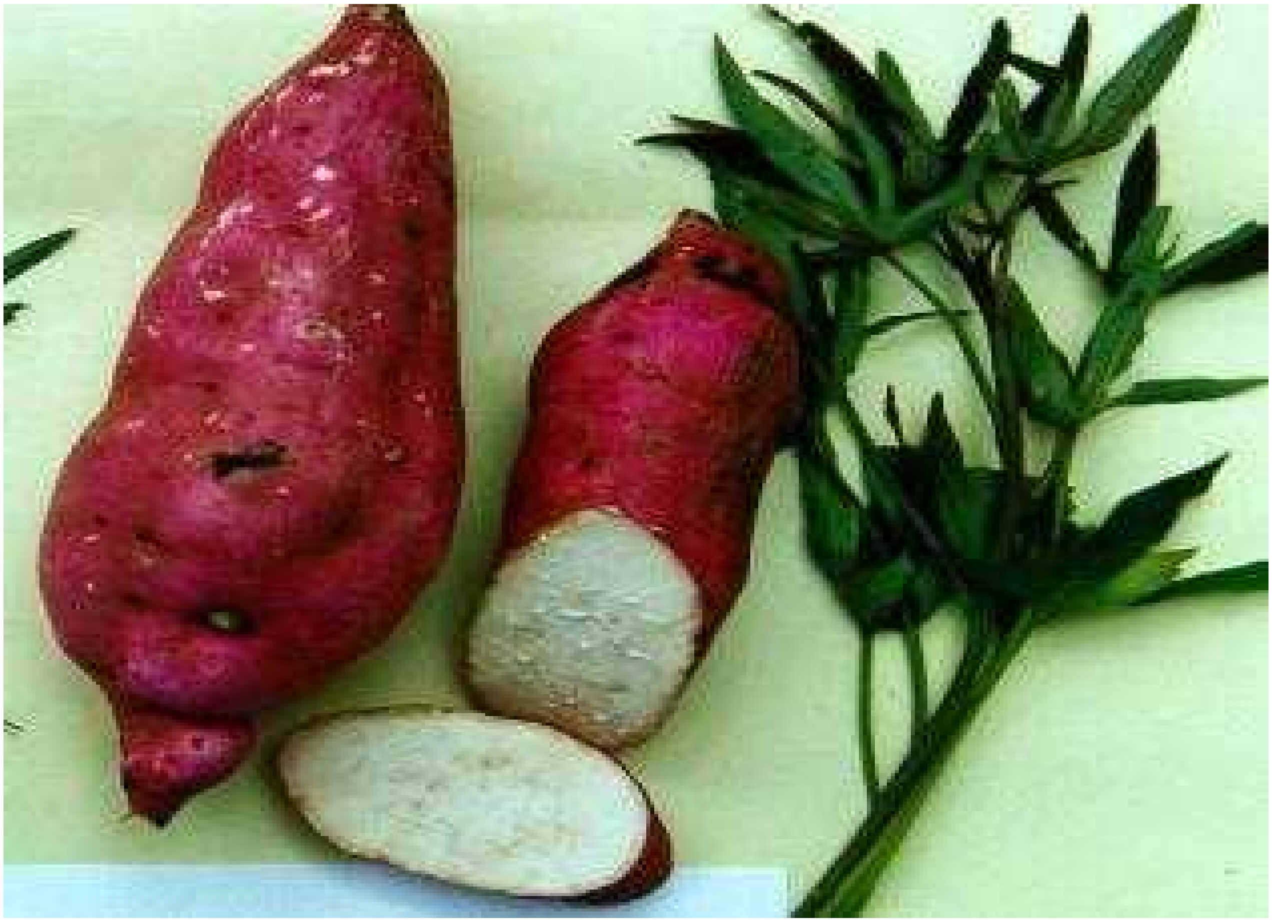

Plate 2.1: White-fleshed sweetpotato cultivar

The WFSP cultivars contain no carotenoids and anthocyanins (Hagenimana & Low, 2000; Low *et al.*, 2001) but are a great feedstock to the white starch industry and preferred by most Ghanaian consumers because of its dry texture after cooking (Baafi *et al.*, 2015).

However, the intensity of the orange colour of the flesh is associated with higher concentration of phytochemicals such as β-carotene (Vimala, Sreekanth, Binu, & Wolfgang, 2011). Thus yellow-fleshed cultivars (Plate 2.2) possess lower concentration of β-carotene compared with the deep orange-fleshed cultivars (Plate 2.3).

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Plate 2.2: Yellow-fleshed sweetpotato cultivar

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Plate 2.3: Orange-fleshed sweetpotato cultivar

The purple-fleshed sweetpotato (PFSP) cultivars (Plate 2.4) are not common in Ghana, but contains high amount of stable and bioavailable anthocyanins in the storage root which possess many health benefits such as antioxidative, antineoplastic, as well as anticancer properties (Odake, Terahara, Saito, Toki, & Honda, 1992; Terahara, Konczak, Ono, Yoshimoto, & Yamakawa, 2004; Terahara *et al.*, 1999). It is also used as natural food colorant, and the deep purple paste and flour are used for the preparation of noodles, bread, jams, chips, confectionery, juices and alcoholic beverages.

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Plate 2.4: Purple-fleshed sweetpotato cultivar

2.3 Nutritional and health significance of sweetpotato

Sweetpotato is rich in dietary fibre, minerals, vitamins, and antioxidants, such as polyphenols, anthocyanins, tocopherol and β-carotene (Woolfe, 1992). These phytochemicals, especially polyphenols, have high free-radical scavenging activity, which helps in suppressing chronic diseases, such as cardiovascular disease, melano-genesis, cancer, hepatoma invasion, human immunodeficiency virus (HIV) replication, mutagenesis and age-related neuronal degeneration (Suda *et al.*, 2003). The free radicals that exist in different forms, including superoxide, hydroxyl, hydroperoxyl, peroxyl and alkoxyl radicals are generated in the human body through normal metabolism and naturally can damage biological structures such as proteins, lipids and DNA, and induce a variety of human diseases (Thrasivoulou *et al.*, 2006).

Generally, natural antioxidant enzymes in healthy individuals remove these free radicals (Suda *et al.*, 2003). However, dietary antioxidants are helpful in assisting the body to neutralise free radicals. Therefore, it is important to consume a diet high in antioxidants, such as fruits and vegetables, to reduce the harmful effects of oxidative stress. The antioxidant potential of phenolic compounds in sweetpotato storage root tissue is higher than in many vegetables (Yamakawa & Yoshimoto, 2001). In addition to acting as antioxidants, carotenoids and phenolic compounds also provide sweetpotato with their distinctive flesh colours (cream, deep yellow, orange and purple). The OFSP and PFSP cultivars contained high amounts of carotenoids and anthocyanins, respectively.

OFSP cultivars contain significant levels of β-carotene (Tumwegamire *et al.*, 2014) which is a precursor of vitamin A and its intake could improve on the vitamin A status of consumers especially in developing countries where VAD is a public health concern.

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2.4 Sweetpotato production in Ghana

In Ghana, after cassava, sweetpotato is regarded as the second most important root crop that augment staple crops such as maize (Agbemafle *et al.*, 2014). The crop is widely cultivated throughout the country, especially the northern parts for its nutritious roots and leaves though the leaves are not widely consumed. The production of sweetpotato is currently being encouraged in Ghana due to its potentials in promoting food security (Teye, Amoah, & Tetteh, 2011b) and alleviating vitamin A deficiency (VAD) (Laurie & Van Heerden, 2012). VAD is a public health concern in developing countries (World Health

Organization, 2009) including Ghana. Furthermore, sweetpotato is promoted by the development of various food recipes for improved diets for people by the Root and Tuber Improvement and Marketing Programme (RTIMP) (Amoah, Teye, Abano, & Tetteh, 2011).

Commercial sweetpotato production in Ghana is scattered all over the country with major production areas being Upper East and Eastern Regions (Ministry of Food and Agriculture/Statistics Research and Information Directorate, 2012). An estimated total of 9,622 hectares translating into a total output of 131,990 metric tons (Mt.) of sweetpotato was obtained during the 2012 cropping season (Ministry of Food and Agriculture/Statistics Research and Information Directorate, 2012). The Upper East Region alone accounted for 5,550 hectares (58%) of total area and an output of 46,000 Mt. (35%). The Bawku municipality alone accounts for 1000 ha and 12,500 Mt. for total area cultivated and output respectively (Ministry of Food and Agriculture/Statistics Research and Information Directorate, 2012). Therefore apart from income generation, the nutritional needs of the rural poor can be addressed with sweetpotato cultivation in addition to other staple crops such as: Sorghum, maize and onion. The availability of sweetpotato especially the OFSP cultivar is important for regular consumption for improved food and nutrition security. However the short shelf life of sweetpotato particularly OFSP, remains a major stumbling block, limiting its availability for regular consumption. To this extent, pre and post-harvest techniques that can potentially improve the shelf life of sweetpotato roots for regular household consumption by the rural poor are worth investigating.

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2.5 The role of sweetpotato in improving food security

There is a high prevalence of food insecurity in most parts of Africa (Dittoh, 2003). This could be largely attributed to the pockets of conflicts and erratic rainfall patterns as

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purported by Kapinga et al. (2005). While the food security situation in Ghana has shown a steady increase based on per capita food production, other factors (rainfall and drought, pest and disease, bushfires, poor storage facilities and roads) pose a threat to food production and distribution (Nyanteng & Asuming-Brempong, 2003). The three regions from the north: Northern, Upper East and Upper West regions are the most vulnerable (Quaye, 2008) with agriculture being their main livelihood activity. According to the World Food Programme (2010), Bawku municipality and its environs in the Upper East region of Ghana, is the hardest hit in terms of food insecurity. This might probably be due to the protracted inter-tribal conflict that adversely affected agriculture and other livelihood ventures. This confirms earlier studies by Kapinga *et al.* (2005) that revealed that, conflicts may contribute to the food insecurity in the affected areas.

Sweetpotato and other root crops have often been used to mitigate disaster situations because of their relatively short maturity (3-4 months), low input crop and ability to thrive under adverse climatic conditions (Kapinga *et al.*, 2005). Moreover, the nutritional value of sweetpotato is important in mitigating diseases among the vulnerable in the rural communities. The UN millennium Project Task Force on Hunger concluded that, hunger can be halved by 2015 if only there is improved nutrition for the persistent vulnerable households among other factors (Quaye, 2008). Sweetpotato, OFSP especially, is best suited in achieving this feat due to its hardy nature, ability to do well on marginal soils and relatively rich in both macro and micronutrients particularly vitamin A. Northern Ghana has been identified as an area where there is prolonged months of food insecurity (Ghana Living Standards Survey, 2000). This situation might be attributed to low productivity as a result of droughts as well as inadequate storage facilities. In view of this, it is important to

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pay particular attention to crops such as sweetpotato that has the potential of giving good yields on marginal soils that characterize the northern soils. Furthermore, reducing postharvest losses through good pre and postharvest techniques is critical in achieving food and nutrition security in northern Ghana. The current study evaluates the potentials of preharvest (dehaulming) and post-harvest (field-piled) curing method as well as homestead storage method for improved nutrition.

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2.6 Post-harvest losses

Storage of agricultural produce is crucial in ensuring availability of food beyond the production harvest period. However, in the tropics between 25 and 40% of stored agricultural products are lost each year because of inadequate farm and household-level storage methods (Hayma, 2003).

In the case of sweetpotato, physiological and pathological factors have been indicated to contribute to losses of up to 30-35% in developing countries (Jenkins, 1982). Sweetpotato losses resulting from post-harvest handling, and transport were reported to be 20 and 86% respectively (Tomlins, Ndunguru, Rwiza, & Westby, 2000). This conforms with suggestions by Ray and Ravi (2005), that sweetpotato root quality is adversely affected by careless post-harvest handling commonly practiced in tropical developing countries. In all these instances it is obvious that losses due to post-harvest handling is a concern and should be promptly addressed for food security. Addressing these concerns does not only require improved storage structures but also good pre and post-harvest techniques as well as optimum temperature and other ambient conditions which are all being considered in the current study.

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2.7 Causes of sweetpotato post-harvest losses

There are various schools of thoughts about the causes of post-harvest losses. Woolfe (1992) identified the high moisture content (60-70%) and the thin delicate skin of sweetpotato as the primary cause of post-harvest losses. Freshly harvested sweetpotato have been reported to have a high rate of respiration and the resultant heat softens the texture reducing its shelf life (Ray *et al.*, 2010). The cause of poor storage of sweetpotato according to Sowley and Oduro (2002) is mainly due to wounds sustained during harvesting, transportation and post-harvest handling before storage. These wounds serve as entry points for microbial infection. Rees *et al.* (2001) suggested that breakage, cuts, weevils infestation, rot and superficial damages are the cause of the short shelf life of sweetpotato. Altogether, about 41 to 93% of roots were damaged when sweetpotato arrived in the urban Tanzanian markets from production centres resulting in about 13 to 46% shelf life reduction (Rees *et al.*, 2001).

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Post-harvest losses of sweetpotato in the tropics and sub-tropics is mainly as a result of physical, physiological and biological factors and the losses are often considerable (Ray & Ravi, 2005).

2.7.1 Physical factors

These are mainly pre-harvest and harvest conditions. Pre-harvest conditions include principal edaphic factors such as moisture, temperature etc. The importance of these soil factors varies with agro-ecology. For example, cold has been a constraint only at high altitudes (above 2,200 m) (Schneider, Widyastuti, & Djazuli, 1993). Likewise, excess soil moisture (40%) in the field can cause subsequent post-harvest loss (Ravi *et al.*, 1996).

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2.7.2 Mechanical Damage

Mechanical damage is the most important harvest factor, much of which occur during the harvest itself, transport and marketing (Rees *et al.*, 2001; Rees *et al.*, 1998; Tomlins *et al.*, 2000). Harvesting is usually done manually in the tropics using a wide range of tools such as digging sticks, spades, hoes, and knives (Ali *et al.*, 1991; Jana, 1982; Karuri & Ojijo, 1993). Mechanical harvesting using tractors or animal-drawn ploughs and other sophisticated machines are confined to areas of large-scale production. Sweetpotato roots are often cut, skinned, and bruised by the harvesting implements. Roots found to be damaged during harvesting using spade was 26 and 24% respectively in Bangaladesh (Jana, 1982) and India (Prasad, Srinivasan, & Shanta, 1981). Similar estimates were reported on damaged roots (Rees *et al.*, 2001; Rees *et al.*, 1998; Tomlins *et al.*, 2000) in developing countries where hoes are mostly used for harvesting. In countries where roots are transported by different means such as lorry, motor cycle, cart etc. over bumpy roads to markets, increased root damage and loss of quality frequently results (Rees *et al.*, 1998). The practice of overfilled heaps or use of polypropylene sacks for transportation and storage have led to physical damage which could have been prevented if fewer roots were carefully packed in cardboard boxes, cartoons or crates (Jenkins, 1982; Tomlins *et al.*, 2000).

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2.7.3 Physiological Factors

2.7.3.1 Respiration

Respiration and transpiration in sweetpotato contribute to weight loss and changes in internal and external appearance (Picha, 1986b). Transpiration losses are due to evaporative loss of the cellular water caused by vapor pressure difference between the root interior and

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the outside environment (Walter, Hammett, & Giesbrech, 1989). Most of the works indicated that respiration was highest immediately after harvest than during curing or storage (Picha, 1986b; Walter *et al.*, 1989). Furthermore, the respiration rate was highest on the day of harvest, decreased during curing, and continued to decrease at a slower rate during the first several months of storage (Picha, 1986b). Because starch is used as a respiratory substrate, the content of starch, the predominant form of carbohydrate in the roots, decreased during storage (Ray & Ravi, 2005) and subsequently the dry matter content decreased in the roots. Wounding of sweetpotato roots resulted in an increase in both the respiration rate and subsequent weight loss (Jenkins, 1982; Picha, 1986b). Sweetpotato roots having 58-78% moisture content showed a low respiratory rate of <0.5 mg of CO per gram dry weight per hour, whereas at moisture levels >75% the rate increased drastically, reaching up to 2.0 mg CO per gram dry weight per hour. This indicates that cultivars having low dry matter content may have a shorter storage life (Hirose, Data, & Quevedo, 1984). All these studies on respiration and consequently moisture loss were conducted in temperate conditions. However, respiration losses are much greater under tropical conditions. For example, the high temperature (<35 and low R.H. (30–40%) during summer in Bangladesh result in virtually maximum rates of respiration and rapid evaporation of moisture through the root skin (Jenkins, 1982). Further, loss in moisture leads to a condition known as ‘pithiness’ in which cavities appear within the tissues (Picha, 1986b). Prolonged moisture losses, as those occurring in tropical conditions, could result in collapse of tissues which begins at the distal ends of the roots and may ultimately cause total desiccation, especially in small sized roots (Jenkins, 1982). In Indonesia, to prevent desiccation, the piled roots are usually covered by coconut palm or banana leaves or plastic sheets (Watson, Dimyati, Husni Malian, & Wargiono, 1991).

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Percentage weight loss is sometimes used to evaluate the level of physical damage caused by various sweetpotato harvests and handling methods (Tomlins *et al.*, 2000).

2.7.3.2 Sprouting

Sprouting in sweetpotato roots occurs very quickly especially when soil moisture is high and the harvest is delayed. It also occurs during prolonged storage in conditions of high temperature and humidity (Jana, 1982). In the tropics, sprouts are generally broken off as they appear (Ravi *et al.*, 1996). Sprouting can be suppressed or inhibited by storing the roots at relatively cool temperature (14°C). The other methods for suppressing sprout formation are gamma irradiation and application of growth regulators. Exposure to gamma irradiation (0.03-0.15 kGy) markedly suppressed sprouting (Bonsi & Loretan, 1988). In unirradiated samples, 100% roots sprouted after one-month storage whereas those treated with 0.05 kGy gamma radiation showed 2.5 and 9% sprouting after one and five months, respectively. The percentage decay and weight loss of the roots were highest at doses between 0.1–0.15 kGy when stored at 21–23°C for 12 months (Bonsi & Loretan, 1988). Besides gamma irradiation, growth regulators were found effective as sprout suppressants. Sprouting was reduced in roots, stored for four to eight months with treatment of maleic hydrazide (MH) (Jenkins, 1982). Naphthalene acetic acid (NAA) at all concentrations either delayed or inhibited sprouting and reduced cumulative weight loss during storage. Ethrel (2-chloroethyl phosphonic acid) enhanced both sprouting and rooting. Maleic hydrazide (MH) delayed sprouting, but more sprouts were produced later. Cycocel had no significant effect on sprouting. Sprout numbers were significantly reduced by treatment with 3.0-9.0% (weight by volume) sodium hypochlorite (NaOCI) solution after 102 days of storage, but weight loss was high (Lewthwaite & Triggs, 1995).

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2.7.4 Biological factors

Biological factors include storage pests, and diseases.

2.7.4.1 Storage Pests

2.7.4.1.1 Weevils

In most parts of the tropics and subtropics, one of the most serious problems in storage is the sweetpotato weevil (*Cylas formicarius* Fabricius) (Ali *et al.*, 1991; Jana, 1982; Jenkins, 1982; Kurup & Balagopalan, 1991; Mtunda *et al.*, 2001) and two closely related species (*C. puncticollis* Boheman, and *C. brunneus*) (Smit, Downham, Laboke, Hall, & Odongo, 2001). *Cylas puncticollis* is confined to several countries in Africa (Downham *et al.*, 1999; Jana, 1982; Smit *et al.*, 2001). However, *C. formicarius* is more cosmopolitan, being distributed from West to East Africa, in South Africa, Madagascar, Mauritius, Vietnam, the Seychelles, India, Bangaladesh, Sri Lanka, China, Papua New Guinea, eastern Australia, the Solomon Islands, Hawaii, Samoa, Fiji, southern USA, Caribbean Islands, Mexico, Guyana, and Venezuela (Ray & Ravi, 2005; Woolfe, 1992). The insect feeds on the vines of the growing crop and migrates down to the roots and infests those roots near the soil surface (Jenkins, 1982). In some instances, weevil attack was so serious that the farmers could not harvest edible roots, but only vines (Ray & Ravi, 2005). Further, harvested roots may contain the weevils in any of its life stages which damage roots during subsequent storage (Jenkins, 1982). Such contamination may not be readily visible to the naked eye and apparently healthy appearing roots may be stored only to be attacked when eggs hatch and larva tunnel through the storage roots resulting in major damage and loss. Weevils prefer storage roots to stems and leaves (Ray & Ravi, 2005). The female however, uses storage roots for ovipositor rather than as a source of food (Smit & Matengo, 1995). Moreover, phenolics of unspecified chemical composition increased significantly for up to

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14 days in roots fed upon by adult weevil or its larvae (Padmaja & Rajamma, 1982). This coincided with the development of an unpleasant turpentine odor and a bitter taste in the roots. The bitter taste was due to production of phytoalexins such as ipomeamarone and ipomeamaranol (Uritani, 1998). Regardless of the toxicity of this compound, the unpleasant odor makes sweetpotato less acceptable for human consumption. In India, under traditional conditions, sweetpotato roots showed 32-60% loss due to weevil damage after two months of storage (Ray & Ravi, 2005). There was no significant difference in weevil infestation between cured and uncured roots stored inside soil, sand or saw dust as more than 50% roots were spoiled (Ray, Chowdhury, & Balagopalan, 1994). Smit (1997) reported yield loss of up to 73% from Uganda, which is the world's fourth largest sweetpotato producers.

Control of sweetpotato weevils is still a major constraint, which is yet to be solved. Integrated pest management program and some cultural practices are mostly followed in various sweetpotato growing countries for controlling weevils (Jansson & Raman, 1991). These include the use of terminal cuttings, hilling up, sex pheromone traps, irrigation, dipping planting materials in insecticide solution, and early harvest (Jansson & Raman, 1991; Smit, 1997). Weevils could be killed in the store if the temperature was lowered to 20°C (Ray & Ravi, 2005). Furthermore, roots immersed in hot water at 52-62°C for 10 min or 42°C for 30 min could kill all larvae and adult weevils. Partial control of weevils using a repellant water trap baited with synthetic pheromone and storage in dry sand mixed with tobacco leaf powder have been reported (Ali *et al.*, 1991). Sweetpotato roots heaped on the floor and covered with a 2 cm thick layer of sand and rice husks were either free from infestation or had negligible infestation after three months of storage. Gamma irradiation kills sweetpotato weevils (Hallman, 2000; Hallman, 2001). Gamma radiation between 0.2-

1.0 kGy had no effect on surface injury or storage decay when roots were evaluated after one month storage at 13°C and 90% R.H. During storage, weight loss by irradiated roots was 0.5 to 3.3% more than that of non-treated ones. In some instances, this affected root firmness. When baked, irradiated sweetpotato roots were sweeter than non-irradiated roots but they were not preferred due to the darker appearance (McGuire & Sharp, 1995). The entemo pathogenic fungi *Metarrhizium anisopliae* and *Beauveria bassiana* (Alcazar, Cisneros, & Morales, 1997*)* were found to be effective in controlling weevils. However, in the drier regions of Africa, *B. bassiana* had limited potential for weevil control. In the traditional agricultural systems in the tropics and sub-tropics where inputs are low, the use of weevil resistant varieties is the most economical way of effectively controlling weevils. Several attempts have been made during the past five decades to find resistance to this pest with limited success (Collins, Jones, Mullen, Talekar, & Martin, 1991; Yasuda, 1998).

To improve the shelf life of sweetpotato, care must be taken right from production ensuring that clean planting materials are used. In addition, careful and gentle harvesting and transportation is also very important in reducing skinning that compromise the quality and shelf life of the crop. The complex nature and interplay between these factors responsible for post-harvest losses is still not well elucidated. This study seeks to fill these voids as far as a post-harvest loss of sweetpotato is concern.

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2.8 Minimizing losses in sweetpotato

2.8.1 Curing

Sweetpotato has a delicate thin skin that easily damages during harvesting and transportation. It however has the potential of healing its wounds as other plant tissues do. This property has been exploited to improve upon the shelf life of sweetpotato (van

Oirschot *et al.*, 2003b). Curing is a post-harvest practice whereby harvested roots are held at moderate temperatures (29-33ºC) and high humidity (90-95%) for 7 days (Picha, 1986b; Ravi *et al.*, 1996; Ray & Ravi, 2005). Curing encourages the formation of a surface layer of protective lignified/suberised wound periderm tissue at the wound sites (Tomlins *et al.*, 2010). The protective layer and the wound periderm not only reduce the rate of moisture loss but also the risk of microbial infection that leads to root decay (Ravi *et al.*, 1996; Ray & Ravi, 2005; Sowley & Oduro, 2002).

In the tropics, curing is hardly practiced (Ravi *et al.*, 1996; Woolfe, 1992) largely due to lack of knowledge and high cost of regulating temperature and relative humidity. However, tropical ambient conditions are similar to commercial curing conditions and curing may occur naturally. There seem to be a knowledge gap with respect to curing before storage in Ghana. This current study seeks to bridge this knowledge gap by investigating the effect of farm-level curing methods: pre-harvest (dehaulming) and post-harvest (field-piled) curing on the storability of sweetpotato.

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2.8.1.1 In-ground curing (Dehaulming)

Another potential alternative to field-piled curing that may overcome the cost and security issues is in-ground (pre-harvest) curing. It is done by removing the plant stem and canopy (dehaulming) up to 14 days before harvest (Tomlins *et al.*, 2010). La Bonte and Wright (1993) reported that in-ground curing reduced injury to roots by 62% in a whole after 10 days of canopy removal before harvest. Removing the canopy one week before harvest was also noted to improve the recovery of market quality roots by 48% (Tomlins *et al.*, 2007b). In-ground curing for 14 days had no effect on the recovery of marketable roots elsewhere (Ndunguru, Tomlins, Kimenya, & Westby, 2007).

2.8.1.2 Field-piled

An *incidental curing* which is practiced by some farmers involves leaving the roots on the fields covered with fresh sweetpotato vines (Hayma, 2003) for several days due to lack of storage rooms during harvest (Personal observation). Therefore harvested sweetpotato are temporally stored outside on the fields until there is enough space. The current study seeks to uncover and recommend a curing option that would not only be less expensive, but easily adaptable.

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2.9 Importance of curing in the formation of lignin

Lignin is a highly branched polymer of phenylpropanoid compound (Moura, Bonine, Viana, Dornelas, & Mazzafera 2010). It forms an integral part of the cell wall which supplements cellulose largely in conducting water in most vascular plants (Bhinu *et al.*, 2009). According to Gholizadeh (2014) lignin is a biopolymer which is produced from the oxidative polymerisation of radicals of hydroxycinnamyl subunits called monolignols, mainly: Coniferyl, coumaryl and sinapyl alcohol (Figure 2.1). Lignin is mostly synthesized and deposited in the secondary cell wall of specialized cells namely: Xylem vessels, tracheary elements, phloem fibres, and the periderm (Bhinu *et al.*, 2009). Apart from providing mechanical support and rigidity, lignification has also been linked with response to different ecological cues such as wounding and pathogen infections (Gholizadeh, 2014).

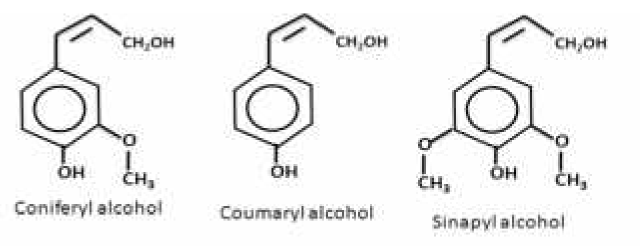

Figure 2.1: Chemical structure of monolignols

Although careful and gentle harvesting and post-harvest handling are recommended for handling the storage roots of sweetpotato, skinning and bruises are inevitable during harvest and post-harvest handling of the roots (van Oirschot *et al.*, 2003b). The situation gets worsen by practices such as over packing sacks and rough handling of sweetpotato. In other to improve the storage life of sweetpotato, there is a need to exploit the inherent potential of sweetpotato to heal wounds. Curing has been noted to be a crucial step in achieving wound healing in sweetpotato (van Oirschot, Rees, Aked, & Kihurani, 2006). This study therefore explores the used of curing and household-level storage methods to improve the storability of root in Ghana.

2.9.1 Wound healing process in sweetpotato

Skinning during harvesting and post-harvest handling of sweetpotato is inevitable and when it occurs, wound healing process is initiated. Desiccation of the surface cell layers occurs resulting in the lignification and subrisation of the underlying cell layers (Legendre, 2015). Although sweetpotato is not sold by weight in Ghana, the crop losses water from the desiccation hence reducing its shelf life and market value. Rees *et al.* (2003) showed that cultivars varied significantly in weight loss ranging from 8-30% in East Africa. Similarly, the amount of lignification and desiccation may vary with cultivar and relative humidity. A significant positive correlation was also observed between transpiration rates (a measures of water loss; and the amount of lignification (van Oirschot *et al.*, 2006). Artschwager and Starrett, (1931) reported that the establishment of a wound periderm is the final stage of wound healing. High relative humidity (90-95%) and moderate temperature (29-33°C) in curing chambers have been reported to promote wound periderm formation in sweetpotato (Picha, 1986b; Ravi *et al.*, 1996; Ray & Ravi, 2005). Different cultivars may exhibit

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differences in gene expression that contribute to a more efficient wound healing physiology. Though not considered in this current study, selection of sweetpotato cultivars with overexpression of wound-healing related genes and integrating superior genotypes into breeding programs could lead to the development of new varieties with better wound healing ability.

2.9.2 Genes involved in wound healing

As sweetpotato production in Ghana is being promoted as a food-based approach in fighting VAD, it is imperative to take a multi-pronged approach to minimize skinning on sweetpotato roots which compromises storability. As producers are encouraged to embrace good and proper pre and postharvest procedures to minimise skinning, breeders can assess a series of genes associated with wound healing. Cinnamyl alcohol dehydrogenase (CAD) is an enzyme which plays a major role in catalyzing the synthesis of monolignols, an important precursor to lignin biosynthesis (Legendre, 2015). The desiccation response in sweetpotato wound according to Effendy, La Bonte and Baisakh (2013) may be as a result of early light inducible proteins (ELIP3). Although genes expression previously found to be expressed in underlying epidermal tissue in response to skinning injury is out of the scope of this current study, it is worth mentioning these genes so that they can be related to the lignification behavior of the cultivars considered in the present study. Recognizing that cultivars differ in their wound healing ability as reported by van Oirschot *et al.* (2001) may suggest that these genes associated with wound healing are over expressed in certain cultivars than others. This may allow breeders to identify these cultivars for breeding sweetpotato lines with superior wound healing responses to skinning injury, whether cured or not.

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2.10 Sweetpotato storage methods

Generally, sweetpotato does not store for long because when the storage roots are detached from the stem, it loses its source of water and nutrients, hence, the short shelf life (Ray *et al.*, 2010; Woolfe, 1992). Apart from their high moisture content (50-80%), Ray *et al.* (2010) noted the high rate of respiration leading to softening and damage of the roots due to the resultant heat produced.

Sweetpotato production in northern Ghana is important in the socioeconomic life of the people. Sweetpotato being an important root crop, various storage methods and strategies have been practiced since time immemorial. Some of these storage methods are almost unsatisfactory leading to heavy losses up to 20-25% on the average (Jenkins, 1982). Reduction in both physical and nutritional quality due to weevil infestation, weight loss and sprouts (Ray & Ravi, 2005), also undermines the crop's potential to promote food security in developing countries. Therefore, for sustainable storage alternatives strategies to be developed, it is important to take a critical look at existing practices.

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2.10.1 Pit method

This method is the commonest storage practice in tropical sweetpotato growing areas (Ray *et al.*, 2010). This confirms the observation in Bawku municipality and its environs where the pit storage of sweetpotato has long been practiced. This storage method however, presents a lot of challenges (sprouts, weevil's damage and rots) and risky since detection of rots is difficult making most farmers to resort to alternative methods. The method however is still being practiced in some communities in the Bawku/Pusiga areas. A cylindrical pit of about (1 m × 1m × 1 m) is dug under a tree as shown in Plate 2.5.

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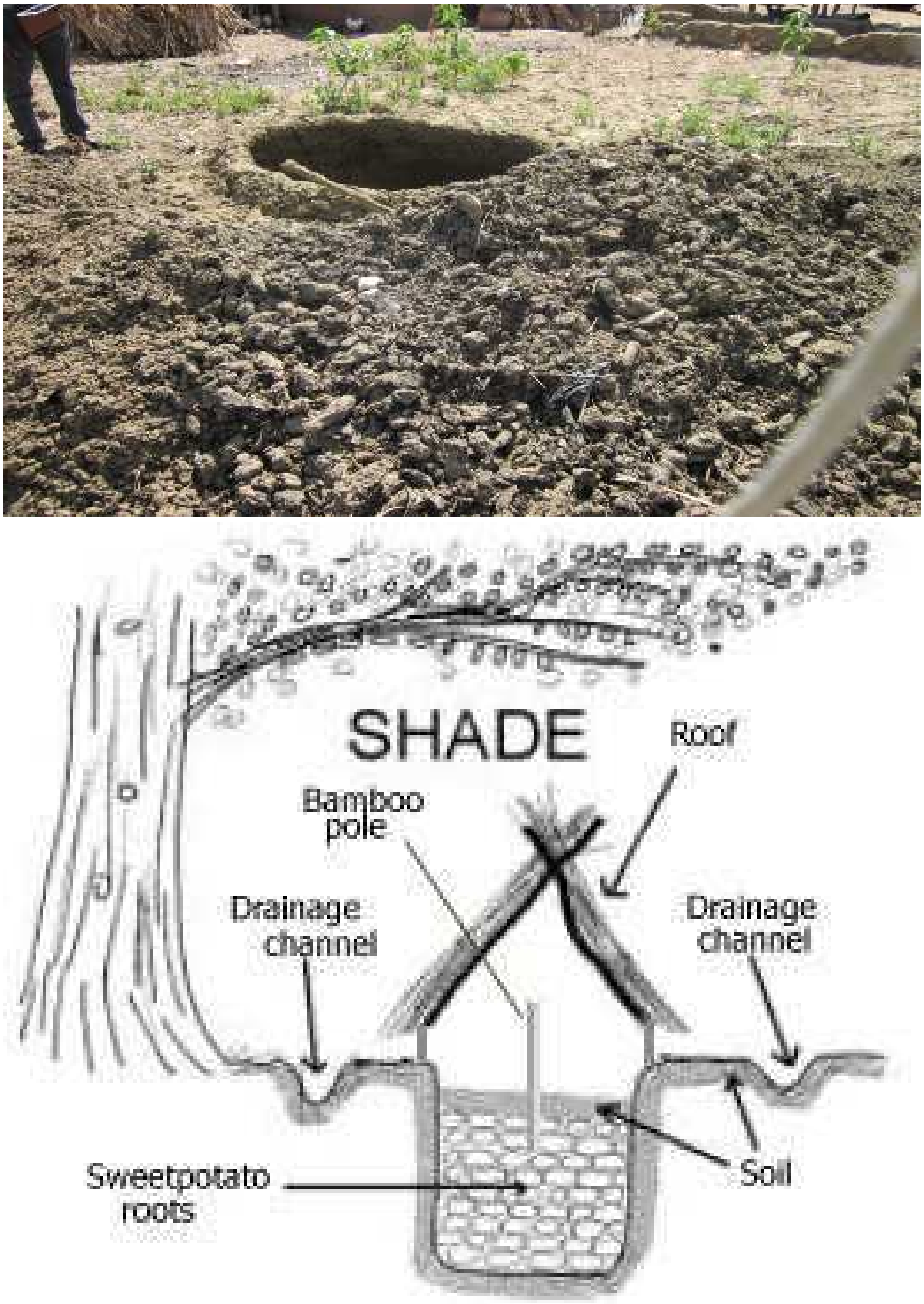

Plate 2.5: Pit storage method

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These pits are similar to those used in certain parts of India except that in the Indian case, the inner surface is smeared with cow dung slurry (Ravi *et al.*, 1996). A pit with this dimensions can hold about 40 bags (approximately, 4 tons) of roots. The roots are packed nicely in the pit after sorting to exclude non-marketable/rotten and weevil infested roots. A short wall of about 0.5 m high is built around the pit sometimes with vents to allow for air circulation and covered with moistened straw. Roots can store up to 3 months before they begin to deteriorate as claimed by the farmers. Attempts have been made to improve upon the existing traditional pit storage in Ghana (Amoah *et al.*, 2011; Teye, Amoah, Abano, Sam-Amoah, & Tetteh, 2011a), Tanzania (Mpagalile, Silayo, Laswai, & Ballegu, 2007; van Oirschot *et al.*, 2007) and Nigeria (Dandago & Gungula, 2011). Expectedly, improved pits performed better than the unimproved traditional pits. However, none of the improved pits were foolproof, leaving the challenge of weevil's infestation, sprouts and rots unsatisfactorily addressed. A survey in Uganda showed that, more than 95% of respondents in Apac and Mbale used the pit covered with sand (Bashaasha, Mwanga, Ocitti p'Obwoya, & Ewell, 1995). The study also observed sprouting and rotting associated with this method.

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2.10.2 Heap method

The method is widely used by sweetpotato farmers in Bawku, Ghana where sweetpotato is a commercial staple crop. Ray *et al.* (2010) found out that in the tropics, this method is commonly used confirming this observation in Bawku. In the heap storage method, sweetpotato is stored in rooms, preferably, thatch roofed buildings. The roots are heaped on the floor sometimes lined with river sand or straw before roots are heaped. The roots are then covered with moistened straw to keep a relatively high humidity and low temperature (Plate 2.6).

Plate 2.6: Heap storage method

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The storage losses associated with this method are relatively higher and has been reported to be about 20-25% (Ray & Ravi, 2005). Weevil damage and rots have been identified as the major causes of these losses (Ray & Ravi, 2005). This probably could be due to the fact that weevils have easy access to roots as they can easily move from one root to the other causing severe damage. Rodent attack and high weight loss have also been identified. Considering the quantum of loss associated with the available storage methods, this study evaluates the potential of sand box method against the heap for improved storability of sweetpotato roots for household-level consumption.

2.10.3 Slice-and-dry method

This is not a major storage practice in sweetpotato producing communities in northern Ghana as compared to the pit and the heap methods.

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Plate 2.7: Dried sweetpotato chips from slice-and-dry method

The method is only used when harvested or stored roots are found to be weevil infested. To reduce these losses, damaged roots are sorted, peeled and sliced into pieces which are then sun dried (Hayma, 2003) as shown in plate 2.7.

Processed sweetpotato chips can be stored in this manner for more than 4months (Bashaasha *et al.*, 1995). The method is best suited in the drier parts of low income countries where early harvesting (to avoid heavy losses to weevils) is a priority (Bashaasha *et al.*, 1995). Sun dried sweetpotato are stored in pots, bowls and sacks. Sweetpotato dry chips are mixed with either maize or sorghum, milled and used to prepare local dishes such as '*Waalsa'* during famine periods (May-August) in Bawku. According to Woolfe (1992) this practice is also commonly found in East and West African countries. Oke and Workneh (2013) further proposed that in some communities in sub Saharan Africa, peeled dried sweetpotato chips are milled with sorghum into flour which is used to prepare porridge.

2.10.4 Sand box storage (proposed method)

Namanda and co-workers (2013) recently developed the triple-S system that allow production of sweetpotato planting material from small storage roots stored in dry sand and then sprouted.

The potential of this system as a household-level storage method has not yet been evaluated, but it should be easily adopted for homestead storage of sweetpotato required to ensure regular consumption of sweetpotato in the lean season. This can significantly improve on the nutrition and overall health of the rural households. The method relies on locally available material for construction. The sand box is a storage structure built with

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laterite to the dimensions 0.5 m × 0.5 m × 0.6 m in a room preferably thatch roofed (Plate 2.8).

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Plate 2.8: Storage structure with sand boxes

Quality cured storage roots are stuck in the sand box and then air-dried sand spread over to form a first layer. It is expected that root quality (weight loss, weevil damage, rots and sprouts) and nutritional quality will not be adversely affected with this storage method. Therefore, this storage method can potentially extend the availability of sweetpotato especially OFSP, for household consumption to improve the dietary intake of β-carotene.

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2.11 Changes in root quality with storage

The quality of an agricultural produce is critical with storage (Kader & Rolle, 2004). Depending on the intended use of the commodity, Kader and Rolle (2004) reported that the value of each commodity depends on a combination of attributes, properties, or characteristics. Post-harvest handling procedures including curing and storage largely influence the quality attributes of sweetpotato as freshly harvested roots may be quite different from those that have been through post-harvest procedures (Woolfe, 1992). After harvest sweetpotato remain metabolically active and this may affect the internal composition and quality during storage (Lin *et al.*, 2011). Therefore, good pre and post-harvest techniques are those that will not adversely influence the quality of sweetpotato roots.

2.11.1 Physical quality

The physical appearance of any agricultural commodity is crucial in price determination and improved shelf life (Affognon, Mutungi, Sanginga, & Borgemeister, 2014). In terms of monetary value, sweetpotato and other root and tuber crops suffer losses up to 11-63% due to physical bruises at harvest, and post-harvest (Affognon *et al.*, 2014). Depending on the type of storage, storage conditions and post-harvest handling, the physical attributes of sweetpotato can be adversely affected leading to reduced profits as consumers initially purchase based on these attributes (freshness) but subsequently based on the consumer's satisfaction (Kader & Rolle, 2004). The rate at which an agricultural commodity respires and transpires contribute to weight loss and changes in both internal and external appearance (Picha, 1986b). Myriad factors account for the poor storage of sweetpotato roots. These include: type of store (heap or pit), genotype/cultivar, O_2 and CO_2 levels, relative humidity and temperature, root condition and weight loss (Tomlins *et al.*, 2010; van Oirschot *et al.*, 2007).

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2.11.1.1 Weight loss

The physiological weight loss of sweetpotato is inevitable once the crop has been detached from the parent plant. Physiological weight loss in three sweetpotato cultivars increased significantly as storage advanced (Chattopadhyay, Chakraborty, Kumar, Nanda, & Sen, 2006) reaching its maximum at 75 days. Different cultivars respond differently to environmental factors that encourage physiological weight loss. The type of storage is also important in determining the rate at which sweetpotato losses fresh weight. Chattopadhyay et al. (2006) found that storage in sand and saw dust recorded weight loss of 15 and 18% respectively. However, higher weight loss of 25% was observed in the control (exposed) storage. Probably in the sand storage sweetpotato roots were well protected which reduced metabolic activities such as respiration and transpiration (that contributes to physiological weight loss) in sweetpotato compared to the saw dust and exposed. Variation among cultivars with respect to weight loss was also observed by Mehra and Dayal (1991).

Proper pre- and post-harvest handling techniques and storage is very crucial in reducing physiological weight loss which leads to rots and reduced market value. The current study

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considers pre- and post-harvest procedures that would likely reduce the incidence of factors that affect root quality (weight loss, weevil, rots and sprouting) in sweetpotato.

2.11.1.2 Rot and decay

Microorganisms infection during pre- and post-harvest are serious causes of post-harvest loss of sweetpotato roots (Ray & Ravi, 2005). The commonly pathogenic molds observed during storage of sweetpotato include; *Aspergillus fumigatus*, *Aspergillus niger, and Rhizopus stolonifer* (Agu *et al.*, 2015). The susceptibility of storage roots to pathogenic microbial attack increases with physical damage. Ray and Ravi (2005) observed that significant amount of losses occur as a result of rots leading to undesirable qualities (tissue breakdown, surface blemishes). This renders sweetpotato roots unattractive and unmarketable. It greatly hampers the storability of sweetpotato for long (4-5 months) especially when the storage conditions are not suitable. The incidence of decay was observed to be the major form of deterioration in storage (Agbemafle, Owusu Sekyere, Diabor, & Essien, 2013).

Therefore, when recommending storage methods for adoption by farmers, it is ideal to evaluate their potentials in reducing the incidence of decay. The current study evaluates the storage potentials of the sand box storage relative to the current farmer's practice, heap storage, highlights on root decay as a damage factor that will render the roots undesirable for consumption and unmarketable for profits.

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2.11.1.3 Weevil damage

The sweetpotato weevil (*Cylas spp)* is an important storage pest in the tropics and sub-tropics (Korada, Naskar, Palaniswami, & Ray, 2010; Kurup & Balagopalan, 1991; Tomlins *et al.*, 2010). In northern Ghana, it has been reported that the sweetpotato weevil is the most

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abundant and economic important insect among other insects (Tanzubil, 2015). The weevil infestation was over 90% in all the fields sampled (Tanzubil, 2015). Jenkins (1982) and Ray and Ravi (2005) opined that the pest damage begins from the vines and finally descend to the roots infesting the roots near the soil surface. According to Korada, *et al*. (2010) yield loss as a result of weevil damage can be up to 4-50% in India. Tanzubil (2015) reported an estimated mean damage of 40.1 and 30.8%, respectively on roots and vines. This explains the economic importance of sweetpotato weevils in areas where it is cultivated. All previous studies focused on the economic importance of the insect on the field. However, the damage caused by the insect in storage cannot be underestimated. Therefore, it is worth investigating pre-harvest (dehaulming) and post-harvest (field-piled curing and sand box storage) technologies that have the potential of minimizing the damage caused by weevils.

Apart from yield loss, the sensory qualities of roots are also affected by weevil infestation making them unfit for consumption (Kurup & Balagopalan, 1991). Integrated pest management and, careful removal of weevil infested roots before storage are very important in combating the devastating effect of weevil in stores (Ray *et al.*, 2010). A common practice to combat the damage of the sweetpotato weevil by commercial farmers in Bawku is the use of agro-chemical (magic powder) which could render the produce unsafe for consumption. In this study the sand box storage and the heap storage are being evaluated for their ability to check weevil damage. Storage in air-dried cold river sand is expected to restrict the movement of sweetpotato weevils from root to root causing damage. The damage caused by weevils during storage could be reduced significantly with this method since roots are isolated from each other in the sand.

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2.11.1.4 Sprouting

Sprouting occurs very rapidly in sweetpotato roots especially during delayed harvest and moist soil conditions (Ray & Ravi, 2005). According to Edmunds *et al.* (2008) sprouts results due to elevated storage temperature. For instance, when temperatures are above 16°C, sweetpotato storage roots will sprout. Sprouts may begin to show within weeks at 24°C or warmer and it is always accompanied by respiration and weight loss (Edmunds *et al.*, 2008). It is a very important parameter influenced by storage and post-harvest procedures and has been observed to be more profuse in the exposed storage compared to the sand and saw dust storage (Chattopadhyay *et al.*, 2006). Ray *et al.* (2010) concluded that, in the tropics where storage occur in high relative humidity and temperature, sprouting is often common. Sprouts over three-fourths inch (approximately 2 cm) longer by USDA standards are considered a defect (Edmunds *et al.*, 2008).

Sprouts are generally controlled by breaking off sprouts as they appear (Ray & Ravi, 2005; Tomlins *et al.*, 2010). This control mechanism according to Lin *et al.* (2011) does not prevent further deterioration. Therefore the current study investigates how pre-harvest treatments influence the incidence of sprouts while stored in cool dry river sand.

2.11.2 Nutritional/compositional quality

2.11.2.1 Carbohydrates/starches

Generally, carbohydrates constitute the dry matter portion of sweetpotato which exist mainly in the form of sugars and starches (Picha, 1986a). About 55% of the dry weight of sweetpotato consist mainly of starch (Rukundo, Shimelis, Laing, & Gahakwa, 2013; Woolfe, 1992). For example, starch constituted a major portion of six sweetpotato

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genotypes with a mean dry weight of 56% at harvest (Zhang, Wheatley, & Corke, 2002). The starch content was observed to slightly decrease during storage and varied among genotypes (Zhang *et al.*, 2002).

Changes in the carbohydrates content of sweetpotato has been found to be influenced by curing, storage duration and conditions as well as genotype (Picha, 1986a; Zhang *et al.*, 2002). Chattopadhyay and co-worker (2006) reported a declining trend in starches during storage. The likely reason for the declining trends was mainly due to breakdown of starch to sugars by the activities of α-amylase enzyme. This corroborate the findings of Zhang *et al.* (2002) that the α-amylase activity among four lines of sweetpotato showed the largest increase in dextrin content but decreased starch content during storage. Again, earlier studies by Scott and Mathews (1957) observed about 30.2% (53% to 37%) decline in the starch content of sweetpotato during a 3 month storage period. Dandago and Gungula (2011) also suggested starch being a respiratory substrate as the reason for the decline in starch content during storage.

2.11.2.2 Total sugar

Carbohydrates metabolism during curing give rise to a net synthesis of total sugar since both reducing (glucose and fructose) and non-reducing sugar (sucrose) content increase (Picha, 1986a). The total sugar content of raw sweetpotato is a combination of glucose, fructose and sucrose (Huang, Liao, Chan, & Lai, 2013). According to Zhang *et al.* (2002) the amounts of glucose, fructose and sucrose in raw sweetpotato roots varied among genotypes. For example, the total sugar concentrations continued to increase with storage time in four OFSP (‘Centennial’, ‘Jasper’, ‘Jewel’ and ‘Travis’) while experiencing a

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decline in two WFSP (‘Rojo Blanco’ and ‘White star’). Picha (1986a) therefore concluded that OFSP contained more total sugars than their WFSP counterparts during storage.

Since post-harvest practices (curing and storage) greatly influence the levels of total sugars which also affect the culinary qualities of sweetpotato, it is ideal to consider their concentrations in all storage studies.

2.11.2.3 Dry matter content

The dry matter content is an important characteristic of storage roots of sweetpotato genotypes. For instance high dry matter content according to Rukundo *et al.* (2013) is the main trait preferred by consumers and processors of sweetpotato. A dry matter content of above 25 and 30% of fresh root weight is ideal for farmer’s adoption and commercial use respectively (Rukundo *et al.*, 2013). However, during post-harvest handling processes (curing and storage), the dry matter content is greatly affected. Earlier works by Scott and Mathews (1957) showed fluctuating changes in percent dry matter in the first two months and at the end of the storage of sweetpotato roots. After 46 weeks of storage, dry matter decreased about 3% of their initial dry matter content (Picha, 1986a). Chattopadhyay *et al.* (2006) also showed a similar trend in dry matter content while in storage. They further showed that, irrespective of the variety, the storage media, the dry matter content was significantly affected during the entire duration of the storage. The possible reason for the instability (declining trend) of dry matter content as storage progressed could be due to severe sprouting (Chattopadhyay *et al.*, 2006).

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Once there is an evident decline in dry matter content as storage progressed, a good storage option as this study seeks to explore would be the one that could significantly extent the shelf life with the quality characteristic such as dry matter content being less affected.

Zhang *et al.* (2002) proposed that, in screening for high dry matter and starch content, the stability of these qualities in raw sweetpotato roots during storage should be taken into consideration.

2.11.2.4 Carotenoids

Carotenoids are noted to have a diverse structural distribution and function (Rodriguez-Amaya & Kimura, 2004). Carotenoids in foods are generally C_{40} tetraterpenoids formed from eight C_5 isoprenoid units. A symmetrical molecule is formed as a result of the linkage of these units head-to tail, but reverses to a tail-to-tail linkage at the centre (Rodriguez-Amaya & Kimura, 2004). According to Rodriguez-Amaya and Kimura (2004) carotenoids possess an attractive colour due to their centrally located uniquely extended conjugated double-bond system which constitute the light absorbing chromophore. Carotenoids are divided into two main groups: carotenes (β-carotene (Figure 2.2) and lycopene) are hydrocarbon carotenoids, and xanthophylls that are oxygenated hydrocarbons (EL-Qudah, 2009; Eldahshan & Singab, 2013).

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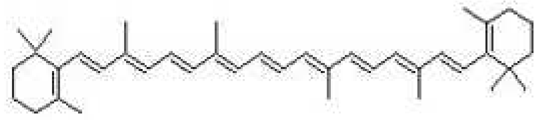

Figure 2.2 Chemical structure of β-carotene

Carotenoids are liable to isomerization and oxidation during processing and storage due to their unsaturated nature (Rodriguez-Amaya, Rodriguez, & Amaya-Farfa, 2006). Therefore post-harvest handling procedures that encourage the degradation of these important phytochemical is not worth adopting.

2.11.2.5 β-carotene

It has long been established that OFSP contains significant amounts of β-carotene (Vimala *et al.*, 2011) responsible for conferring provitamin A activity that contributes to the amelioration of VAD among lactating mothers and children (van Jaarsveld *et al.*, 2005). The β-carotene content of sweetpotato cultivars vary widely (Grace *et al.*, 2013) depending on the flesh colour; the deeper the orange pigment, the higher the β-carotene content.

The stability of carotenoids in general has been found to vary considerably in different crops such as carrot, leafy vegetables and sweetpotato (Vimala, Nambisan, & Hariprakash, 2013). Carotenogenesis continues to take place after harvest in intact fruits and vegetable (Rodriguez-Amaya, 1997). However, pre- and post-harvest handling procedures such as temperature, curing time, irradiation time, and exposure to light can affect the phytochemical content of produce due to biochemical responses (Grace *et al.*, 2013). Previous works have shown either an increase (Ezell & Wilcox, 1952) or insignificant change in β-carotene content with period of storage (Vimala *et al.*, 2013). However, other study have shown that β-carotene content increased up to the 50th day of storage and declined thereafter (Chattopadhyay *et al.*, 2006). The data corroborates with that of Tumuhimbise, Namutebi and Muyonga (2010) who reported an increase in β-carotene content in the first month of storage and a decline thereafter. The storage type also plays a significant role in the retention of β-carotene. After 75 days of storage in sawdust, sand medium and ambient , the sand medium showed a better retention of β-carotene compared with saw dust and exposed storage (Chattopadhyay *et al.*, 2006).. The current study takes a look at how pre- and post-harvest practices such as curing and storage affect β-carotene content of sweetpotato roots.

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2.11.3 Sensory quality

Post-harvest processes such as curing and storage may affect the sensory properties of fresh roots that may either be desirable or undesirable (van Oirschot, Rees, & Aked, 2003a). Tomlins and co-workers (2004) reported that consumer acceptability in terms of both sensory and utilization traits are as important as production traits for a successful introduction of a new variety. These traits appears to differ sharply between regions, cultivars, post-harvest procedures and the method of processing (Martin & Rhodes, 1984). For example, low dry matter varieties are preferred in South Africa and North America while the high dry matter varieties are preferred in East Africa (Tomlins *et al.*, 2004). This suggests that consumers' preference is widely affected by their nationality as well as the genetic properties of the sweetpotato cultivars. George and Kamara (1988) revealed that a certain undesirable taste in stored sweetpotato cultivars become apparent after frying.

It is therefore important that in improving the storability of sweetpotato through pre-harvest and post-harvest practices, the sensory qualities are not overlooked. Keeping the above in mind, this study considers evaluating the sensory qualities of stored sweetpotato roots to be sure that they are not adversely affected by efforts to improve the shelf life through storage and other pre-harvest and post-harvest practices.

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2.12 Summary of chapter two

Sweetpotato is an important food crop that meets the economic and nutritional needs of people in the sub-regions including Ghana. It is a hardy crop that requires low input and able to grow well on marginal soils. Therefore, sweetpotato is a very good food security crop as inputs, example fertilizer; to improve yields in developing countries are limited. Sweetpotato (OFSP especially) is an excellent source of β-carotene, a pro vitamin A, and is being promoted as a food-based approach to combating VAD which is considered a public health concern in the sub-region. Regular consumption of sweetpotato (OFSP) improved the vitamin A status of primary school children.

Sweetpotato is often consumed within 2-3 weeks without storing due to its perishability. Poor post-harvest handling among other factors has been cited as the major cause of its short shelf life. The current post-harvest practices used by farmers are almost unsatisfactory as fast deterioration of the roots remains a challenge.

Compositional changes, sensory and culinary qualities resulting from post-harvest procedures are as well acknowledged and considered in the current study.

The next chapter, chapter three provides a vivid description of the location of work, experimental design, methods and instruments used in the collection of data both the field and laboratory. Statistical analysis of data is as well considered here.

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CHAPTER THREE

3 Materials and methods

3.1 Introduction

Materials and methods is the framework for the research study; it encompasses the research methods, procedures and tools for collecting and subsequently analyzing the data obtained in order to respond to the research objective(s). Therefore, it is absolutely important that the materials and methods are well designed and conducted to obtain appropriate and valid data for analysis and interpretations. This chapter explains the study location, the experimental design used and data collection procedures for both the curing and storage experiments during the two consecutive years.

3.2 Location of study area

Field work (storage root production and curing) was carried out in the fields of Council for Scientific and Industrial Research-Savanna Agricultural Research Institute, Nyankpala, and Bontanga Irrigation Scheme, Kumbungu. The storage experiment was carried out at University for Development Studies, Nyankpala Campus from December, 2014 to February 2015 and November 2015 to January 2016 for the first and second years respectively. These areas fall within the Savanna Agro-ecological Zone of Ghana. Laboratory work on sweetpotato quality was carried out at the Sweetpotato Quality and Nutrition Laboratory for Post-harvest Technology at Crops Research Institute of the Council for Scientific and Industrial Research, Fumesua, Kumasi, Ghana and Food and Nutrition Laboratory in International Livestock Research Institute, Kenya. Wound healing test was also carried out

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at the Spanish Laboratory of the Faculty Agriculture, University for Development Studies Nyankpala campus.

3.3 Orange-fleshed sweetpotato cultivars used

Apomuden (Plate 3.1) is a released variety by the Crops Research Institute of the Council for Scientific and Industrial Research Ghana. It has significant levels (2100-5500 µg/100 g fwb) of β-carotene (Tumwegamire *et al.*, 2014).

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Plate 3.1: Apomuden, OFSP variety used in the study

Nane (Plate 3.2) is a farmer cultivar in Ghana that is currently undergoing evaluation process to be released.

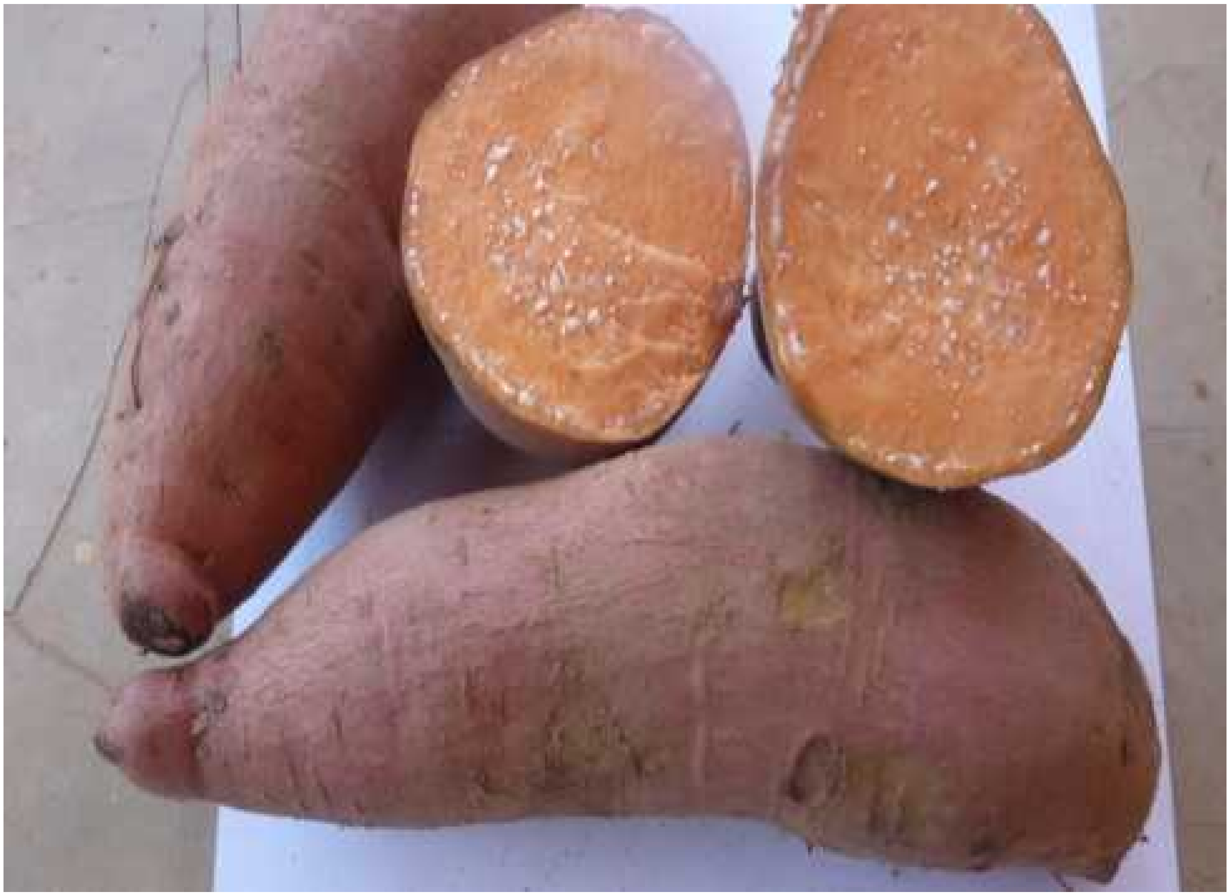

Plate 3.2: Nane (OFSP) the farmer cultivar used in the study

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3.4 Field layout and experimental design

An area of 38×32 m^2 was ploughed and harrowed. Ridges were made and divided into 9 plots of dimension 10×12 m^2. Three sub plots (four ridges) were allocated in each division for the in-ground curing, field-piled and the uncured.

The experimental design used for the root production was 2×3 factorial (2 cultivars and 3 curing methods) arranged in split plot all in triplicates. The cultivars (Apomuden and Nane) were the main plot treatment and the curing methods (in-ground, field-piled curing and no curing), the subplot treatment. Plots that were to be used for the in-ground and field-piled curing treatments were planted 7 days earlier than the uncured plot. A 2×3×2 factorial design was also used for the storage experiment where the two cultivars cured using the three curing treatments mentioned above and then stored in either sand box or under moistened straw heap.

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3.5 Studies on the response of Apomuden and Nane, OFSP cultivars to curing

3.5.1 In-ground curing (Dehaulming)

The vines of the two cultivars were cut leaving about 30 cm to the base at maturity and allowed to remain in the ground for 7 days before harvest as shown in Plate 3.3.

Plate 3.3: In-ground curing/dehaulming

3.5.2 Field-piled curing

Roots were harvested manually and carefully not to injure them. The harvested roots were heaped on the field and covered with fresh sweetpotato vines and allowed to cure for 7 days (Plate 3.4). Freshly harvested roots (uncured) served as the control.

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Plate 3.4: Field-piled curing

3.5.2.1 *Temperature and relative humidity*

The ambient temperature and relative humidity, as well as temperature and relative humidity in the piles of Apomuden and Nane were taken and recorded using HOBO loggers. During the seven day curing period, no rains were recorded.

3.5.2.2 *Weight loss and shrinkage*

About 5 kg of roots were tied in a net bag for monitoring of weight loss for a 7-day curing period. Weight loss was determined as a difference between the final and initial weights for 7 days in both years. Percent weight loss was calculated as the difference between the final and initial weight divided by the initial weight, expressed as a percentage.

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The shrinkage test was carried out using three wholesome storage roots, small, medium and large in most instances. A veneer caliper was used to measure take the axial diameter of the storage roots. Percent shrinkage was computed as the difference between the final and initial diameter divided by the initial diameter expressed as a percentage.

3.5.3 Wound healing test

On the first day of curing, 3 wounds were also created on 21 roots each from both cultivars while in-ground or field-piled cured with a potato peeler for both years. The wounds were stained with phloroglucinol for the presence or absence of lignin from the first day up to the sixth in year I and seventh day in year II.

A wound healing score of 0, 0.5 or 1 was given based on the level of lignin formed (no lignification, patchy lignification and complete lignification respectively) as shown in Plate 3.5. The Weiners' phloroglucinol-HCl test was used and wound sections were stained with phloroglucinol (1% in 95% ethanol) for 2 minutes and transferred to concentrated HCl for 30 seconds and rinsed in water for 30 seconds for the presence or absence of lignin (van Oirschot *et al.*, 2001).

In the first year, wound healing test was done on only field-piled cured storage roots but was extended to the storage roots cured in-ground in year II. A lignification index (LI) was obtained from the average of three wounds from the same root.

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0=No lignification

0.5= Patchy lignification

1= Complete lignification

Plate 3.5**:** Wound healing ability score of sweetpotato cultivars

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3.6 Shelf life studies on Apomuden and Nane, OFSP cultivars

3.6.1 Heap storage (current farmer's practice)

About 5 kg of roots for each cultivar were tied in a net bag. These roots were then placed on straw, and then covered with the same straw followed by sprinkling of water; (Plate 3.6. The sprinkling of water continued after every second day. In the second year about 15 kg of roots from each of the two cultivars was stored. Damage/loss factors considered for the shelf life studies were: weight loss, rots, weevil damage and sprouts for each storage method studied.

Plate 3.6: The heap storage (farmers' method) evaluated

3.6.2 Sand box storage (proposed method)

The sand boxes were built with laterite in a thatched-roofed room with dimensions of 0.5 m×0.5 m×0.6 m (Plate 3.7). About 5 kg of roots for each cultivar was tied in a net bag and carefully stacked in the sand box and air-dried cold sand was then spread on top. In the second year about 15 kg of roots from each of the two cultivars was stored. Out of these, 5 kg was tied in a net bag for the monitoring of weight loss, rots, weevil damage and sprouts.

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Plate 3.7: Sand box (proposed method)

3.6.2.1 Weight loss

In storage weight loss was recorded biweekly in the first year and weekly during the second year's trial. Percent weight loss was determined as the difference between initial and final weight divided by initial weight and expressed as a percentage as reported elsewhere (Amoah *et al.*, 2011; Teye *et al.*, 2011b).

3.6.2.2 Percent rot, weevil damage and sprouts

The incidence of rot, weevil and sprouts were observed and the number of roots counted and then divided by the total number of roots and expressed as a percentage.

3.6.2.3 Cumulative loss

This represents the total loss as a result of removal of damaged roots due to weevil and rots as well as physiological weight loss. The cumulative loss was computed as the difference between root weight before storage and root weight after successive weeks divided by the weight of roots before storage expressed as a percentage.

3.6.3 Studies on the β-carotene content of Apomuden and Nane as affected by storage methods

All compositional quality analysis involving β-carotene, dry matter, fructose glucose, sucrose and starch in the first year were done at the Sweetpotato Quality and Nutrition Laboratory for Post-harvest Technology in Fumesua, Kumasi, Ghana using Near Infrared Reflectance Spectroscopy (NIRS). In the second year, only the β-carotene analysis was done using High Performance Liquid Chromatograph (HPLC) at the Food and Nutrition Laboratory, ILRI, Kenya.

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Harvested storage roots for each of the curing methods were sampled into coded brown paper bags from the field and then sent to the laboratory at harvest. Samples were also taken at the end of the storage period for the analysis in the first year. In the second year, roots were taken at harvest, one month after storage and two months after storage. Three storage roots (small, medium and big) were purposively selected for the quality analysis. The selected roots were washed, peeled and washed again with deionised water before quartering longitudinally and slicing it into pieces. The sliced samples were put into zip-lock bags and 50 g each weighed and put into a freezer (Plate 3.9). The frozen samples were then freeze-dried for 72 hours using the TK-118 Vacuum Freeze-Dryer (True Ten Industrial Company Limited Taichung, Taiwan) as shown in Plate 3.8

Plate 3.8: Freeze Dryer used to freeze dry roots samples

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Quartering with a knife

Sliced with potato peeler

Sliced roots packaged in polypropylene sample bags prior to freeze drying

Plate 3.9: Preparation of root samples for freeze drying

The freeze-dried samples were crushed into smaller pieces and then milled into flour using a stainless steel mill 3383-L70, Thomas Scientific, Dayton Electric Manufacturing Company Limited, Niles, IL 60714, USA as shown in (Plate 3.10) and sieved through a 60 mm mesh screen. The flour from the mill was collected and stored in zip-lock bags which were duly sealed. The milled samples in the second year were couriered to Kenya for β-carotene assay only.

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Plate 3.10: Mill used for milling freeze dried root samples

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3.6.3.1 Compositional quality

This was accomplished by determining glucose, fructose, sucrose starch dry matter and β-carotene. Thus, 5 g of flour of each sample was put into the cuvette and scanned for all the compositions using XDS Rapid Content Analyser (Hoganae, Sweden) as shown in Plate 3.11. The parameters analysed include: glucose, fructose, sucrose, starch, dry matter and β-carotene. All determinations were assayed in triplicate.

Plate 3.11: XDS Rapid Content Analyser (Hoganae Sweden)

3.6.3.2 High Performance Liquid Chromatography (HPLC) Analysis for β-carotene

OFSP samples kept in the freezer (-20°C) were removed and allowed to thaw at room temperature in a room illuminated with yellow fluorescent lights. About 0.5 g of each sample was weighed (OHAUS, Biospec East Africa Ltd) in duplicate in 15 mL screw capped glass tubes. About 5 mL of methanol (Sigma-Aldrich, ≥ 99.8% HPLC grade, USA) was added to each tube, vortexed (Scientific Industries, 0166, USA) for 1 minute and incubated in a water bath (SW23GB, JULABO) at 70°C for 10 minutes. The tubes were immediately cooled in a bucket full of ice. Distilled water (3 mL) was added to each tube while still immersed in ice and vortexed for 1 minute. About 5 mL of hexane (Sigma-Aldrich, ≥ 99.8% HPLC grade, USA) was added to each tube and vortexed for 1 minute. The tubes were placed in a rack, completely covered with an aluminum foil and centrifuged (Eppendorf, Centrifuge 5810) for 10 minutes at 3000 rpm. The upper hexane phase was extracted using Pasteur pipettes into separate labelled 15 mL test tubes corresponding with each sample. Extraction and separation was repeated three more times by adding 4 mL, 3 mL and 3 mL to each sample pellet respectively. The solvent was evaporated under nitrogen using N-Evap machine (Organomation, Model OA-8125) with a water bath set at 40°C. Dried tubes were reconstituted in 25 mL of Methanol and Tetrahydrofuran (Sigma-Aldrich, ≥ 99.8% HPLC grade, USA) in the ratio 85:15 v/v. This was done by adding 10 mL of 85:15, Methanol: THF to the tubes, mixing homogeneously for 1 minute by a vortex and transferring to 25 mL volumetric flasks. This was topped to 25 mL mark using the same solution. All the flasks with extracts were vortexed and sonicated (JIRCAS, 101489, JAPAN) for 30 seconds before transferring 1 mL of each to HPLC vials. A volume of 50µl was injected into the HPLC. The HPLC system used was Waters 2695 separation module with 2996 PDA detector and a C30 carotenoid column (3µm, 150X4.6 mm, YMC

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Wilmington, NC) utilizing a reverse phase gradient HPLC method. Mobile phase A consisted of methanol/tert-butyl methyl ether/water (85:12:3, v/v/v, with 1.5% ammonium acetate in the water) and Mobile Phase B: methanol/tert-butyl methyl ether/water (8:90:2, v/v/v, with 1% ammonium acetate in the water).

Quality control sample (OFSP flour) was run alongside samples in every batch for quality control purposes. The amount for each beta-carotene component in the sample was calculated based on the area under the curve for each chromatogram.

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3.6.4 Sensory analysis

Sensory analysis was conducted using sensory ballot. A five point hedonic scale: *1= extremely dislike, 2= dislike, 3=neither like nor dislike, 4= like and 5= like extremely* was used to assess the sensory qualities of boiled roots. In the first year, 121 untrained panelists (male=45 and female=76) were used while in the second year 92 untrained panelist (male=14 and female=77) also evaluated the boiled roots. The sensory attributes assessed were: *general appearance, sweetness (sugariness), finger-feel firmness and overall acceptability.* Sweetness was explained to panelist to mean desired taste as described by other researchers (Kapinga, Jeremiah, Rwiza, & Rees, 2003). Consumers rinsed their mouth with water before and in-between samples during the assessment.

3.6.4.1 Sample preparation

A kilogram each of Apomuden and Nane from each curing option in storage in sand box and in the heap method were selected and put into labelled net bags. These roots were then washed, and wet cooked for 20 minutes to become soft. The cooked roots were peeled using a knife and sliced to thumb sizes for the consumer acceptability test. Three figure-coded disposable plates were used to serve the samples for scoring by the panelists. The consumer acceptability test took place at a dining room of Alimento Catering Service, University for Development Studies, Tamale.

3.7 Statistical analysis

Data on the damage/loss parameters (weight loss, shrinkage, rot, weevil damage and sprout) and nutritional quality (glucose, fructose, sucrose, starch dry matter and β-carotene) was analysed using two-way analysis of variance in Minitab.v16.2.4.4^{TM} (Minitab Inc., State College, PA, USA). The Tukey's studentised range test was used to compare differences between means when the ANOVA result was significant ($p< 0.05$).

Statistical analysis of the consumer acceptability data was performed using Microsoft® Excel 2010/XLSTAT$^{©}$-Pro (Version 2016.02, Addinsoft, Inc., Brooklyn, NY, USA). The Mann-Whitney test was used to analyse treatments with only two levels (cultivar and storage type). Kruskal-Wallis non-parametric test procedure was employed to analyse the curing treatment. Multiple pairwise comparisons was done using the Steel-Dwass-Critchlow-Fligner procedure/Two-tailed test when $p < 0.05$.

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3.8 Summary of chapter three

The materials and methods section mainly focused on the location of the field trial and storage experiment of the research which were carried out at SARI trial fields in Nyankpala, Tamale, Ghana. A 2×3 and 2×3×2 factorial designs were used for the curing and storage experiments respectively. Apomuden and Nane were the two OFSP cultivars used while the curing treatments were in-ground, field-piled and uncured. The wound healing ability of cultivars while being cured was also considered. The storage types

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evaluated were the heap (farmers' current method) and the sand box storage (proposed method). Data was collected on wound healing ability score of cultivars weight loss, and shrinkage during curing. The physical root quality factors were taken and recorded biweekly or weekly for the two years. The compositional quality roots were also taken at specific times; before, during and after storage. Consumer preference test was done on roots after the storage periods in both years.

The next section, Chapter four, presents the findings of this study mostly in graphs and tables. These findings would be in two fold, outcomes from the curing and storage experiments.

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CHAPTER FOUR

4 Results

4.1 Introduction

The results of the study are presented in Figures 4.1 – 4.12, and in Tables, 4.1 – 4.6. The presentations have been accordingly reported upon critical statistical observation. The study was divided into two phases, I and II. Phase I constituted the curing and wound healing experiment while the storage experiment made up phase II. Therefore results of this work are presented based on these two thematic areas for the two years. The chapter presents findings on ambient weather (temperature and relative humidity) and field-piled conditions. The weight loss and shrinkage during field-piled curing and the wound healing ability of cultivars were as well considered. The second phase focused on the storage experiment and how the former (curing methods), cultivar and storage method solely or collectively influence the physical, compositional and sensory qualities of the stored sweetpotato roots. All the results are presented in graphs and tables.

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4.2 Relation of temperature and time for field-piled curing

4.2.1 Temperature and relative humidity in field-piled condition

Results of temperature and relative humidity in the ambient as well as within the piles of Apomuden and Nane were recorded over a 7-day curing period during the second year only and are shown in Figure 4.1. The average ambient temperature was significantly higher (29.58°C *vs.* 29.23°C *vs.* 28.94°C, respectively; $p < 0.0001$) compared with the temperature within piles of Apomuden and Nane. The average ambient relative humidity (77%) was significantly lower (p < 0.0001) compared with those within the piles of Apomuden (91%) and Nane (94%) over the 7-day field piled curing Figure 4.2.

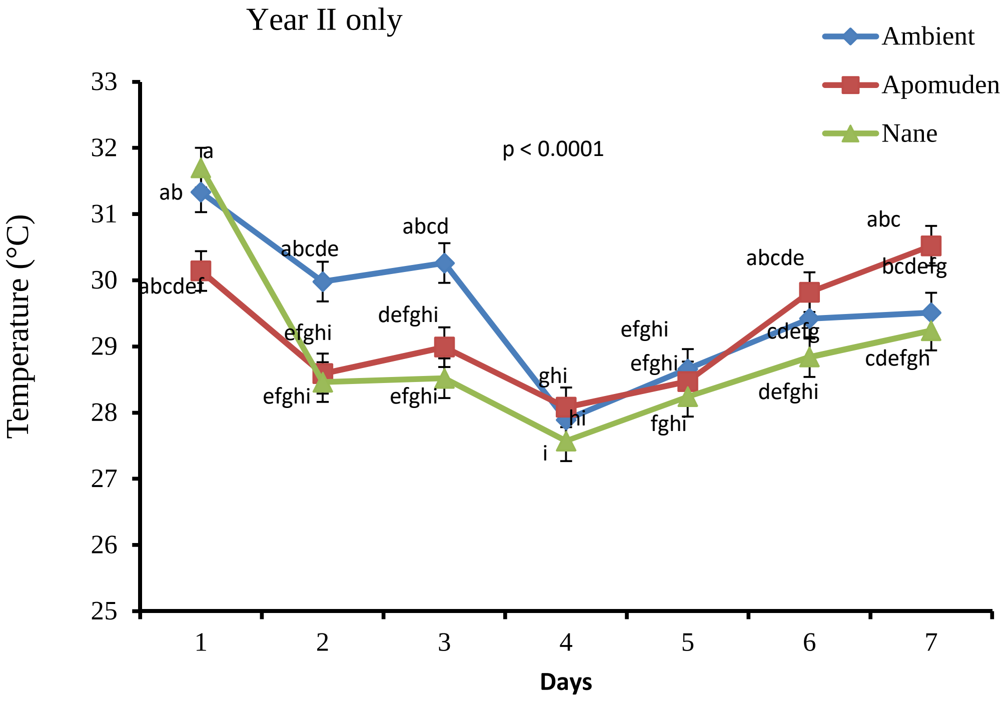

Figure 4.1: Relation of temperature and time for field-piled curing
Values are least square means ± SEM, *n* = 3. Least square means with similar letters are not significantly different (p>0.05)

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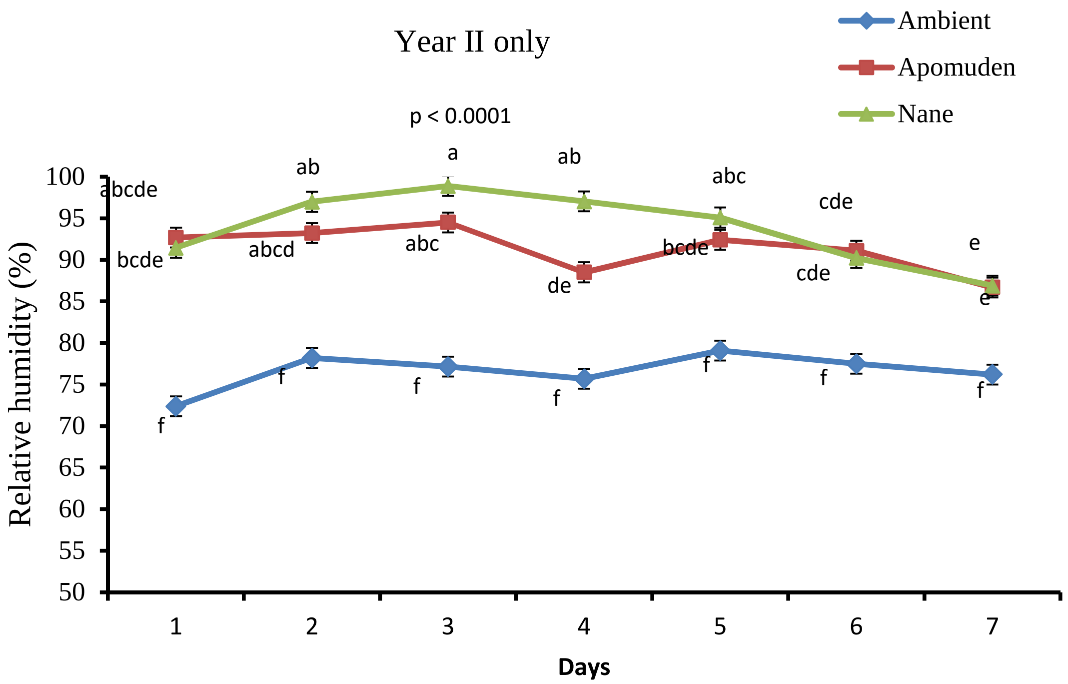

Figure 4.2: Relation of relative humidity and time for field-piled curing
Values are least square means ± SEM, *n* = 3. Least square means with similar letters are not significantly different (p>0.05)

4.2.2 Weight loss and shrinkage during field-piled curing

Figure 4.3 shows the percent weight loss and shrinkage of Apomuden and Nane in field-piled curing conditions for seven days. No significant differences (p > 0.05) were observed between the cultivars in the first year for percent weight loss and shrinkage. However, in the second year, Apomuden recorded significantly higher weight loss (1.5% *vs.* 0.92%; p = 0.037) compared with Nane.

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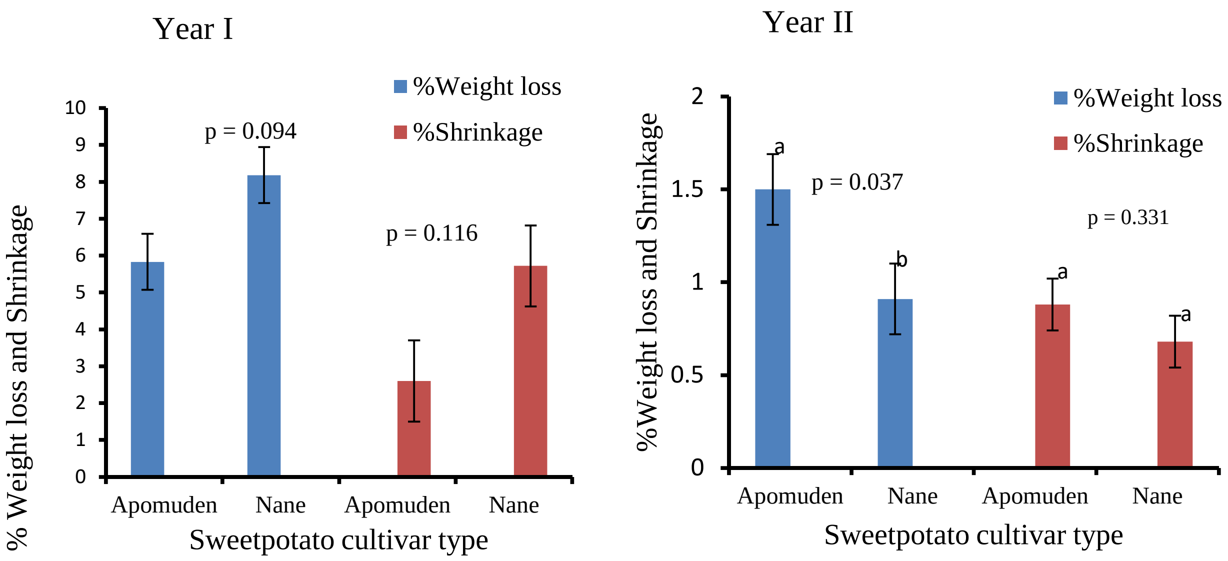

Figure 4.3: Weight loss and shrinkage of storage roots of sweetpotato during field-piled curing for Year I and II
Bar values (least square means ± SEM, *n* = 3). Least square means with similar letters are not significantly different (p>0.05)

4.3 Wound healing test

A measure of the wound healing ability of Apomuden and Nane using lignification score was conducted for a maximum of seven days during field-piled curing. The results are presented in Figure 4.4 below. Apomuden recorded a significantly higher (0.81 *vs.* 0.60; p = 0.001) wound healing score compared to Nane in the first year. However, no statistical differences (p = 0.120) were observed between the two cultivars in the second year.

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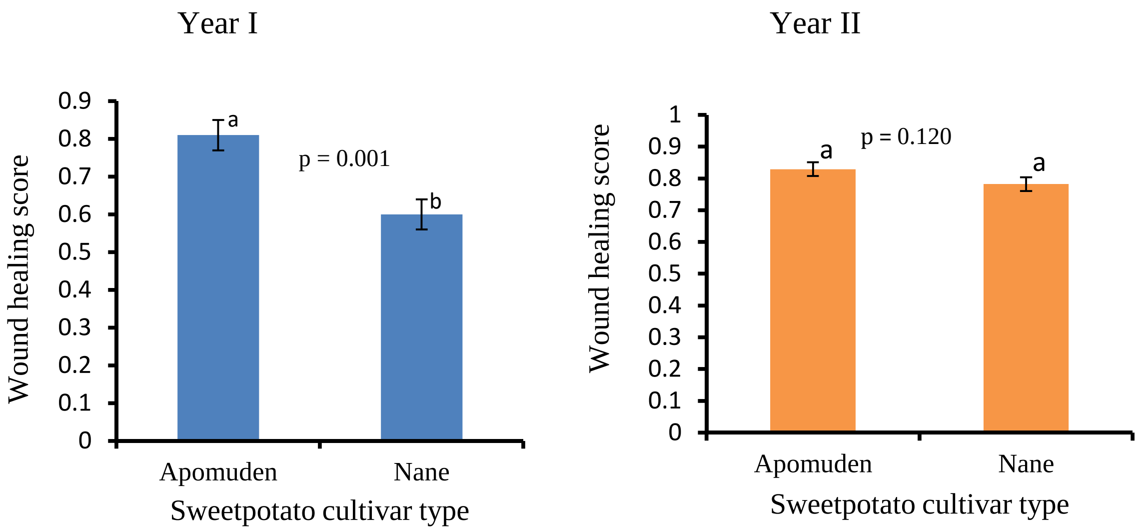

Figure 4.4: Cultivars response to wound healing during curing for the Year I and II
Bar values (least square means ± SEM, *n* = 3). Least square means with similar letters are not significantly different ($p>0.05$)

Wound healing score of both Apomuden and Nane generally increased significantly ($p < 0.05$) and levelled off on the 4th and 5th days respectively in the first and second years (Figure 4.5). In Figure 4.6, the interaction between cultivar and curing day was consistently not significantly different ($p > 0.05$) for both years.

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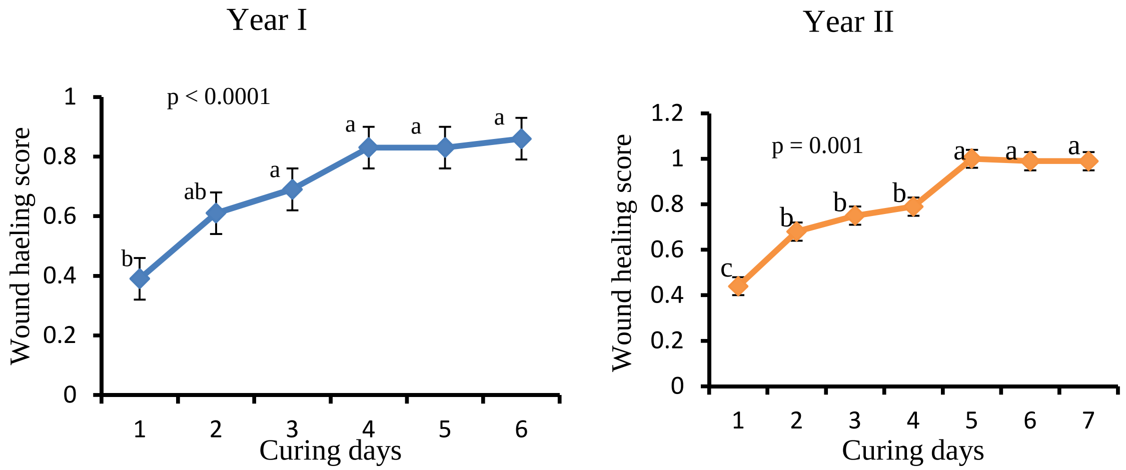

Figure 4.5: Average daily wound healing scores during curing for year I and II
Values are least square means ± SEM, *n* = 3. Least square means with similar letters are not significantly different (p>0.05).

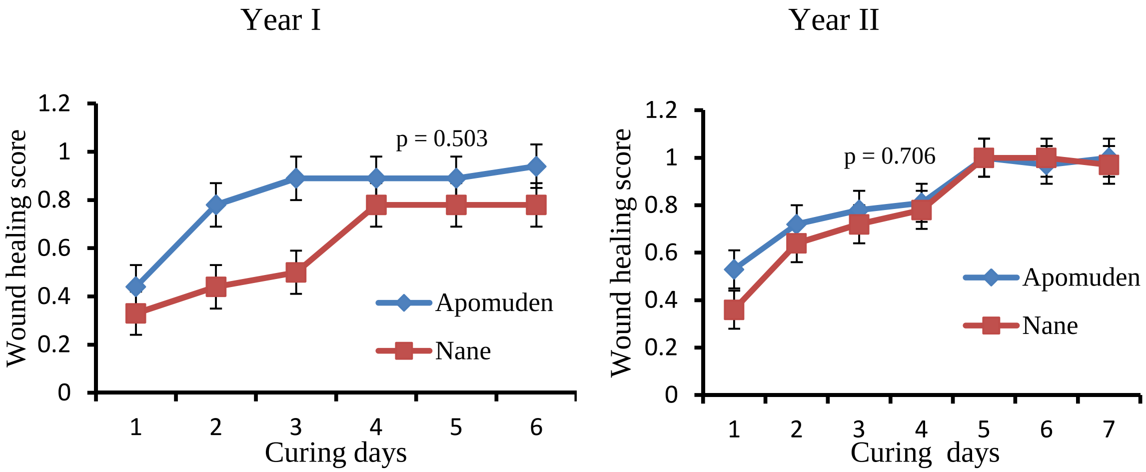

Figure 4.6: An interaction plot between cultivar and day on the wound healing score for year I and II.
Values are least square means ± SEM, *n* = 3

4.4 Changes in root quality in relation to curing storage methods

4.4.1 Effect of curing and storage methods on physical storage root qualities

Figure 4.7 presents results of curing methods and the influence they had on root quality factors during curing for the two consecutive years. No significant difference was observed among stored roots from in-ground, field-piled and uncured treatments with respect to

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weight loss in the first year. However, during the second year, roots from the in-ground treatment recorded a significantly lower weight loss (7.4%; $p = 0.003$), followed by uncured (9.3%) and field-piled (12%). In terms of rots, there was significant difference ($p < 0.05$) between curing methods with dehaulming having the least rots. Weevil damage was observed not to significantly affect ($p = 0.912$) curing, in year one. However, the subsequent year recorded no weevil damage during the period of storage. On the other hand, sprouts were significantly higher ($p < 0.0001$) in dehaulming (2.3%) when compared to field-piled (0%) and uncured (0.28%). No incidence of sprouts was however, observed during the period of storage in year two.

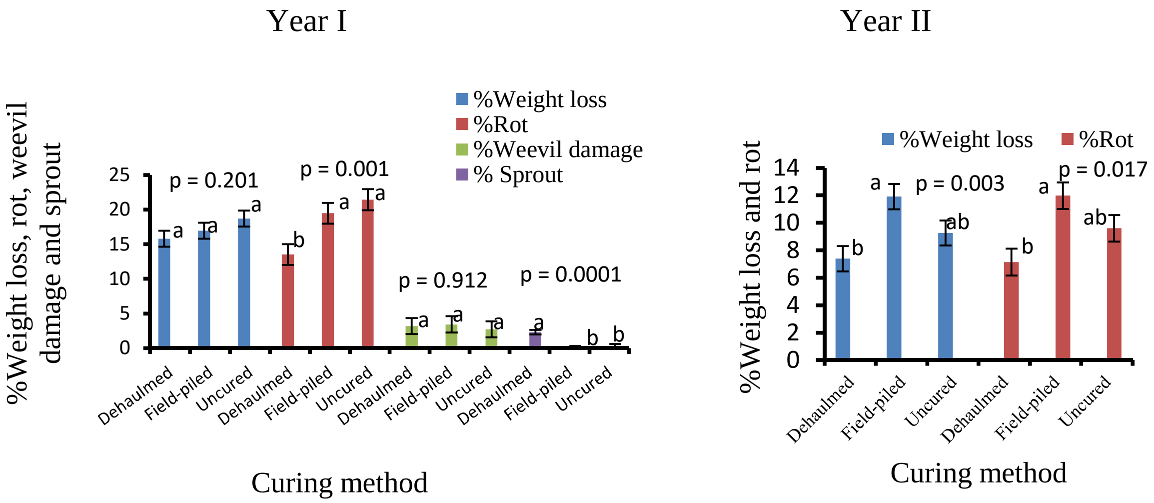

Figure 4.7: The effect of curing method on the physical quality of roots for year I and II
Bar values (least square means ± SEM, *n* = 3). Least square means with similar letters are not significantly different ($p>0.05$)

Figure 4.8 show results of the quality parameters of stored sweetpotato roots for the two years. Apomuden recorded a significantly higher ($p < 0.05$) percent weight loss and rots in both years. However, no significant difference ($P > 0.05$) was observed between Apomuden

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and Nane with regards to percent weevil damage and sprouts during the first year. Weevil damage and sprouts were not observed in the second year.

4.4.2 Sweetpotato cultivar effect on damage/loss factor

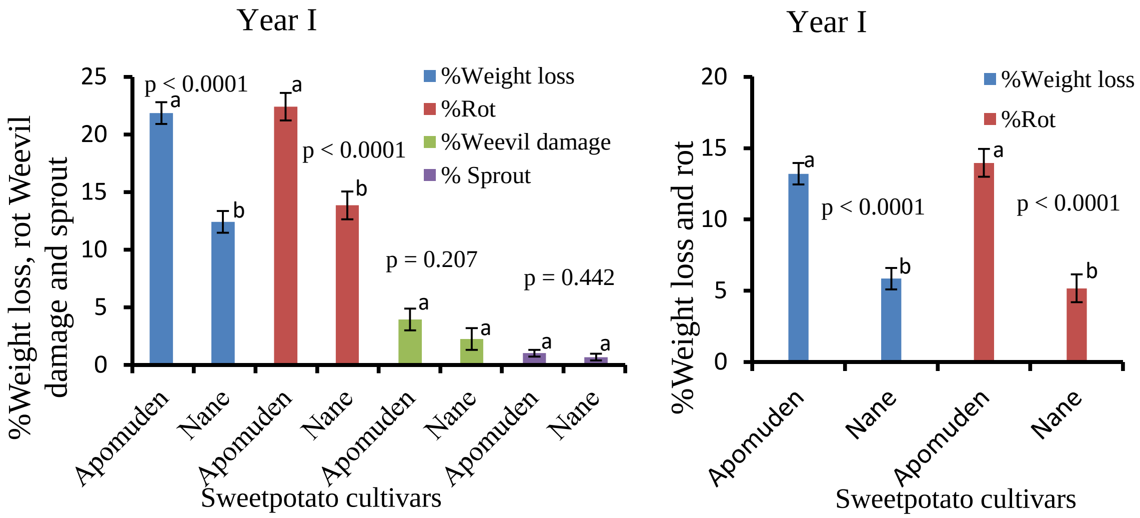

Figure 4.8: Physical root qualities of cultivars during storage for year I and II
Bar values (least square means ± SEM, *n* = 3). Least square means with similar letters are not significantly different (p>0.05)

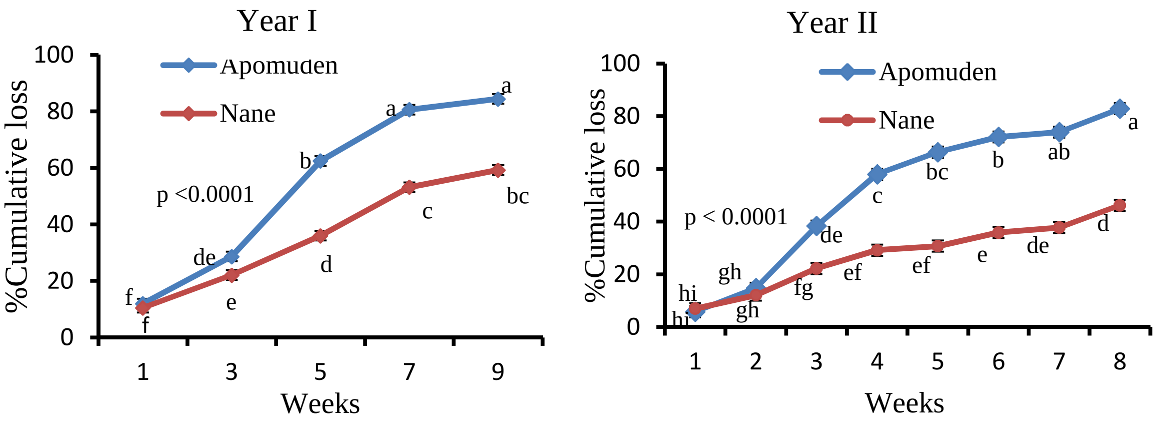

Figure 4.9: Cumulative loss during storage for year I and II
Values are least square means ± SEM, *n* = 3. Least square means with similar letters are not significantly different (p>0.05)

The biweekly (year I) and weekly (year II) cumulative loss is presented in Figure 4.9. Apomuden constantly recorded a significantly higher ($p < 0.0001$) loss compared with Nane. After a 9 week storage period, Apomuden recorded a maximum cumulative loss of 84%, which is about 1.4 times more than Nane (59%) during the first year. Similarly in the second year, the loss in Apomuden was about 1.8 times higher than Nane.

4.4.3 Damage/loss quality as affected by storage type

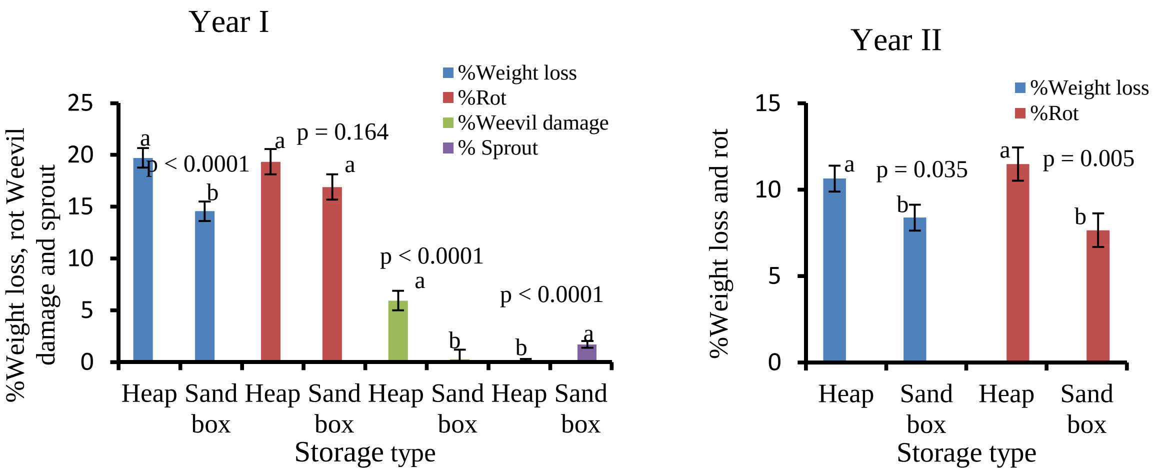

Figure 4.10: Physical root qualities of sweetpotato storage root as influenced by storage type for year I and II
Bar values (least square means ± SEM, *n* = 3). Least square means with similar letters are not significantly different ($p > 0.05$).

The sand box storage method recorded significantly lower weight loss in the first (15% *vs.* 20%; $p < 0.0001$) and second (8.4% *vs.* 10.7%; $p = 0.035$) years compared with the moistened straw heap storage method (Figure 4.10). No significant difference ($p = 0.164$) was observed between the sand box and heap storage methods with respect to rots in the first year. However, in the second season, the sand box method recorded significantly lower (7.7%; $p = 0.005$) rots relative to the heap method (12%). Weevil damage in year one was significantly higher (6% *vs.* 0.27%; $p < 0.0001$) in the heap method while sprouts was

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significantly lower (0% *vs*. 1.7%; $p < 0.0001$) in the heap storage compared to the sand box storage. No weevil damage or sprouts were observed in the second year in both storage methods.

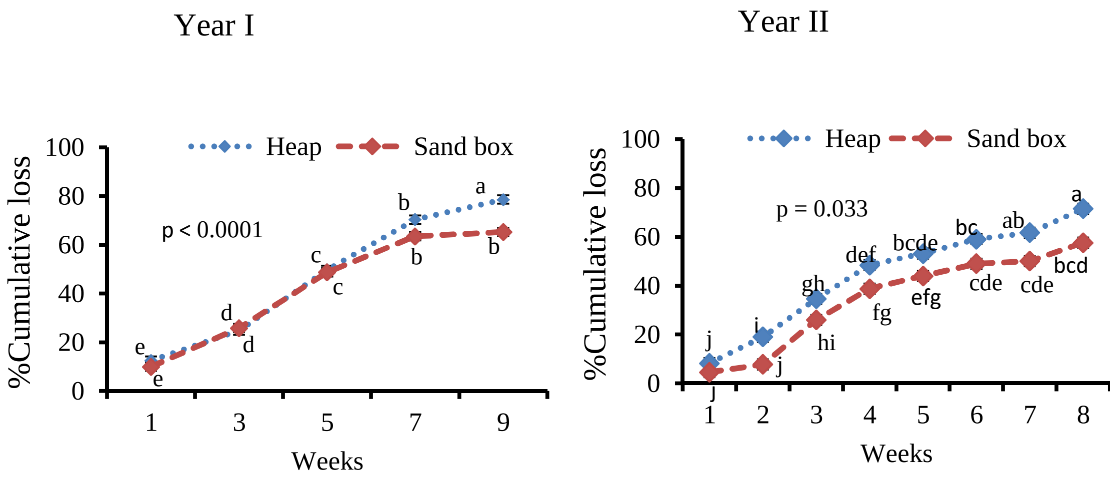

Figure 4.11: Cumulative loss of sweetpotato storage roots as influenced by storage type for year I and II
Values are least square means ± SEM, n = 3. Least square means with similar letters are not significantly different ($p>0.05$).

The cumulative loss in both years was significantly lower ($p < 0.05$) in the sand box storage compared with the heap over the nine (year I) or 8 weeks (year II) of storage (Figure 4.11). The mean cumulative loss of roots stored at the end of the first year's study was respectively 79 and 65% in heap and sand box storage methods. Similarly, in the second year, cumulative loss in the heap storage was 72 and 58% in the sand box storage after the 8-week storage period. Generally, losses in the sand box storage were less, compared with the heap storage over the period of storage.

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4.4.4 Compositional changes of sweetpotato storage roots as affected by curing and storage methods

Table 4.1 and Table 4.2 shows the compositional quality of roots either cured or uncured and then stored under either moistened straw heap or in sand boxes for year I and II respectively.

4.4.4.1 Starch

The starch content of sweetpotato cultivars varied significantly ($p < 0.0001$) with Nane having the higher starch content ranging from 54-56%, almost 1.2 times higher than Apomuden for both years (Table 4.1 and Table 4.2). However, both curing and storage types did not significantly ($p > 0.05$) influence the starch content of roots for the two years. On the other hand, the interaction between cultivar and storage time as well as between curing types and storage time was significant ($p < 0.05$) while the combined effect of storage type and time was not significantly ($p > 0.05$) affected as shown in Table 4.4 and Table 4.5. Although not significant ($p > .05$), there was generally a marginal decline in the starch content as storage progressed.

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Table 4.1: Compositional quality (dry matter basis) of roots either cured/uncured and then stored under heap or sand box storage for nine weeks during the first I

	Root compositional quality					
Culti	Fructose (%)	Glucose (%)	Sucrose (%)	Starch (%)	Dry matter (%)	β-carotene (mg/100 g)
Apor	4.23 ± 0.21^{a}	6.78 ± 0.32^{a}	21.05 ± 0.93^{a}	46.16 ± 1.00^{b}	25.62 ± 0.48^{b}	28.29 ± 0.68^{a}
Nane	1.93 ± 0.21^{b}	3.19 ± 0.32^{b}	18.97 ± 0.93^{a}	54.81 ± 1.00^{a}	32.89 ± 0.48^{a}	17.20 ± 0.68^{b}
p-val	< 0.0001	< 0.0001	0.125	< 0.0001	< 0.0001	< 0.0001
Curi						
Field	3.19 ± 0.25^{a}	5.28 ± 0.40^{a}	22.15 ± 1.14^{a}	49.00 ± 1.23^{a}	29.55 ± 0.59^{a}	24.96 ± 0.83^{a}
In-gr	3.17 ± 0.25^{a}	5.01 ± 0.40^{a}	20.45 ± 1.14^{ab}	49.73 ± 1.23^{a}	27.79 ± 0.59^{ab}	22.26 ± 0.83^{ab}
Uncu	2.89 ± 0.25^{a}	4.66 ± 0.40^{a}	17.42 ± 1.14^{b}	52.81 ± 1.23^{a}	30.42 ± 0.59^{b}	21.01 ± 0.83^{b}
p-val	0.635	0.549	0.021	0.093	0.011	0.007
Stor						
At ha	3.36 ± 1.69^{a}	5.28 ± 2.75^{a}	19.18 ± 4.60^{a}	52.50 ± 7.09^{a}	29.64 ± 3.82^{a}	24.47 ± 6.44^{a}
Heap	*	*	*	*	*	*
Sand	1.80 ± 1.19^{a}	4.69 ± 1.68^{a}	20.83 ± 4.22^{a}	48.47 ± 5.28^{a}	28.86 ± 4.48^{a}	21.02 ± 6.67^{a}
p-val	0.258	0.445	0.270	0.063	0.595	0.124

Value means of triplicate determinations ± standard error of means. Means in the same category in a column with the same letter are no fferent (P > 0.05)

#Valu re means of triplicate determination ± Standard deviation

¥No va roots stored in the heap got rotten before samples were taken for analysis

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Table 4.2: Compositional quality (dry matter basis) of roots either cured/uncured and then stored under heap or sand box storage for eight weeks during the second year

	Root compositional quality					
Culti	Fructose (%)	Glucose (%)	Sucrose (%)	Starch (%)	Dry matter (%)	β-carotene (mg/100 g)
Apor	3.74 ± 0.11^{a}	6.19 ± 0.15^{a}	20.74 ± 0.33^{a}	46.30 ± 0.41^{b}	25.06 ± 0.23^{b}	13.80 ± 0.22^{a}
Nane	1.95 ± 0.11^{b}	3.53 ± 0.15^{b}	16.74 ± 0.33^{b}	56.16 ± 0.41^{a}	30.43 ± 0.23^{a}	11.33 ± 0.20^{b}
p-val	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Curi						
Field	3.20 ± 0.14^{a}	5.18 ± 0.19^{a}	17.98 ± 0.41^{b}	51.67 ± 0.51^{a}	28.19 ± 0.28^{a}	12.33 ± 0.27^{a}
In-gr	2.52 ± 0.14^{ab}	4.58 ± 0.19^{a}	18.47 ± 0.41^{ab}	51.39 ± 0.51^{a}	27.67 ± 0.28^{a}	12.51 ± 0.26^{a}
Uncu	2.80 ± 0.14^{b}	4.82 ± 0.19^{a}	19.78 ± 0.41^{a}	50.64 ± 0.51^{a}	27.37 ± 0.28^{a}	12.85 ± 0.25^{a}
p-val	0.003	0.075	0.007	0.343	0.092	0.352
Stor						
At ha	3.61 ± 0.23^{a}	6.22 ± 0.31^{a}	15.27 ± 0.62^{b}	52.16 ± 1.05^{a}	$26.\ 08 \pm 0.55^{b}$	13.83 ± 0.32^{a}
Heap	2.35 ± 0.23^{b}	3.97 ± 0.31^{b}	20.79 ± 0.62^{a}	50.99 ± 1.05^{a}	29.59 ± 0.55^{a}	11.23 ± 0.34^{b}
Sand	2.57 ± 0.23^{b}	4.39 ± 0.31^{b}	20.16 ± 0.62^{a}	50.55 ± 1.05^{a}	27.57 ± 0.55^{b}	12.42 ± 0.32^{c}
p-val	< 0.0001	< 0.0001	< 0.0001	0.531	< 0.0001	< 0.0001
Culti						
Apor	3.70 ± 0.16^{a}	6.07 ± 0.21^{a}	21.80 ± 0.47^{a}	45.77 ± 0.59^{a}	25.60 ± 0.30^{a}	13.65 ± 0.34^{a}
Apor	3.70 ± 0.16^{a}	6.31 ± 0.21^{a}	19.70 ± 0.47^{b}	46.84 ± 0.59^{a}	24.60 ± 0.30^{a}	13.94 ± 0.29^{a}
Nane	1.86 ± 0.16^{a}	3.39 ± 0.21^{a}	16.35 ± 0.47^{c}	56.94 ± 0.59^{b}	31.40 ± 0.31^{a}	10.74 ± 0.29^{a}
Nane	2.03 ± 0.16^{a}	3.67 ± 0.21^{a}	17.13 ± 0.47^{c}	55.38 ± 0.59^{b}	29.50 ± 0.31^{a}	11.92 ± 0.29^{a}
p-val	0.806	0.930	0.004	0.030	0.171	0.141

Value means of triplicate determinations ± standard error of means). Means in the same nutrient category per treatment in a colum letter are not significantly different (P > 0.05)

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4.4.4.2 Total sugar

Apomuden had a significantly higher ($p < 0.0001$) level of glucose, fructose and sucrose compared with Nane. For the two years, the glucose content of Apomuden ranged from 6.19 to 6.78% , and fructose 3.74 to 4.23%, almost twice that of Nane for both glucose and fructose (Table 4.1 and Table 4.2). The sucrose content followed a similar trend with that of Apomuden ranging from 20.05 to 20.74% and Nane 16.74 to 18.97%. Both glucose and fructose level of cultivars and roots either cured or uncured generally decreased over storage time whiles the sucrose levels increased (Table 4.3) for year II. A similar observation was made in farming year I before and after storage in sand box. The decline in glucose content of roots stored in the heap and sand box was 40 and 26%, respectively over 2 months period of storage. Fructose on the other hand declined by 39% in heap storage and 32% in the sand box storage over 2 months storage period.

4.4.4.3 Dry matter content

Generally, dry matter content of roots increased as storage progressed. However, cultivars varied remarkably ($p < 0.0001$) in their dry matter content with Nane having higher dry matter content than Apomuden in both years (Tables 4.1 and 4.2). The curing type had a significant ($p = 0.011$) effect on the dry matter content in the first year. Conversely, in the subsequent year, curing type did not have a significant ($p = 0.092$) effect on the dry matter content of roots. The dry matter content of roots stored in the heap method was significantly higher (29% *vs*. 27%, respectively; $p < 0.0001$) compared with the sand box storage (Table 4.2). During the 2 month period of storage, the dry matter content of roots stored (irrespective of the cultivar) in heap storage increased by 15% almost 2.4 times more than sand box storage.

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4.4.4.4 β-carotene

The β-carotene content of Apomuden and Nane for year I and II is respectively presented in Table 4.1 and Table 4.2. Apomuden had a significantly ($p < 0.0001$) higher β-carotene compared with Nane in both years. Field-piled curing in the first year had a significantly higher ($p = 0.007$) β-carotene content compared with dehaulmed and uncured roots. However, in year II (Table 4.2), curing type had no significant influence on the β-carotene content of cultivars.

A paired sampled t-test showed no significant ($p = 0.124$) influence on β-carotene before and after storage in sand box (Table 4.1) for year I. The roots stored in the heap storage method all got rotten and samples could not be taken for analysis in year I therefore the two storage methods could not be compared. However, in year II, storage in the sand box showed a significantly (12.93 mg/100 g *vs.* 12.20 mg/100 g; $p = 0.015$) higher β-carotene content compared with the heap storage (Table 4.2).The β-carotene content of Apomuden and Nane stored in either sand box or by the heap storage methods over a 2-months period in the second year showed significant ($p < 0.0001$) differences. For both cultivars, the β-carotene content generally declined from harvest to 2 months storage.

Storage type interacting with length of storage, showed some significant ($p = 0.045$) difference in β-carotene during the second year. The β-carotene content ranged from 10.77-13.74 mg/100 g for heap storage and 12.25-14.00 mg/100 g for sand box storage. The decline in β-carotene content of storage roots was 10% in the sand box while in the heap storage; the decline was 19% (Table 4.2). These indicate better β-carotene retention in the sand box storage compared with the heap storage method.

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Table 4.3**:** Combined effects of cultivar and storage time on the root compositional quality (dry matter basis) during year II

Cultivar type*Month		**Root compositional quality**					
		Fructose (%)	Glucose (%)	Sucrose (%)	Starch (%)	Dry matter (%)	β-carotene (mg/100 g)
Ap	0	4.83 ± 0.20^{a}	8.13 ± 0.26^{a}	18.13 ± 0.58^{bc}	45.42 ± 0.73^{cd}	22.70 ± 0.37^{d}	16.03 ± 0.36^{a}
	1	3.37 ± 0.20^{b}	5.26 ± 0.26^{b}	21.29 ± 0.58^{a}	48.26 ± 0.73^{c}	26.40 ± 0.37^{c}	12.42 ± 0.36^{b}
	2	3.02 ± 0.20^{bc}	5.18 ± 0.26^{b}	22.81 ± 0.58^{a}	45.24 ± 0.73^{d}	26.20 ± 0.37^{c}	12.94 ± 0.43^{b}
	0	2.40 ± 0.20^{cd}	4.32 ± 0.26^{b}	12.41 ± 0.58^{d}	58.9 ± 0.73^{a}	29.50 ± 0.37^{b}	11.71 ± 0.35^{bc}
	1	1.81 ± 0.20^{d}	3.08 ± 0.26^{c}	17.33 ± 0.58^{c}	55.60 ± 0.73^{b}	30.10 ± 0.37^{ab}	10.90 ± 0.35^{c}
	2	1.63 ± 0.20^{d}	3.18 ± 0.26^{c}	20.47 ± 0.58^{b}	53.97 ± 0.73^{b}	31.70 ± 0.37^{a}	11.39 ± 0.35^{bc}
p-val		0.02	0.001	0.017	< 0.0001	< 0.0001	< 0.0001

Values ıeans of triplicate determinations ± standard error of means. Means in the same category in a column with the same letter are not signifi > 0.05)

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Table 4.4**:** Combined effects of curing and storage time on the root compositional quality (dry matter basis) during year II

Curing type*Month	**Root compositional quality**					
	Fructose (%)	Glucose (%)	Sucrose (%)	Starch (%)	Dry matter (%)	β-carotene (mg/100 g)
Field	4.96 ± 0.24^{a}	7.71 ± 0.32^{a}	16.34 ± 0.71^{d}	49.50 ± 0.89^{cd}	26.51 ± 0.46^{a}	13.72 ± 0.45^{a}
	2.12 ± 0.24^{b}	3.64 ± 0.32^{d}	17.49 ± 0.71^{cd}	54.32 ± 0.89^{a}	29.21 ± 0.46^{a}	11.06 ± 0.45^{a}
	2.53 ± 0.24^{b}	4.15 ± 0.32^{cd}	20.09 ± 0.71^{bc}	51.19 ± 0.89^{abcd}	28.85 ± 0.46^{a}	12.22 ± 0.51^{a}
In-gr	2.73 ± 0.24^{b}	5.30 ± 0.32^{bc}	14.55 ± 0.71^{d}	53.09 ± 0.89^{abc}	25.55 ± 0.46^{a}	14.15 ± 0.43^{a}
	2.74 ± 0.24^{b}	4.33 ± 0.32^{bcd}	19.71 ± 0.71^{bc}	51.40 ± 0.89^{abcd}	28.17 ± 0.46^{a}	11.44 ± 0.43^{a}
	2.10 ± 0.24^{b}	4.12 ± 0.32^{cd}	21.14 ± 0.71^{ab}	49.67 ± 0.89^{cd}	29.30 ± 0.46^{a}	11.95 ± 0.48^{a}
Uncu	3.15 ± 0.24^{b}	5.62 ± 0.32^{b}	14.91 ± 0.71^{d}	53.90 ± 0.89^{ab}	26.17 ± 0.46^{a}	13.74 ± 0.43^{a}
	2.91 ± 0.24^{b}	4.55 ± 0.32^{bcd}	20.73 ± 0.71^{ab}	50.06 ± 0.89^{bcd}	27.36 ± 0.46^{a}	12.49 ± 0.43^{a}
	2.36 ± 0.24^{b}	4.28 ± 0.32^{bcd}	23.69 ± 0.71^{a}	47.95 ± 0.89^{d}	28.60 ± 0.46^{a}	12.33 ± 0.43^{a}
p-val	0.0001	0.0001	0.003	0.0001	0.157	0.339

Values neans of triplicate determinations ± standard error of means. Means in the same category in a column with the same letter are not signifi > 0.05)

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Table 4.5**:** Combined effects of storage type and storage time on the root compositional quality (dry matter basis) during year II

Stc	**ıth**	**Root compositional quality**					
		Fructose (%)	Glucose (%)	Sucrose (%)	Starch (%)	Dry matter (%)	β-carotene (mg/100 g)
Heap	0	3.62 ± 0.20^{a}	6.25 ± 0.20^{a}	15.60 ± 0.58^{c}	52.09 ± 0.73^{a}	26.19 ± 0.37^{cd}	13.74 ± 0.36^{ab}
	1	2.50 ± 0.20^{b}	4.16 ± 0.20^{b}	19.22 ± 0.58^{b}	52.15 ± 0.73^{a}	28.94 ± 0.37^{ab}	10.77 ± 0.36^{d}
	2	2.20 ± 0.20^{b}	3.78 ± 0.20^{b}	22.56 ± 0.58^{a}	49.83 ± 0.73^{a}	30.23 ± 0.37^{a}	12.08 ± 0.42^{cd}
Sand	0	3.60 ± 0.20^{a}	6.20 ± 0.20^{a}	14.94 ± 0.58^{c}	52.23 ± 0.73^{a}	25.96 ± 0.37^{d}	14.00 ± 0.35^{a}
	1	2.68 ± 0.20^{b}	4.19 ± 0.20^{b}	19.41 ± 0.58^{b}	51.71 ± 0.73^{a}	27.54 ± 0.37^{bc}	12.55 ± 0.35^{bc}
	2	2.45 ± 0.20^{b}	4.59 ± 0.20^{b}	20.92 ± 0.58^{ab}	49.38 ± 0.73^{a}	27.60 ± 0.37^{bc}	12.25 ± 0.36^{c}
p-val		0.779	0.198	0.375	0.899	0.008	0.045

Values ıeans of triplicate determinations ± standard error of means. Means in the same category in a column with the same letter are not signifi > 0.0

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4.4.5 Sensory quality of sweetpotato cultivars as affected by curing and storage methods

All the sensory attributes had a sensory scores ranging from 3.20 to 3.84 and 3.32 to 3.93 during the first and second years, respectively, indicating good consumer preference for both cultivars. However, in the first year, Apomuden had significantly lower score for sweetness (3.30 *vs*. 3.83, $p < 0.0001$) and overall acceptability (3.44 *vs*. 3.76, $p = 0.000$) compared with Nane (Table 4.6). In the second year, cultivars did not differ ($p > 0.05$) in all sensory attributes except for finger-feel firmness where Nane had a significantly higher score (3.63 *vs*. 3.35, $p = 0.003$). In the two consecutive years, in-ground curing consistently had higher mean rank for general appearance ranging from 278.97-329.57 compared with field-piled (266.00-271.49) and uncured (233.68-307.98) as shown in Table 4.6. Field-piled curing had significantly higher ($p < 0.05$) mean rank for all sensory attributes assessed for the second year except for general appearance where in-ground curing was significantly higher (278.98, $p = 0.000$). Storage type showed no significant difference ($p > 0.05$) in all sensory attributes in both years.

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Table 4.6: Sensory scores of boiled sweetpotato roots after being cured/uncured and stored using two household-level storage methods (heap *vs*. sand box)

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	Year I (*n*=121; Male=45, Female=76)				**Year II** (*n*=91; Male=14, Female=77)			
	Sensory Attributes							
Cultiv	**General ppearance**	**Finger-feel Firmness**	**Sweetness**	**Overall Acceptability**	**General Appearance**	**Finger-feel Firmness**	**Sweetness**	**Overall Acceptability**
Apom	3.49±1.26^{a}	3.26±1.16^{a}	3.30±1.16^{a}	3.44±1.15^{a}	3.53±1.07^{a}	3.35±1.11^{a}	3.54±1.11^{a}	3.63±1.15^{a}
Nane	3.39±1.13^{a}	3.39±1.15^{a}	3.83±1.03^{b}	3.76±0.98^{b}	3.66±1.18^{b}	3.63±1.12^{b}	3.66±1.09^{a}	3.75±1.13^{a}
P-Val	0.149	0.116	<0.0001	<0.0001	0.094	0.003	0.210	0.224
Curin								
Field-	271.48^{a}	304.94^{a}	288.61^{a}	288.62^{a}	266.10^{b}	298.93^{b}	296.29^{b}	288.99^{b}
In-gro	329.58^{b}	309.40^{a}	312.42^{a}	317.07^{a}	278.98^{b}	243.80^{a}	238.49^{a}	255.57^{ab}
Uncur	307.97^{ab}	297.98^{a}	306.54^{a}	304.49^{a}	233.69^{a}	233.69^{a}	241.03^{a}	229.59^{a}
P-Val	0.004	0.779	0.335	0.261	0.000	<0.0001	0.000	0.001
Stora								
Heap	3.40±1.14^{a}	3.32±1.13^{a}	3.84±1.04^{a}	3.69±1.01^{a}	3.63±1.16^{a}	3.51±1.12^{a}	3.54±1.13^{a}	3.63±1.15^{a}
Sand l	3.45±1.21^{a}	3.35±1.17^{a}	3.47±1.13^{b}	3.60±1.10^{a}	3.58±1.12^{a}	3.49±1.13^{a}	3.70±1.06^{a}	3.75±1.13^{a}
P-Val	0.491	0.569	<0.0001	0.397	0.539	0.903	0.157	0.224

Means egory in a column with the same letter are not significantly different (P > 0.05)
*Valu Standard Deviation; #Values are mean of ranks
Scale *dislike, 2= dislike, 3=neither like nor dislike, 4= like and 5= like extremely*

In both years, the sex of respondents showed that both males and females similarly ranked all the sensory attributes (p > 0.05) with the exception of general appearance and finger-feel firmness for year I (Figure 4.12).

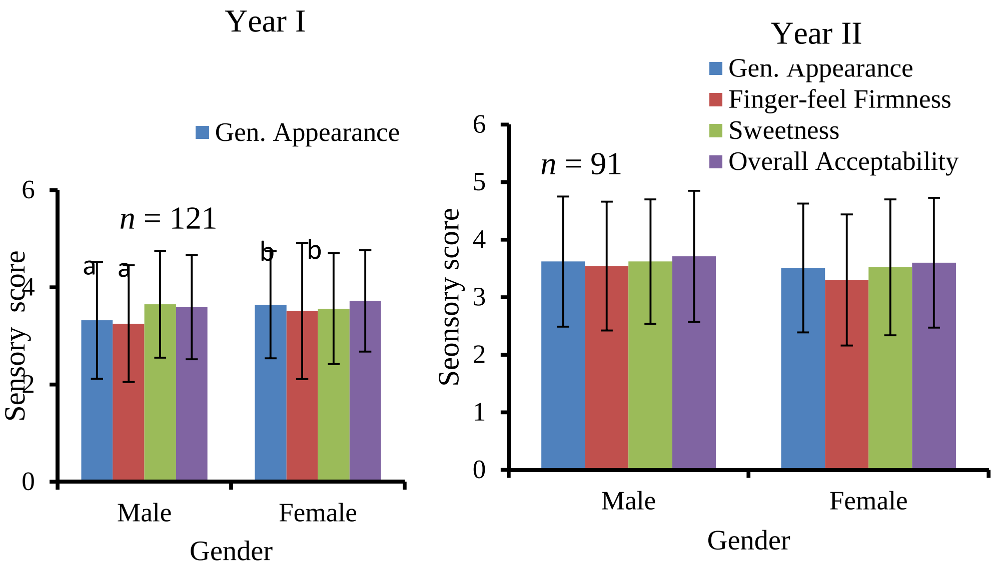

Figure 4.12: Sensory attributes of boiled OFSP roots as affected by respondents' gender Bar values (least square means ± SD). Least square means with similar letters are not significantly different (p>0.05). Comparison is between males and females with respect to the sensory attributes.

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CHAPTER FIVE

5 Discussion

Post-harvest management practices such as curing and storage of sweetpotato are crucial in ensuring long-term availability of good quality roots for food and nutrition security. However, these post-harvest management practices may influence the qualities of the roots. The results of the study therefore, have been accordingly discussed under the following headings.

5.1 Curing of sweetpotato

5.1.1 Field-piled curing

5.1.1.1 Temperature and relative humidity in field-piled curing condition

The temperatures and relative humidity were all within the ideal curing ranges 29-33°C and 90-95% (Picha, 1986b; Ravi *et al.*, 1996; Ray & Ravi, 2005) suggesting that field-piled curing method actually leads to proper curing of roots, although farmers are not aware they are curing. The ambient temperature and relative humidity of this study were not in the appropriate ranges for curing, in contrast to the suggestion that ambient tropical conditions may naturally assist curing (Ravi *et al.*, 1996; Ray *et al.*, 2010).

Therefore, the suitable curing conditions are obtained with roots heaped and covered with fresh vines to trap self-generated heat and moisture (Kitinoja & Kader, 2002) and left to cure on the field for at most 7 days. In this study area of this work curing was achieved by the fifth day.

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5.1.1.2 Weight loss

The average weight loss of Apomuden in field-piled curing suggests higher metabolic activity in Apomuden compared with Nane. High metabolic activity has been suggested to be the major contributory factor of the higher weight loss of sweetpotato cultivars during curing (Ravi *et al.*, 1996; Scott & Mathews, 1957). The percent shrinkage was directly related to weight loss suggesting that shrinkage may be a contributory factor for weight loss in sweetpotato.

5.1.1.3 Wound healing during field-piled curing

The data in this study suggest that Apomuden would be less susceptible to weight loss and pathogenic microorganisms compared with Nane. However, Nane had better shelf life and lower weight loss. Thus, lignification alone cannot be used as a quality index of the root quality of these two OFSP cultivars. The finding agrees with previous works by van Oirschot *et al*. (2001) who reported that sweetpotato cultivars differ remarkably in their wound healing ability. This observation could largely be due to genetic factors as genes associated with wound healing may be over expressed in certain cultivars than others.

Wound healing scores increased with curing time, an indication of more lignin being produced with curing. This corroborates earlier reports that lignified cell score, directly relates to curing time (Walter *et al.*, 1989). The findings further suggest that cultivars might have established their wound periderm after the 4th day of field-piled curing. Artschwager and Starrett (1931) reported that the establishment of a wound periderm is the final stage of wound healing. Therefore, the minimum curing time could be 5 days after harvest.

5.2 Changes in root quality with storage

5.2.1 Curing methods

Generally, the in-ground curing (dehaulmed) treatment proved to reduce weight loss and rots during storage compared with the field-piled and the uncured treatment and should be encouraged. The weevil damage in first year was as a result of a high weevil attack of roots before storage as not too good roots were stored. However, in year II no weevil damage was found in stored roots either cured or uncured. This explains why it is crucial for good root to be stored in other to minimise damage. Sprouts were significantly high in dehaulmed treatment compared with field-piled and uncured.

5.2.2 Sweetpotato cultivars

The data shows that Apomuden is susceptible to decay compared with Nane although the wound healing ability of Apomuden tends to be better than Nane. This susceptibility in spite of better wound healing ability could be attributed to the observed thin skin of Apomuden which is easily damaged making it prone to pathogenic microbial attack. Apomuden showed a high wound healing score, an indicator of good storage life (van Oirschot *et al.*, 2001). However, Apomuden did not store better than Nane suggesting that other factors aside from wound healing (Amand & Randle, 1991; Walter *et al.*, 1989) could be responsible for sweetpotato shelf life extension. Previous studies showed that Beauregard had superior wound healing characteristics but has been considered skinning susceptible in U.S production regions (Rees, van Oirschot, & Aked, 2008). Nane on the other hand

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showed good storage qualities and could potentially serve as a household-level dietary source of vitamin A.

5.2.3 Storage type

The lower weight loss of roots in the sand box storage supports that of Chattopadhyay *et al*. (2006) who reported that physiological loss of weight of sweetpotato cultivars were less in sand medium (15%) compared to saw dust (17%) after 75 days of storage and 25% in exposed storage (control) when stored for 50 days. This is an indication that the sand medium provided enough protection to roots thereby reducing respiration and transpiration that largely contribute to physiological weight loss in sweetpotato (Jenkins, 1982; Picha, 1986b). Although no significant difference was observed between the two storage types in terms of rots during the first year, the sand box recorded low rots (17%) relative to the heap storage (19%). The sprinkling of water every other day in the heap could have created conducive environment for the growth of pathogenic microbes resulting in increased root decay. The data on the low incidence of weevil damage of the roots stored in the sand box method indicate that the sand medium served as a block restricting the movement of the weevils from one root to the other, while in the heap storage they could easily move from one root to another to cause extensive damage. The findings of this study therefore suggests that sweetpotato, especially OFSP, can be stored in sand boxes up to 9 weeks which will allow for household consumption for food and nutrition security in northern Ghana. During the second year no weevil damage was observed in the two storage methods. This also shows that careful removal of all weevil infested roots before storage is important for

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improved storage life of sweetpotato roots. Sweetpotato sprouted almost twice as much in the sand box storage as compared with the heap method contrary to the findings of Chattopadhyay *et al.* (2006) who reported no sprouts in the sand medium storage. The observed sprouts in the sand box storage could be an indication of good quality roots as reported elsewhere that good roots sprout often in storage (van Oirschot *et al.*, 2007). Nonetheless sprouts are often broken off as a control measure.

5.2.4 Compositional quality of sweetpotato cultivars as influenced by curing and storage methods

5.2.4.1 Starch

The data shows that the starch content of sweetpotato cultivars varied significantly, with Nane having the highest starch content (56%), about 1.2 times higher than that of Apomuden. The findings support earlier works by Zhang *et al.* (2002) that sweetpotato genotypes vary in their starch content. The data further shows that starch constitute more than half of the total dry matter portion of sweetpotato and this corroborates previous findings that the dry matter portion of sweetpotato is mainly starch (Rukundo *et al.*, 2013; Woolfe, 1992). Thus the higher the starch content, the higher the dry matter. This was confirmed in this study as the dry matter content of Nane was higher than Apomuden.

Curing and storage types were found not to affect the starch content of roots. However, the interaction between cultivar and storage duration was found to be significant. The findings in this study supports previous works by Zhang *et al.*

(2002) and Chattopadhyay *et al*. (2006) who both reported a slightly declining starch content during storage and varied among genotypes. The likely reason for the declining trends could be mainly due to breakdown of starch to sugars by the activities of α-amylase enzymes. The α-amylase activity among four lines of sweetpotato showed the largest increase in dextrin content but decreased starch content during storage (Zhang *et al.*, 2002) confirming the above observation. Furthermore, the declining starch content was also attributed to starch being used as a respiratory substrate during storage (Dandago & Gungula, 2011).

5.2.4.2 Total sugar

The finding agrees with Zhang *et al.* (2002) who opined that both reducing fructose and glucose and non-reducing sucrose sugar vary widely with sweetpotato genotype. Both glucose and fructose level of cultivars and roots either cured or uncured generally decreased over time while the sucrose levels increased. This inverse relationship between the monosaccharides, glucose and fructose and disaccharide, sucrose could be as a result of the synthesis of sucrose during storage from glucose and fructose since the two monosaccharide units form sucrose. In wild-type potato tubers water stress led to the synthesis of sucrose (Geigenberger, Reimholz, Deiting, Sonnewald, & Stitt, 1999). This observation could also be linked to the increased levels of sucrose during storage as in this current study. The current findings supports Chattopadhyay *et al*. (2006) who reported that the roots stored in the sand medium had better retention of sugar compared with exposed and sawdust storage methods.

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5.2.4.3 Dry matter content

Generally, dry matter content of roots increase as storage progresses due to depletion of moisture (Vimala *et al.*, 2013). The same pattern was observed in this study. Nane, having a higher dry matter content at harvest, after curing and storage than Apomuden, could be related to its higher starch content as reported in other studies (Rukundo *et al.*, 2013; Woolfe, 1992). The variation between Nane and Apomuden in terms of starch and dry matter content could also be due to varietal differences (Tomlins, Owori, Bechoff, Menya, & Westby, 2012). The high dry matter content of the uncured and stored roots as compared with the cured ones could be due to rapid moisture depletion of the uncured ones compared with the field-piled and in-ground cured and stored roots during the first year. However, in the second year, curing type had no effect on the dry matter of roots. Storage type on the other hand, had an effect on the dry matter content as the heap method recorded higher dry matter content relative to the sand box method. The likely reason for this observation could be that the sand medium protected the roots well enough to reduce respiration and evapotranspiration hence reduced moisture loss. The findings support previous studies elsewhere (Chattopadhyay *et al.*, 2006) that showed that the medium of storage had a remarkable influence on the dry matter content of roots irrespective of the cultivar. Similar findings were made after 50 days when sweetpotato roots were stored in either sand medium, sawdust or under ambient condition (Chattopadhyay *et al.*, 2006).

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5.2.4.4 β-carotene

Apomuden, the released variety in Ghana being higher in β-carotene makes it superior to Nane when considering them as food-based crops to address VAD. The results support previous studies that showed that sweetpotato cultivars vary widely in their β-carotene content (Grace *et al.*, 2013; Vimala *et al.*, 2011). However, it is worth highlighting that over the 2 months storage period, the β-carotene content of Apomuden reduced drastically, about 19% compared with Nane that recorded about 2.7% loss of its β-carotene. This observation could be attributed to varietal difference. Thus some varieties are able to retain their β-carotene content better than others. In this current study, curing was found to have an influence on the β-carotene content of roots only in the first year. This data confirms earlier studies by Grace *et al.* (2013) who found that, carotene levels increased during curing and storage. It is possible because, as reported by Rodriguez-Amaya (1997) that carotenogenesis is continuous if fruits and vegetables remain intact after harvest.

In the first year, all the roots stored in the heap storage method got rotten even before samples could be taken for the β-carotene assay due to low root quality during harvest. The quantities of storage roots were few; hence selections of wholesome roots were not strictly adhered to. This confirms the recommendation of the relevance of selection of sound roots of sweetpotato for storage (Ray & Ravi, 2005). However, in the subsequent year, both the sand box and the heap storage methods had roots for β-carotene assay at 2 months after storage, because the yields were better and selection of wholesome roots was strictly adhered to.

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The data implies that the sand box storage method retained β-carotene better compared to the moistened heap storage method. The current findings corroborates with previous works by Chattopadhyay *et al.* (2006) who reported better β-carotene retention in sand medium compared to sawdust and ambient storage methods. Elsewhere, it has also been reported that pit storage of sweetpotato roots resulted in high β-carotene retention relative to ambient and dark room storage conditions (Tumuhimbise *et al.*, 2010). High temperature (Dutta, Raychaudhuri, & Chakraborty, 2005) or a combination of temperature and cultivar type (Chattopadhyay *et al.*, 2006) has been cited for the degradation of β-carotene in sweetpotato. Therefore, the sand medium in the current study could have provided favourable temperature that minimized the degradation of β-carotene compared to the heap.

5.2.5 Sensory quality

The sensory scores for all the sensory attributes were above 3 on the 5-point hedonic scale in both years an indication of good consumer preference (Muhimbula, Issa-Zacharia, & Kinabo, 2011) for both cultivars. However, in the first year, Apomuden had a significantly lower score for sweetness (3.30 *vs.* 3.83, $p < 0.0001$) and overall acceptability (3.44 *vs.* 3.76, $p < 0.0001$) compared with Nane. The lower score of sweetness (sugariness) was in spite of higher fructose, glucose and sucrose concentrations than Nane. It could be deduced that the "sweetness" attribute was rated by the panelists as palatability instead of sugariness. The differences in cultivars' overall acceptability could be attributed to taste (palatability) as it was among other factors being reported to be the main factors for overall acceptability of sweetpotato cultivars (Kwach, Odhiambo, Dida, & Gichuki, 2010).

In the second year, cultivars did not differ ($p > 0.05$) in all sensory attributes except for finger-feel firmness that Nane had a higher score (3.63 *vs*. 3.35, $p = 0.003$) than Apomuden. This could be attributed to the high dry matter content, averagely, 27% for Nane. According to Kapinga *et al*. (2003), firmness is an indicator of high dry matter content, a preferred sweetpotato root quality component. The OFSP cultivars have often been rated poorly regarding finger-feel firmness (Leksrisompong, Whitson, Truong, & Drake, 2012) probably due to their generally, low dry matter (20-24%) contents (Tomlins *et al.*, 2012; Vimala *et al.*, 2013). However, Nane is relatively high in dry matter (27%) and it is reported that, African consumers prefer high dry matter cultivars (Baafi *et al.*, 2015; Tomlins *et al.*, 2004). Based on Walter (1987) it was expected that Apomuden should have been the more preferred cultivar, but it was not the case as this study shows. Thus, Nane, the cultivar under evaluation for release in Ghana could have high consumer acceptability.

In the two years, in-ground curing consistently had higher consumer ranks for general appearance compared with field-piled curing and uncured. This may imply that roots cured in-ground and stored in sand box or under heap methods could improve the cooking properties of the roots. Considering that it is easier to do, dehaulming should be recommended to all sweetpotato farmers.

The curing method could have promoted the synthesis of α- and β-amylase enzymes that hydrolyses starch during cooking leading to the formation of

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monosaccharides, precursors for vital flavour components e.g. sweetness as reported elsewhere (Wang, Horvat, White, & Kays, 1998). Both curing methods generally resulted in roots with better sensory quality than uncured treatment because the increased enzyme activity and sugars concentration make the boiled-cured roots become sweet and moist (Walter, 1987).

Storage type showed no significant difference ($p > 0.05$) in all sensory attributes in both years. This is an indication that cultivars stored either in sand box or under heap for a maximum of 8-9 weeks will be equally accepted by consumers. The findings agree with van Oirschot *et al*. (2003a) who reported that apart from fibrousness, storage had no significant influence on all the sensory qualities of sweetpotato roots of the cultivars they studied. Mpagalile *et al.* (2007) also reported that improved open pit, improved house pit and raised woven structure had no significant influence on the acceptability of sweetpotato except for the traditional pit storage.

Gender is a major factor that determines the success and sustainability of any intervention including OFSP cultivation and consumption. Both males and females similarly ranked sweetness and overall acceptability with the exception of general appearance and finger-feel firmness, for year I. This is an indication that both cultivars could be equally accepted by both male and female. Importantly, the preference of the OFSP cultivars by men, who are usually household heads in Northern Ghana, implies that these β-carotene-rich food crops are likely to be prepared and consumed at the household-level. However, the finding in this study contradicts earlier studies by Tomlins *et al.* (2004) and (2007a) who reported that

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female consumers preferred some sweetpotato cultivars more than their male consumers.

The high ranking of general appearance and finger-feel firmness by the female consumers suggest that Ghanaian children would prefer the OFSP cultivars as have been reported elsewhere (Skinner, Carruth, Bounds, & Ziegler, 2002), since foods not preferred by mothers are not normally offered to children.

Therefore, in Ghana, and particularly in the rural communities where VAD prevalence is usually high, OFSP has the potential to be a dietary source of vitamin A for at least two months in the year.

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CHAPTER SIX

6 Conclusions and Recommendations

This chapter contains summary conclusions of the research outcomes, a re-visit of the research objectives to confirm whether they have been achieved. The next components of this chapter are recommendations and limitation of the research. The study considered cultivars' responses to wound healing when subjected to in-ground/dehaulming and field-piled curing methods. The storability of the two OFSP cultivars was also compared under heap and sand box storage. Changes in root compositional and sensory quality with storage were as well considered.

6.1 Conclusions

Based on the results and discussions in relation to the objectives of the study the following conclusions were drawn:

Objective 1:

- Tropical ambient conditions may not automatically lead to curing of sweetpotato roots unless the conditions are created by covering roots piled on the field with fresh vines to trap self-generated heat and moisture as in the case of field-piled curing in this study.
- The average weight loss of sweetpotato roots during field-piled curing was between 1.2-7.01% for the two years.
- Both in-ground and field-piled curing methods resulted in reduced weight loss and rot during storage, and also increased consumer acceptability of boiled roots after 2 months of storage.

- Sweetpotato roots are able to cure their wounds better in field-piled curing compared to in-ground curing.
- Field-piled curing should be done for 4 days as wound healing was completed for both cultivars by the 4th day.

Objective 2:

- During the 2-month period of storage under heap (farmers' current practice) and sand box methods (proposed method) for both years, root damage factors such as percent weight loss, rot, and weevil attack were minimal in the sand box compared with the heap storage.
- Percent root sprouts were higher in the sand box storage relative to the heap storage which is an indication that soundness of the roots in sand box is maintained for a longer time.

Objective 3:

- Curing and storage types had no adverse influence on the starch content of sweetpotato roots.
- β-carotene content was higher in Apomuden than Nane. However, the degradation in storage was higher in Apomuden than Nane
- Nane had the highest dry matter and starch contents at harvest, curing and in storage
- Both cultivars were preferred by male and female consumers alike indicating sustainability of these OFSP cultivars.

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- Generally, the sensory data from the two years suggested moderate consumer (males and females) preference after two months of storage.

6.2 Recommendations and future perspectives

On the basis of the experimental results taking into consideration the objectives of the study, it is recommended that:

- Field-piled and in-ground curing should be encouraged among sweetpotato farmers for improved storage and culinary qualities.
- Field-piled curing within 4 days should be encouraged as wound healing would have been completed within this period for improved storage life.
- Efforts should be intensified in the release of Nane, the OFSP cultivar with high dry matter content (27%), to complement other existing varieties in Ghana.
- The sand box storage method should be encouraged at the household-level for long-term (2 months) availability of fresh sweetpotato roots for consumption.

For further research

- A wide range of OFSP cultivars and local checks should be evaluated for the wound healing ability and storage potentials.
- Histological analysis should be used to confirm results obtained from the phloroglucinol-HCl staining used during wound healing experiment
- The changes in polyphenol content of sweetpotato roots with curing and storage

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- Locally available storage material such as saw dust or rice husk should be used as alternatives to river sand used in the sand box storage.
- Identification and characterisation of the type of rots in the stores should be considered in future studies. Pathogenicity test should also be considered.

6.3 Limitation

- The exclusion and/or removal of ethylene were not done but that could manipulate the curing/storage environment to affect quality of storage roots. Kitinoja (1987) indicated that during curing and storage the concentration of ethylene and other gases could affect the storage quality of stored roots.

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7 Research Output

Based on the data obtained from this thesis, the following papers have been published, under review or yet to be submitted to a journal.

I. **Atuna, R. A**., Amagloh, F. K., Carey, E. E., & Low, J. W. (2017). Sensory quality of orange-fleshed sweetpotato cultivars as affected by curing and household-level storage methods. *African Journal of Food Science, 11*(1), 18-23.

II. **Atuna, A. R.,** Carey, E. E., Low, J. W., & Amagloh, F. K. (2017). Wound healing and dry matter content of orange-fleshed sweetpotato cultivars as influenced by curing methods *Open Agriculture* (Vol. 2, pp. 274-279).

III. Shelf life extension of sweetpotato roots using household-level storage methods. Submitted in International Journal of Post-harvest Technology and Innovation (Manuscript, ID: IJPTI-131019, accepted for publication)

IV. Shelf life extension and sensory properties of orange-fleshed sweetpotato using pre- and post-harvest techniques. Under review as chapter contribution to a new book titled: Root and Tubers in Ghana: The State-of-the Art.

V. Changes in β-carotene, dry matter, sugar and starch content of two orange-fleshed sweetpotato cultivars with curing and household-level storage methods. To be submitted to the Journal of Agricultural Science

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9 Appendices

9.1 Appendix A: Consumer preference testing ballot sheet

Evaluation Sheet-Consumer Preference Testing

Sex: Male ☐ Female ☐ **Age:** __________ Date: …………

Community: ________________ Name of enumerator: ………………………

Please give an appreciation on the attributes for each of sample presented (list the samples) using a scale from 1 to 5 below:

1: "Dislike extremely"; **2**: "Dislike"; **3**: "Neither like nor dislike"; **4**: "Like"; **5**: "Like extremely"

Rinse mouth with water after tasting each sample

	Boiled sweetpotato roots							
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Attributes								
General appearance								
Finger-feel firmness								
Sweetness (sugariness)								
Overall acceptability								

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