EFFECT OF STORAGE ON THE PHYSICO-CHEMICAL CHARACTERISTICS AND ACCEPTABILITY OF FRESH CASSAVA (*Manihot esculenta Crantz*) ROOTS

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DECLARATION

I declare that this thesis is my original work and has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

____________________ Date 22/08/2011

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This thesis has been submitted for an examination with our approval as supervisors.

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DEDICATION

I wish to sincerely dedicate this project work to my husband. George and our children for all the moral and material support.

I also cannot forget the great support and encouragement both from my Dad, Mr. Samuel Kamano and Mum, Mary Nyambura without which I would not have reached where I am today. Above all I want to thank God for His grace without which I would not have completed this work.

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ABSTRACT

Cassava roots are highly perishable and some varieties can start showing symptoms of deterioration within 24 hours after harvest. Due to this short "green life", it is therefore difficult to maintain the quality of fresh cassava to await transportation, preparation for consumption or even processing to acceptable products. This study was designed to assess the shelf life of freshly harvested cassava at room temperature and under refrigeration temperature.

The physical-chemical characteristics and acceptability of fresh cassava *(Manihot esculenta crantz)* was determined after storage. Three popular cassava varieties (Muchericheri, Ex-Ndolo and KME 1) were obtained from KARI research station in Embu and transported within 2 hours to the laboratories of the Department of Food Science, Nutrition and Technology within hours. Each variety of a total of 210 roots was divided into four batches and a batch from each was stored at room temperature (23 ± 3°C), 2°C, 4°C and 6°C. Each batch in storage was analyzed initially and thereafter after every 3 days for dry matter, visible browning, invisible browning, total sugars, texture, visual discolouration and sensory acceptability. Data was analyzed using SAS version 6.0 and means separated using the Duncan Multiple test range.

All cassava varieties stored at room temperature retained freshness for two days only. During storage at 2°C, 4°C and 6°C, the cassava varieties manifested different shelf lives depending on the variety. Muchericheri stored for 6 days at 2°C, for 9 days at 4°C and 6 days at 6°C. Ex-Ndolo stored for 12 days at 2°C, for 6 days at 4°C and 6 days at 6°C. Finally KME 1 stored for 9 days at 2°C, for 6 days at 4°C and 9 days at 6°C. Contrary to expectations, not all varieties stored best at 2°C. Muchericheri stored best at 4°C and KME 1 stored equally well at 2°C and 6°C. Only Ex-Ndolo stored best at 2°C. Results showed that fresh cassava can be stored at ambient temperature for a maximum of 2 days, at 2°C for a maximum of 12 days, at 4°C for a maximum of 9 days and at 6°C for a maximum of 9 days without significantly losing its eating quality.

The study concluded that retention of freshness by cassava during storage depended on variety and temperature of storage.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Cassava (*Manihot esculenta Crantz*) or (*Manihot carthaginensis*) belongs to the family Euphorbiaceae and is grown almost entirely within the tropics where its large tuberous roots serve as a major source of dietary energy in many countries. Cassava is also known by other common names: manioc, manihot and yucca. Cassava originated in Latin America and was later introduced into Asia and Africa (FSANZ) (Aalbersberg and Limalevu, 1991). In recent years it has become the most widely cultivated tropical root crop (Aalbersberg and Limalevu, 1991) and is one of the most important sources of food in sub-Saharan Africa. According to FAO statistics (FAO, 1987) as reported by DeBruijn and Fresco (1989) cassava ranks fourth after rice, wheat and maize as the major food crop in developing countries on the basis of energy production. It has an annual worldwide production of about 130 million tons cropped in a total net area of 14 million hectares distributed in over 80 tropical countries.

Cassava grows well in tropical climate and is eaten in Africa, Pacific Island Countries, South America and regions of Asia including Indonesia (Knudsen et al 2005). It is consumed in a number of forms: flour, root slices, grated root (baked, steamed and pan fried), steamed whole root and tapioca pearls made as a pudding (Knudsen *et al,* 2005). Processed cassava is one of the major staple foods consumed by the population of the Democratic Republic of Congo (DRC) and may provide more than 60% of the daily energy requirements (Ngudi et al 2002).

In Kenya, cassava is an important food crop and especially in the Coast and Western provinces of the country. Kenya produced 540,000 mt of cassava in 1997, of which 60% came from Western Kenya (Kamau and Ndolo, 1997). In

1999 Kenya produced an estimated 910,000 mt from an estimated area of 98,000 ha (FAOSTAT Web2000) (see Fig 1). The Coastal and Central regions produced 30% and 10% respectively. The main cassava growing areas are: Migori, Suba, Siaya, Busia, and Teso in Western Kenya and Kilifi, Kwale and Malindi in the coastal region. In Central and Eastern province, cassava is an important crop in Machakos, Makueni, Mwingi, Embu, and North Meru districts. A number of varieties are cultivated including sweet and bitter varieties.

Cassava is largely grown for home consumption but the surplus is sold in local markets or at home for income. Small holders dominate the production of the crop. Cassava is rarely grown as a mono-crop in Kenya, but instead is intercropped with maize, beans, peas and other food crops. Cassava plays an important role in the food security of the country as well as generation of income among the farming communities.

Results from a field survey (Kamau and Ndolo, 1997) indicate an increase in the importance of cassava in household diets and source of income for Central Kenya. For example, whereas it previously believed that only cassava tubers were used for human consumption in the central region, it emerged that the leaves were being used as vegetable. Cassava is also increasing being used in animal feeds formulation in the region. Most of the farmers interviewed in a recent survey in the central region indicated that they sourced planting material from other farmers. This is an indication that farmers who previously were not growing cassava are now gaining interest in the crop. A large number also sourced cassava planting material from extension staff more than in any other region in the country. This implies there is a potential niche to promote cassava in this region.

Cassava is seen as a potential crop for addressing food security problems because it can do well in most environmentally stressed areas where most other crops cannot. It survives in poor soils, areas with little and erratic rains and withstands poor management. Although maize is the preferred staple food for majority of Kenyans, its production in the last three years has been less than what the country requires for food self sufficiency. A good proportion of the less than optimal performance can be attributed to changing weather patterns in the country. Less rainfall than is normal has been experienced in most parts of the country. If more emphasis was placed on cassava and other drought and poor soils tolerant crops, Kenya cannot experience food deficit.

Cassava is one of the most reliable crops that can be grown under adverse growth conditions that are often unsuitable for other crop production. The production advantages of cassava are, however, partly offset by the rapid deterioration of the roots, which can begin as quickly as 24 hours after harvest. (FAO journal, 1998) Most varieties of cassava deteriorate within three to four days of harvest. This rapid deterioration is due to physiological processes which are initiated at sites of mechanical damage. Physiological deterioration of cassava roots can lead to substantial quantitative and qualitative post-harvest losses causing high production and market risks. The short shelf-life of cassava has played a major role in the evolution of cultural and post-harvest management practices.

In many regions cassava is moving rapidly from being a subsistence crop to becoming an income-generating crop. Marketing problems are becoming exacerbated as increasing urbanization is placing both distance and time between producers and consumers. Processing of cassava is important for extending the versatility and economic viability of the crop. A continuous supply of roots is needed for efficient processing operations, especially in regions where the trend is towards larger cooperative or commercial units. Physiological deterioration places serious constraints on the crop's suitability for modern production, processing and marketing practices and consequently has an impact on all levels of income generation.

Cassava roots that exhibit visible symptoms of physiological deterioration are considered to have poor eating and processing quality. Although no survey work has been undertaken on this topic, the following observations have been made regarding cassava that has developed physiological deterioration (Rickard, Wheatley and Gilling, 1992; C.C. Wheatley, 1992):

It takes longer to cook, has an unpleasant bitter flavour and an unattractive off colour; *fufu* processed in Ghana from deteriorating roots has a lower and less desirable elasticity than *fufu* prepared from fresh roots; cooked roots are difficult to pound; *gari* processed from deteriorating roots has lower and less desirable swelling properties than *gari* produced from fresh roots.

Avoidance of rapid post-harvest deterioration and reduction of cyanide levels are traditionally the main reasons for processing cassava into different food products. As almost every cassava-growing region in the world has developed its own traditional products there are a large number of foodstuffs based on cassava. Results of the COSCA Phase I survey in Africa show that sweet cassava varieties and non-bitter varieties are more commonly grown and used for processing (NRI, 1992).

Traditional technologies are well adapted to processing cassava into a number of final products characterized by extended shelf-life (Miche, 1984). Traditional processing methods are often very time-consuming and laborious; this is especially the case in Africa where the roots are processed into local products such as *gari*.

Cassava starch is produced for both human consumption and industrial use. In Latin America the cassava starch industry is reported to experience several limitations, including low availability of fresh roots, lack of capital, difficult access to credit, poor management and poor starch extraction efficiency (Chuzel, 1991).

The sedimentation of starch from deteriorating cassava is considered by processors in Latin America to be less efficient than from fresh roots. These observations have not been substantiated by reported technical studies but recent results from CIAT (F. Alverez, 1987) have shown that starch extraction rates were significantly affected by post-harvest deterioration. The possible influence of deterioration on starch production is of importance considering the significant role of starch in the cassava economy of a country such as Indonesia. In 1978 about one-third of all the cassava utilized in Indonesia went into starch production (CIAT, 1987).

Fresh cassava roots are traditionally marketed without post-harvest treatment or protection and therefore have to reach the consumer within a very short time before deterioration becomes visible (Janssen and Wheatley, 1985). A close integration of producer, intermediary, wholesaler, retailer and consumer becomes necessary to guarantee the rapid transfer of the produce from producer to consumer. This highly integrated marketing channel serves to prevent traders from being left with unsold, perishable produce. The result is a reverse marketing integration assuring the flow of information between consumers and producers. Often, traders arrange purchase and sale of their produce in advance to minimize their risk. Cassava is also frequently purchased in the ground and traders supply their own labour to harvest the crop when required.

1.2 PROBLEM STATEMENT

Rapid deterioration of cassava tubers after harvest is the crop's biggest post-harvest processing challenge. The roots cannot be left fresh and remain fit for human consumption for more than three days (Hahn, 1989; Oyewole and Aibor, 1992). The traditional "preservation" technique, in which the tubers are left in the ground until when required for use, has the disadvantage that a large portion of the land is occupied by the mature crop and is unavailable for other farming activities. Furthermore the tubers increase in size, become fibrous and woody accompanied by a decline in the starch content (Onyango, 2001).

1.3 JUSTIFICATION OF THE STUDY

The high perishability of cassava tubers which have a natural storage life of only about 2-3 days after uprooting, their low protein content, 1-3% and the presence of toxic cyanogenic glucosides, linamarin and lotaustralin, have been indicated by several workers as the major factors which limit utilization of the root crop for human food (Nartey, 1968; Cooke and Coursey 1981; Rickard 1985). Fortunately these factors can be overcome by processing (Hahn, 1989; Oyewole and Aibor, 1992).

The high perishability of fresh cassava roots can be overcome by processing into shelf stable products and the tubers are traditionally processed by a variety of methods into various products (Cooke and Coursey, 1981; Sefa-Dedeh, 1989; Dosoo and Amoa-Awua, 1992). Cassava tubers can be detoxified and shelf life lengthened by processing and this has been extensively reported in literature (Coursey, 1973; Nartey, 1978; Vasconcelos *et al.* 1990; O'Brien *et al*, 1992; Muzanila 1993). However, little attempt has been made to assess the storability of the roots

This project was aimed at understanding the effect of storage temperature on the shelf life of fresh cassava roots. Three cassava varieties (Muchericheri, Ex-ndolo and KME 1) were stored under ambient conditions. 2°C, 4°C and 6°C and changes observed after every three days. Varietal differences were also noted as far as responses to the different treatments were concerned.

1.4 OBJECTIVES OF THE STUDY

The project will aim at achieving the following main and specific objectives

1.4.1 Main Objective

To assess the effect of storage temperature on the physico-chemical composition and overall acceptability of fresh cassava roots

1.4.2 Specific Objectives

1. To determine the effect of storage temperature on moisture and dry matter contents
2. To assess the effect of storage on visible and invisible browning of the roots
3. To assess the effect of storage on the sugar contents.
4. To determine the effect of storage on texture of the roots
5. To determine the sensory acceptance of the cassava roots during storage

CHAPTER TWO: LITERATURE REVIEW

2.1 IMPORTANCE OF CASSAVA AS FOOD

Cassava can grow in marginal lands, requires low inputs and is tolerant to drought and pests (Githunguri *et al.*, 1998; Nweke *et al.*, 2002). Despite its great potential as a food security and income generation crop among rural poor in marginal lands, its utilization remains low in Kenya. The potential to increase cassava products utilization is enormous if the available recipe range can be increased (Githunguri, 1995). The International Institute of Tropical Agriculture (IITA) has officially recognized cassava as a new cash commodity, which will help raise foreign exchange and a vital food source throughout Africa. The Amsterdam-based Common Fund for Commodities has also recognized cassava as an internationally tradable commodity. In addition, the Intergovernmental Group on Grains also adopted cassava as a commodity hence expanding its market niche.

The importance of cassava in the world food supply is due to its durability as a plant and also due to its cheap and excellent source of dietary carbohydrate. The drought tolerant cassava often referred to as an excellent famine reserve crop, is undemanding as a crop and able to grow under a variety of climatic and soil conditions including low fertility and high acidity. Once established, it has no critical period when lack of rain causes crop failure and is well adapted to marginal soils on which other crops suffer. It is high yielding, has high return of food per unit of energy input and its harvesting which is flexible can be staggered for up to 3 years. Cassava is also resistant to locust attack (Cooke and Coursey 1981; Cock 1985; Kwatia 1986; De Bruijn and Fresco, 1989). The drought-tolerance of cassava gives it a special advantage as a food crop in an era where persistent drought has taken a toll on food production in several parts of Africa.

2.2 CHEMICAL COMPOSITION OF FRESH CASSAVA TUBERS

2.2.1 Proximate Composition

Cassava roots are considered to be of low nutritional value primarily because of their low protein content, at 1-3%. The roots are therefore disparaged as undesirable food that contains little besides carbohydrate, but Cock (1985) has argued that calories are of paramount nutritional shortage in developing countries. Cassava roots nevertheless are excellent sources of carbohydrate and also rich in calcium, phosphorous, potassium, thiamin, riboflavin and niacin (Table 1). Even though the main value of cassava are the starchy roots, the edible leaves contain about 7% protein and are rich in minerals, vitamins and all essential amino acids except methionine and phenylalanine (Cock, 1985). This value is exploited to advantage in the consumption of the leaves as vegetables. Cassava is also poor in some micro-nutrients especially fat soluble vitamins (A, D, E and K). However, cassava is a good source of vitamin C, but is destroyed during processing as it is heat labile. It is also rich in calcium. Table 1 below compares the composition of four different samples of fresh cassava.

Table 1: Composition of four different cultivars of fresh cassava roots

ITEM	UNIT	COMPOSITION OF CASSAVA ROOTS PER 1000g EDIBLE PORTION			
		1	2	3	4
Food energy	MJ	5.48	6.2	5.48	6.03
Water	G	600	625	647	620
Carbohydrate	G	320	347	327	350
Protein	G	7	12	11	7
Fat	G	Trace	3	3	0
Calcium	Mg	250	330	330	250
Phosphorous	Mg	-	-	530	500
Iron	Mg	10	7	8	5
Vitamin A	IU	0	Trace	Trace	-
Thiamine B1	Mg	0.2	0.6	0.7	0.2
Riboflavin B2	Mg	1	0.3	0.3	0.7
Niacin	Mg	-	6	6	6
Vitamin C	Mg	300	360	400	300

Jones, 2001

2.3 CASSAVA PRODUCTION IN KENYA

In Kenya cassava is grown under smallholder system and mainly for household food security and to some extent for income generation. It is mainly intercropped with maize, beans, and cowpeas depending on the region. Field survey results (Kamau and Ndolo, 1997) indicated that 24.7% grew cassava as a mono-crop. As a food crop cassava is the staple food among some communities in the coast region especially in Kwale, in Western Kenya it is ranked second to maize as main food crop. FAO statistics show that cassava provides 90 calories per capita per day in Kenya, while maize, which is the main staple food, provides about 800 calories per capita per day.

The main processed products from cassava in Kenya are; cassava crisps, dried chips, flour, and starch. Most of the processing is done at household level or at the micro/cottage level. Processing of cassava for commercial purposes in Kenya is still at infant stage. There is only one main cassava processor in the country. This processor specializes in cassava flour and starch. Processing technologies are labour/ manual intensive and require enormous investment in labour time. Current processing involves peeling, chipping, drying, flour milling, crisps or chips making.

Table 2

Projections for Cassava Production in the Year 2020

	1993	Projected Output in 2020	
	Production 000,000t	Baseline 000,000t	High Growth 000,000t
SSA	88.06	168.54	184.04
SE Asia	42.35	47.95	48.30
LAC	30.51	42.93	50.49
TOTAL	160.92	259.42	282.83

Source: Source, G.,J.M.W. Rosegrant and C. Ringler. Roots and tubers for the 21[st] Century. Trends, Projections and policy for Developing countries. IFPRIF Food, Agriculture and the Environment Discussion Paper. A co-publication of International Food Research Institute (IFPR) and CIP, Washington, D.C. In press.

2.4 POST-HARVEST DETERIORATION OF CASSAVA

The high perishability of the cassava tuber is due to rapid physiological deterioration which occurs within 2-3 days after harvest. This is observed as a discolouration of the vascular tissues and storage parenchyma accompanied by biochemical changes including changes in amounts and composition of membrane lipids, increase in phenylalanine, ethylene production, peroxidase and phenol oxidase activity and accumulation of phenolic compounds and ammonia lyase (Beeching et al, 1994). Physiological deterioration is followed within 5-7 days by microbial deterioration and root tissue softening.

2.4.1 Physiological Deterioration of Cassava: Biochemistry of Processes Involved

The rapid development of primary or physiological deterioration in cassava has been strongly associated with mechanical damage which occurs during harvesting and handling operations (Booth, 1976). Frequently, the tips are broken off as the roots pulled from the ground and severance from the plant necessarily creates a further wound. In addition, transport from the field to the markets can result in further abrasion. In most cases, physiological deterioration develops from the sites of tissue damage and is initially observed as a blue-black discolouration of the vascular tissue which is often referred to as vascular streaking. Initial symptoms are rapidly followed by a more general discolouration of the storage parenchyma.

In most plants, tissue damage results in a cascade of wound responses (Bowles, 1990) that quickly result in the defence of the wounded tissue and the subsequent sealing of exposed tissue by regeneration of a protective barrier (periderm formation). Common wound responses directly involved in defence include lytic enzymes (glucanase and chitinase), protease inhibitor proteins and hdroxyproline-rich glycoproteins production. Enzymes associated with the phenylpropanoid pathway, such as phenylalanine ammonia –lyase and chalcone synthase, lead to biosynthesis of phenolics which may act directly as defence compounds (quinines, phytoalexins) or can form polymers, such as lignin, that render cell walls more resistant to water loss and attack from microbial enzymes.

2.4.2 Control of Post-harvest Physiological Damage

In a study by Makokha and Tunje (July, 2000) on traditional utilization and processing of cassava in Kenya, it is reported that in both Western and Eastern provinces, the processing and utilization of cassava products is mainly done at the subsistence levels. The major products are Ugali in Western Kenya, while in Eastern province it is eaten as ugali, mashed cassava, boiled cassava and roasted cassava. The predominant form of processing in Western Kenya is heap fermentation of peeled cassava which are then dried. Flour is then ground from the dried cassava.

There are three levels of cassava processing in Kenya; home based processing, cottage/micro processing and medium-large scale processing. In coastal Kenya all the three levels of processing exist. Home processing is for both home consumed products as well as production of products for sell to micro and medium scale processors based in main urban centers. In the coastal region Cottage/micro processors sell their products direct to consumers or to retailers. There is no known wholesale business of processed cassava. Cottage processing is either home based or done in the urban areas. The main products from the cottage/ home based processing are: Composite flour, dried chips, roasted peeled or unpeeled cassava, fermented chips, cassava chops/slices fed to animals., chips (fried/ or roasted) and crisps.

The only notable effort towards industrial processing of cassava in Kenya was made in 1977 when a company known as Tapioca Ltd (based in Mazeras, Mombasa) was established. This factory can be said to be the only one in Kenya that sought to employs modern technology in production of cassava flour, starch and glue. This factory got its cassava requirements (in form of dried chips) from Kilifi and the neighbouring districts. However, it has since closed down and the plant is no longer operational.

In Western Kenya the main cassava processed products at the cottage/ micro / home are; chips and composite flour (composite-millet/sorghum or maize). It is also used in making of local brews by some sections of the community. There is no medium scale processor of cassava in this region. In Central Kenya only home based processing for home consumption has been recorded. In Nairobi, however some service processing of cassava into flour is done. Some micro companies are also processing cassava composite flour.

Home based processing produces the following products; dried chips and flour. However, processing of cassava in most rural areas of central Kenya is limited as most households eat the cassava in its raw form.

2.4.2.1 Service Processing:

Service processing especially that of milling cassava into flour is very common in Western and Coastal region of Kenya. It is done using normal posho mills. It involves milling of dried cassava chips into flour and then blended with other cereals to form composites.

2.4.2.2 Processing Technology

Kitchen knives are used for peeling, and splitting of cassava tubers into chips before they are sun dried. Once the chips are dry, they can either be taken to local mill for milling into flour or milled using traditional stone or mortar and pestle.

The traditional processing steps for each of the products are summarized below.

- **Dried chips:** peel, dry for a day, slice into strips and then dry again.
- **Crisps:** peel, wash, and slice using a slicer and deep fry. Can also add Masala and salt.
- **Chips**: Peel, wash, make strips, deep fry/ or roast and flavour with lemon and masala.
- **Fermented chips:** Peel, ferment until sour, process to flour and cook or peel, ferment, boil and flavour with coco milk, sugar and cardomoil.

In western Kenya most of the production processes are similar to those found in the coast region, but pounding and flour milling is done more with grinding stone. Chips are fermented before milling unlike in the coast where milling is for dried chips only.

A more practical option would be to process the cassava into fermented or unfermented flour, starch or chips. Cassava processing in Kenya has seriously lagged despite efforts by KIRDI to promote equipment acquired from International Institute of Tropical Agriculture (IITA), Nigeria. Cassava peeling, cleaning and drying are still rural household level activities, though manual and bicycle mounted cassava chippers are increasingly being adopted in Western Kenya. The dried chips are then milled in hammer mills. Cassava chips are sometimes fermented prior to drying and milling. Because fermentation processes involving indigenous ACF are spontaneous, care must be taken to ensure that there is no proliferation of pathogenic and toxigenic micro-organisms in the food. Uncontrolled solid-state heap fermentation may lead to growth of mycotoxigenic fungi. Other traditional methods of cassava processing are boiling, roasting, stewing or frying the root before consumption.

The production of fried cassava crisps is a common feature in the streets of Mombasa. The roots are peeled and sliced into round pieces or finger shaped chips then fried in oil which is then drained out and the chips are packed in polythene bags. The crisps have very low levels of hydrogen cyanide, and this could explain why incidences of cassava poisoning are rare in Coast Province. In contrast, the rest of the country where cassava is sometimes eaten raw, incidences of poisoning and even death is frequently reported.

Post harvest problems such as lack of good processing and storage technologies, compounded by lack of efficient marketing system are also responsible for slow development of the cassava sub-sector (Fig). The policy scenario is also not very clear on the development of the sub-sector. The current policy document merely lumps cassava with other traditional and root crops. The policy says these crops will be promoted for food security.

Reasons why cassava varieties are being abandoned by farmers include late bulking, low yields, weed susceptibility, poor in-ground storability, disease and pest damage, poor processing quality, bad branching habits, high cyanogenic potential, poor cooking quality, low planting materials, better varieties introduced, drought and low leaf yield.

The biggest potential for processed cassava products lies in the cassava flour, starch and chips. These products can find ready market through linkages with other domestic manufacturing companies such as feed mills, food processing companies, textile industry, adhesive industry, pharmaceutical industry and in plywood, and paper making.

Potential for export market especially for cassava chips and starch also does exist. The handicap for exploiting this potential lies in the lack of information on potential supply and demand for these products. Desired qualities for the cassava are also not known.

Lack of awareness of the benefits of cassava flour for human consumption and the cultural and attitude stigma attached to cassava is also another constraint. Cassava products are viewed as inferior just as sorghum and millets flours were viewed a few years ago. The trend for sorghums and millets seems to have been reversed as there is now a big demand for these cereals in milling of baby weaning flours. The demand for the two cereals has increased such that their prices are comparable if not higher than that of maize.

2.5 CURRENT CASSAVA HARVESTING, STORAGE AND PROCESSING TECHNOLOGIES

The technology environment is one of the most limiting factors to cassava development in Kenya but also in other EARRNET countries. Yield levels are the lowest compared to world levels and this caused by limited adoption of improved varieties for various reasons. Harvesting, storage and processing technologies are still rudementally and very laborious making them costly and unattractive.

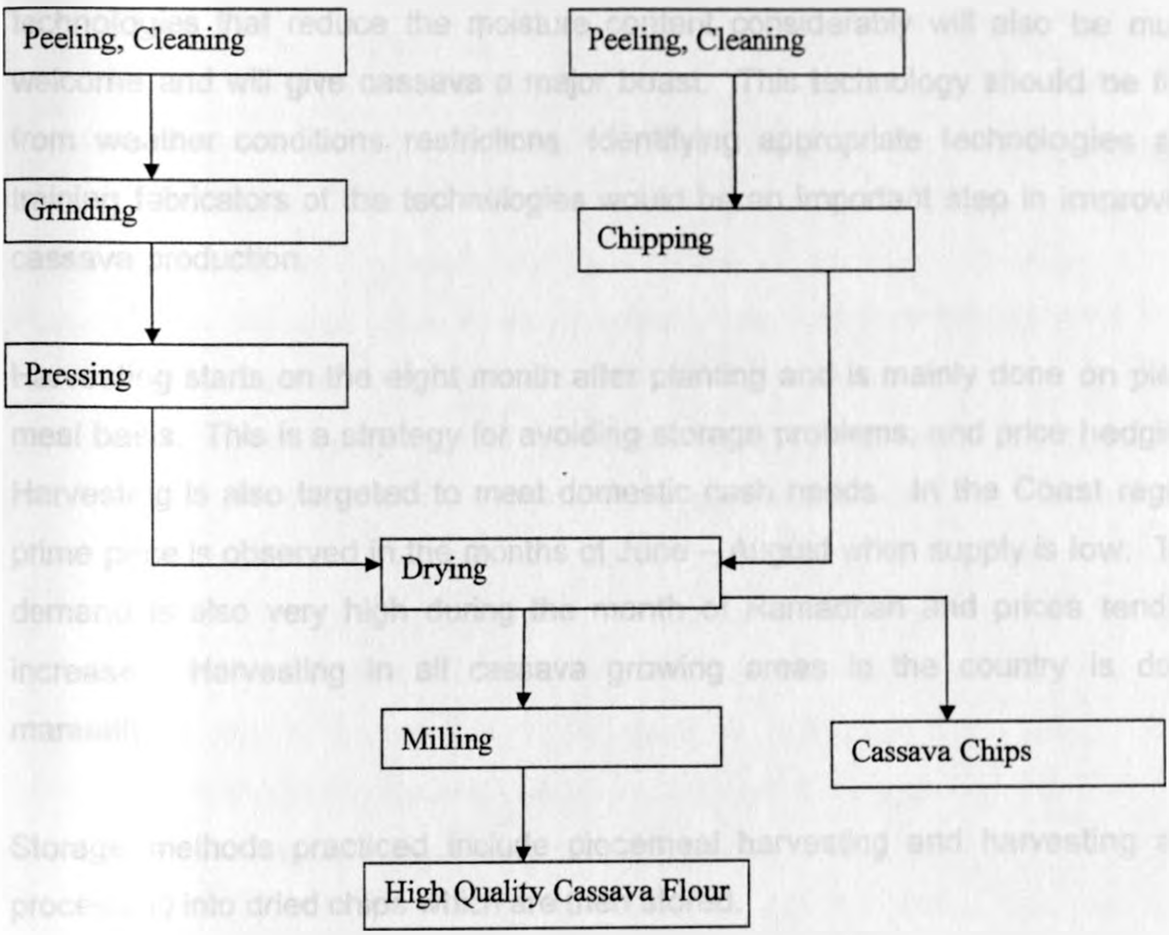
Harvesting should also be done at the appropriate time when the cassava attains maturity so as to maximize on quality. This however cannot be tackled without addressing the twin problems of market and storage. Farmers have been observed to delay harvesting due to lack of market or storage techniques. Research should also be targeted at developing early maturing varieties.

The storage problem is experienced in all the EARRNET countries and special attention needs to be given in identifying appropriate methods. Some of the methods used include; underground storage of the roots. This allows the roots to last up to two weeks.

Peeling and drying of cassava chips is also another method used in cassava storage. The drying part is however impaired if it has to be carried out during the rain season. The gari processing enables one to convert cassava into a formula in which its shelf life is substantially increased. The processing technology is however, prohibitive. In Burundi the machinery excluding the motor is sold for US$1,000. Industrial needs in terms of quality and quantity of cassava should also be researched.

Fig 1

Improved Cassava Processing



Available processing technologies, which are largely traditional, need to be improved. (Fig1). More efficient and less labour and time demanding techniques for processing have to be found if cassava is to compete with cereals. Drying technologies that reduce the moisture content considerably will also be much welcome and will give cassava a major boast. This technology should be free from weather conditions restrictions. Identifying appropriate technologies and training fabricators of the technologies would be an important step in improving cassava production.

Harvesting starts on the eight month after planting and is mainly done on piece meal basis. This is a strategy for avoiding storage problems, and price hedging. Harvesting is also targeted to meet domestic cash needs. In the Coast region prime price is observed in the months of June – August when supply is low. The demand is also very high during the month of Ramadhan and prices tend to increase. Harvesting in all cassava growing areas in the country is done manually.

Storage methods practiced include piecemeal harvesting and harvesting and processing into dried chips which are then stored.

2.6 MAIN CONSTRAINTS TO PROCESSING

Poor processing technologies, e.g. over reliance on sun dried methods which are rendered impossible during the rainy season as the drying process requires a minimum of two days. Most of the techniques used in processing are labour based and therefore putting serious limitations in areas with labour shortages. Manual peeling of the cassava roots is also time consuming and requires a lot of labour input. It is also difficult to ensure quality control. The method also leads to a lot of wastage.

The milling technologies are also not appropriate for cassava chips as they lead to a lot of losses, due to the fine particles of cassava. Processing requires large amount of clean water which may not be available in some areas.

2.7 DETOXIFICATION OF CASSAVA

Cassava processing methods involving different combinations of drying, grating, soaking, boiling and fermentation of whole or fragment tubers have been reported to reduce the total cyanide content of cassava (Coursey 1973). According to Mkpong et al. (1990) generally over 70% of linamarin in fresh cassava is removed during processing. The detoxification of cassava during processing is reported to be due to the activity of linamarase, a b-glucosidase enzyme naturally present in cassava. When cassava tissues are disrupted by grating or mincing, the compartmentally separated linamarase enzyme hydrolyses the cyanogenic glucosides into acetone cyanohydrins and glucose. The acetone cyanohydrin produced further dissociates spontaneously at pHs above 5.0 to yield hydrogen cyanide and acetone (Butler and Conn 1964; Nartey 1968). The hydrogen cyanide produced is removed during processing by either volatilization or solubilization (Mkpong *et al.* 1990, Conn 1969) and unpublished observations reported by Vasconcelos *et al.* (1990). Note that although cyanohydrins hydrolyse non-enzymatically at neutral pHs in cassava, a second enzyme, hydroxynitrile lyase, may also contribute to the dissociation of cyanohydrins into hydrogen cyanide and the corresponding ketone. (Fig 1)

Improved processing hygiene and packaging could improve their shelf life and make them attractive and acceptable in a wider market. Cassava products processing and utilization is done mainly at the subsistence level (Kadere, 2002). At the coastal region, it is men who roast and sell cassava crisps. In both Eastern and Western Kenya, women dominate home-based processing while service processing like milling is male dominated. As processing becomes mechanized.

men tend to play the leading role. The few home-based processors sell their products directly to consumers or retailers. Tapioca Ltd, in Mazeras is the only factory that employs modern technology to produce cassava flour, starch and glue.

Most cassava processing technologies are labour-based facing serious limitations in areas with labour shortages (Mbwika, 2002). Rudimental processing technologies like over reliance on sun-dried methods are rendered impossible during the rainy season. Peeling of cassava roots manually using a knife is time consuming, laborious, difficult to ensure quality and wasteful. The fine particles of cassava flour render current milling technologies wasteful. There is need to identify appropriate storage and processing technologies that are cheap, have low losses, improve shelf life and guarantees quality products. Efforts should be made to involve the food processing industry in making ready to eat cassava products available in supermarkets and retail outlets. Due to the enormous potential demand for cassava by the feeds, pharmaceutical, food, paper printing and brewing industries there is need to involve them in the research and development of this sub-sector.

Peeled tubers can be detoxified by grating followed by sun- or oven drying at temperatures less than 70°C. Grating brings the enzymes in contact with cyanogenic glucosides resulting in generation of hydrogen cyanide that volatilizes at 27°C. Detoxification can also be achieved by fermenting the grated pulp.

Improved processing hygiene and packaging could improve products' shelf life and make them attractive and acceptable in a wider market. Cassava products processing and utilization is done mainly at the subsistence level (Kadere, 2002). At the coastal region, it is men who roast and sell cassava crisps. In both Eastern and Western Kenya, women dominate home-based processing while service processing like milling is male dominated. As processing becomes mechanized, men tend to play the leading role. The few home-based processors sell their products directly to consumers or retailers. Tapioca Ltd, in Mazeras is the only factory that employs modern technology to produce cassava flour, starch and glue.

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2.8 CYANOGENESIS OF CASSAVA

2.8.1 Synthesis of Cyanogenic Glucosides

The toxicity of cassava is due to the presence of the cyanogenic glucosides, linamarin (œ –hyhdroxyisobutyronitrile-ß-D-glucose) and lotaustralin (œ – hyhdroxy-methylbutyronitrile-ß-D-glucose), secondary plant products which upon hydrolysis release hydrogen cyanide (Butler and Conn 1964; Butler et al. 1965; Conn 1969).

Cyanogenesis, the generation and release of cyanide following the rapture of plant tissue and subsequent hydrolysis of cyanogenic glucoside precursors is reported in many plants (Conn E.E 1969; Nartey 1981; Mkpong *et al.* 1990). Cyanogenic glucosides are found in over 2,000 species including important crops like cassava, barley seedlings, sorghum seedlings, rubber tree, almonds and bitter apricot seeds (Brimer *et al.* 1993; Sibbenssen *et al.* 1995). In cassava roots a wide range cyanide levels have been reported in different cultivars, ranging from a few ppm to over 1000 ppm. Grace (1977) reports that concentrations of cyanogenic glucosides in cassava depends upon variety, season, type of soil and other geographical factors. The function of cyanogenesis has been elucidated but Halklier and Moller (1989) suggest that they may act as defense compounds. Belloti and Arias (1993) have demonstrated that the presence of cyanogenic glucosides improves the resistance of cassava tubers to the cassava root borer.

There are a number of varieties of cassava, each of which has varying total HCN levels according to the altitude, geographical location and seasonal and production conditions (Oluwole et al, 2007). In drought conditions there is an increased total HCN content due to water stress (Cardoso et al, 2005). Values from 15-400mg/kg fresh weight of total HCN in cassava roots have been reported in literature (FSANZ, 2004), although there are reports of even higher levels (Oluwole et al, 2007; Cardoso et al, 2005) depending on location of the crops. Sweet varieties of cassava (low total hydrocyanic acid content) will typically contain approximately 15-50mg/kg total HCN on a raw food or 'fresh weight' basis. Sweet varieties of cassava can be processed adequately by peeling and cooking (e.g. roasting, baking or boiling), whereas bitter varieties of cassava (high total HCN content) require more extensive processing, involving techniques such as heap fermentation which take several days (FSANZ, 2004). Samples of processed cassava roots (referred to as 'cossettes') from a range of markets in the DRC were found to have total HCN levels <10mg/kg (Ngudi et al, 2002). Bitter varieties have been reported as not normally being commercially traded (Knudsen et al, 2005); however, due to cassava now being a critical staple crop in a number of countries, it is likely that there is increased trade in varieties of bitter cassava.

The toxicity of ingested cyanogenic glucosides in man are not well understood but Bourdoux *et al.* (1980) postulate that they decompose at the alkaline pH level in the small intestines of man to yield an equal amount of cyanide and cause toxic effects. Toxicity of hydrogen cyanide is indicated by an estimated minimal lethal dose of 0.3 – 0.5 mg/kg body weight (Montegomery 1969). Consumption of cassava with high cyanogenic glucosides content have been associated with a number of cyanide induced disorders including tropical ataxic neuropathy (Osuntokun, 1981), iodine deficiency disorders like goitre and dwarfism (Ermans *et al.*1992), acute toxic effects (Mlingi *et al.* 1992) and the paralytic disease, konzo (Tylleskar *et al.* 1992). According to (Cock.1985) even though the presence of cyanide in cassava presents a drawback to its utilization as food, among millions of consumers worldwide, chronic cyanide toxicity occurs only in certain parts of Africa where it appears to be associated with severely deficient diets combined with under processing.

2.8.2 Factors Affecting the Level of Cyanogenic Glucosides

Several factors influence the level of cyanogenic glucosides in cassava. These include number of leaves, soil conditions, climatic conditions and even drought. During dry spell cassava varieties normally have lower amounts of cyanide as the glucosides are normally synthesized in the leaves.

Biosynthesis of cyanogenic glucosides occurs in the leaves and then they are translocated down to the leaves downwards through the stem to the roots where they accumulate de novo.

In countries like Mozambique, the cassava flour usually comes from plants that have been subjected to two years of drought. Under drought conditions, the cyanogenic content of cassava roots is known to increase due to increased water stress on the cassava plant (Bokanga *et al.*, 1994; Githunguri *et al.*, 1998; Githunguri, 2002). This increased water stress may have caused an increase in the linamarin content of the roots. Serious drought may increase the cyanide intake of individuals, if non-efficient processing techniques are used, to such a degree as to precipitate konzo disease epidemic among consumers as has been observed in Mozambique and parts of Congo (Rosling, 1987). How do we overcome the problem of high cyanide intake levels during drought? Obviously, it is not possible to eliminate the recurrent episodes of drought. Hence, the only possible solution is to reduce the cyanide intake of the populace. Ways to reduce the cyanide intake of the populace include: Improving early warning and food security; encouraging greater use of improved processing methods; improvement of the diet by introduction of other vegetables, pulses and fruits which would help in raising the sulphur containing protein intake, which detoxifies cyanide in the blood system as thiocyanate; and a greater use of low cyanide cassava varieties (Cardoso *et al.*, 1999). It seems as if poor soils and droughts increase toxicity (Cock, 1985; Githunguri, 2002). This is of considerable importance to food security programmes focusing on cassava. The very causes of food shortage i.e. drought and poor soils also increase the toxicity of the cassava grown (Rosling, 1987).

Prevention of toxic effects from cassava consumption should be based on the fact that incidents of cassava toxicity have been reported only when contributing nutritional deficiencies are present and/ or when extraordinary circumstances induce consumption of inadequately processed roots. The nutritional deficiencies are low intake of protein and iodine and the extraordinary circumstances are drought, hunger, war and severe poverty. It must nonetheless be remembered that cassava has saved affected populations in Mozambique and other cassava growing countries like Uganda from starvation under these very circumstances. To advise these populations to reduce cassava cultivation runs counter to common sense (Rosling, 1987).

2.8.3 Poisoning Effects

The consumers' perception of cassava as a toxic crop has contributed significantly to the low consumption of the crop in Kenya. Cassava has toxic cyanogenic glucosides that occur in the cytoplasm. A detoxifying enzyme (linamarase) occurs on the cell wall; and when raw cassava tuber is eaten, the enzyme hydrolyses the cyanogenic glucosides to release toxic hydrogen cyanide.

2.8.3.1 Acute toxicity

When a large amount of hydrogen cyanide is consumed in one meal or over a short period of time, an individual is said to suffer from acute toxicity. An individual may start vomiting and death may occur in 1-2 hours.

2.8.3.2 Chronic toxicity

When small amounts of hydrogen cyanide are consumed over a long period of time, an individual is said to suffer from chronic toxicity. The individual develops goiter, cretinism, mental retardation and neurological disorders.

2.8.4 Cassava Varieties

2.8.4.1 Sweet varieties

This refers cassava varieties that low levels of cyanogenic glucosides. They have less than 50mg/kg HCN on a fresh weight basis. These varieties are very many in Kenya.

2.8.4.2 Biter varieties

This refers cassava varieties that have very high levels of cyanogenic glucosides. The FAO/ WHO codex committee on contaminants in food in a meeting held in Rotterdam, Netherlands 2009 described bitter cassava as follows – "Bitter varieties of cassava as those that contain more than 50mg/kg but less than 200mg/kg HCN (fresh weight basis)".

2.8.5 FAO/WHO Accepted Levels of Cyanogens in Cassava

The Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO) through the Codex Alimentarius Commission has set a recommended safe level of total cyanogens found in cassava roots at 10 ppm (FAO/ WHO, 1991).

The human body, even with low protein intake, is able to detoxify 12.5 mg of cyanide every 24 hours (Rosling, 1994). In a well nourished adult, the body can detoxify about 50 to 100mg of cyanide every 24 hours (Rosling, 1994). In a population where cassava is the main staple food, a basic daily energy need of 1500Kcal can be obtained from consumption of 500gm dry weight of cassava flour. Cassava flour with 25 ppm cyanide may be used to prepare a safe cassava meal. Indonesia has set a safe level for cyanide in cassava at 40ppm (Tivana and Bvochoro, 2005). Since some cyanogens will be lost during preparation of a cassava flour meal, the residual cyanogenic potential values of 19 and 20 ppm (dry weight) obtained by Essers *et al.*, (1995) and Tivana (2005).

In a field survey (in six households in Uganda, it was found that heap fermentation followed by sun drying reduced the cyanogenic potential from 436 to 20 ppm on dry weight basis (Essers *et al.*, 1995). Heap fermentation for four days in three households in Mozambique followed by sun drying reduced the cyanogenic potential of cassava roots from 660 to 19 ppm on dry weight basis (Tivana, 2005). Although heap fermentation is important in reducing total cyanogens in cassava roots, the above levels were still above the World Health Organization (WHO) safe level of 10 ppm (FAO/ WHO, 1991). The removal of cyanogens by heap fermentation has been found to be less effective than those reported above and that initial cyanogenic potential of less than 32 ppm is required for cassava roots, if flour is to reach the WHO safe level of 10 ppm (Tivana and Bvochoro, 2005).

After heap fermentation may be considered safe if the WHO safe level is revised upwards. Reported high cyanogenic potential values, up to 150ppm, of heap fermented cassava flour may have been caused by short cut in the fermentation regime, or results from increased root cyanide levels due to drought or use of high cyanide cultivars (Tivana 2005). Short cuts in processing commonly occur when food supply or the product is for sale. It is important to develop further processing techniques to reduce cyanide such as a combination of grating cassava roots, fermentation and sun drying or soaking of cassava roots in water and sun drying. Grating and crushing of cassava roots are very effective in removing cyanide because of the contact in the wet parenchyma between linamarin and hydrolyzing enzyme, linamarase (Rosling, 1994; Githunguri, 2002).

2.8.6 Awareness Creation

Information on possible acute intoxication must also be included in all forms of cassava promotion programmes, and this problem should thereby be possible to solve or at least control. To try to avoid cassava toxicity by persuading the farmers in these areas to change their staple crops is wishful thinking. New high yielding cassava varieties are an adequate short term solution, as better food security will enable populations to process the roots adequately. Promotion of better processing is a medium term solution, but in the long run, farming systems must be developed to increase productivity and to maintain soil fertility. In this way, a stable dietary situation may be created in which the problems with cassava toxicity can be solved. It should be noted that various methods for determination of cyanogens levels in cassava and its products and its metabolite thiocyanate have been developed (see Fig). One of the simplest methods is the use of simple kits for the determination of the total cyanogens, acetone cyanohydrins and cyanide in cassava roots and cassava products (Egan and Bradbury, 1998; Bradbury *et al*, 1999).

The present state of traditional technology is considered to be inappropriate for women because it is labour intensive, cost effective, strenuous and associated with low productivity. It is therefore imperative to device improved techniques capable of increasing income generating capabilities of rural women and enhancing acceptability of cassava products by a wider consumer clientele. It is necessary to identify constraints facing women employing newly introduced technologies suggested by international institutions. It is also necessary to have a basis for formulating policies guiding the use of appropriate technology and develop programmes that will encourage full utilization of the potentials of Kenyan households in food production, processing and marketing.

Processing of fresh cassava roots would help to increase shelf life, reduce transportation problems and costs and remove cyanogens. It also improves palatability, adds value and extends market especially to medium income urban consumers (Nweke *et al.*, 2002). Whether cassava can be relied upon as a low cost staple food in urban centres and a source of steady real income for rural households will to a larger extent depend on how well it can be processed into safe forms and on how far it can be presented to urban consumers in an attractive form at prices which are competitive to those of cereals.

In some large cassava producing countries like Nigeria, the market for some processed products is highly limited to low income groups, while other forms of cassava e.g. *gari* have a significant market value for middle and high income consumers. How far the market for cassava may be expended would therefore depend largely on the degree to which the quality of the various processed products can be improved to make them attractive to potential consumers without significant increase in processing costs. Cassava processing is therefore an important factor in marketing because an introduction of improved post-harvest handling facilities could lead to a substantial increase in proportion of cassava marketed (Nweke *et al.*, 2002).

Literature review and key stakeholder consultations reveal that there is potential to develop cassava as a food crop as well as a commercial crop if all the limiting factors are identified and addressed. The country's relatively advanced manufacturing sector can provide market for most cassava products. While the increasingly food insecurity situation in the country can be addressed if the crop is given the necessary policy back-up and promoted, through allocation of sufficient resources for research and development.

The primary survey conducted recently indicated that cassava is still an important food crop in the country. The survey involved interviews with 312 randomly selected farmers in Western, Central and Coastal regions of the country. There were also 54 purposively selected processors interviewed across the same regions. The survey findings indicated that cassava is an important food and income generation crop in Kenya. Both cassava tubers and leaves are important for household diets in the country.

Cassava is used mainly for human consumption although 29% of the respondents said they also fed cassava to livestock. In terms of processing, most of the processing of cassava in the country is done at the household level using simple traditional technologies. The most important processed product in the country was flour. Other products included, starch, modified starch and animal feeds. .Cassava utilization is affected by, lack of nutritional information on cassava, narrow range of processed edible products and irregular supplies of cassava products in the market

The East Africa Root crops Research Network (EARRNET) has been promoting cassava in the region through National Research systems. EARRNET's objectives are to; contribute to food sufficiency and socio-economic development and growth by promoting cassava production, utilization and commercialization sectors through developing suitable and acceptable technologies for use by different stakeholders. The research and technology transfer activities can be categorized into the following; research, training, information exchange, and institutional capacity building.

The cassava industry in Kenya is not well studied and most of the available literature relate to EARRNET activities and other institutions whose major focus has been breeding and germplasm development including experimental planting material multiplication and distribution. Available statistics on production and yield levels are more of guess work than reality. The actual production and yields is therefore not well known. Cassava post harvest handling in the country and indeed among many other countries in the region is also a big challenge. Major losses are experienced in storage and processing especially during the rain season. This explains why prices of cassava are usually more than normal during the rainy season.

CHAPTER 3: MATERIALS AND METHODS

3.1 CASSAVA ROOTS

Samples of cassava roots were collected from Kenya Agricultural Research Institute (KARI), Embu station. Cassava tubers were harvested when fully mature and those that were damaged as a result of harvesting or even during transportation were left out. The tubers were handled and transported in a manner that ensured they remained as fresh as possible i.e. After harvesting, they were placed under a shade and then put in fibre bags for transportation on the same day.

Three varieties were used thus: 'Ndolo', 'KME I' and 'Muchericheri'. All the varieties had been in the field for a total of 18 months. 'Muchericheri' is tolerant to the African cassava mosaic, cassava green mites, drought and blight. It is also high yielding per unit area (40 tonnes/ha) and has low cyanide content (below 30mg/ kg). Ndolo and KME I are also drought tolerant but prone to attack by pests. They are also low cyanide varieties.

3.2 PREPARATION OF CASSAVA ROOTS FOR STORAGE TRIALS

The tubers were transported on the same day to the Laboratories of the Department of Food Science and Technology of the University of Nairobi, Upper Kabete campus and stored under ambient conditions, 2°C, 4°C and 6°C.

During storage the following parameters were assessed for all the samples under the different treatments after Day 0, 3, 6, 9, 12 and 15 for: moisture content, browning (visible and invisible), total sugars (%), Texture, physical examination for colour change and sensory evaluation.

3.3 ANALYTICAL METHODS

3.3.1 Determination of Moisture Content

This method is used to determine the percentage of water in a sample by drying the sample to a constant weight. The water content is expressed as the percentage, by weight, of the dry sample.

Apparatus

Drying equipment – An oven, hot plate, field stove or the like suitable for drying samples at a uniform temperature not exceeding 239° F (115° C).

Balance – A balance or scale sensitive to 0.1 percent of the minimum weight of the sample to be weighed and with a capacity equal to the maximum wet weight of the samples to be weighed.

3.3.1.1 Sampling

A representative quantity of the moist sample based on the maximum particle size of the sample should be selected. Quantities for approximate minimum weights are listed in the table below.

Maximum particle size	Minimum Weight of Sample, ounces (grams)
No. 4 (4.75 mm)	4 (100)
¾ in. (19.0 mm)	17 (500)
2 in. (50 mm)	36 (1000)

3.3.1.2 Analysis Procedure

100g Cassava chips of particle size approximately 4mm were weighed and immediately recorded as "wet weight of sample" The sample was dried to a constant weight, at 115° C using an oven and then allowed to cool. The cooled sample was weighed again, and recorded as the "dry weight of sample"

Calculation

The moisture content of the sample was calculated using the following equation:

$$\%W = \frac{A - B}{B} \times 100$$

Where:

%W = Percentage of moisture in the sample,

A = Weight of wet sample (grams), and

B = Weight of dry sample (grams)

3.3.2 Determination of Visible Browning

This type of browning was determined by recording absorbance of extracts at 410nm.

Reagents

50% ethyl alcohol (ethanol): mix 500ml of ethanol and make up to 1L with water

Procedure

20g of cassava chips were weighed in a beaker after which 40 ml of ethanol was then added and the mixture placed in a blender. This was macerated in a blender for approximately 5 minutes until homogeneous. The slurry was filtered into another beaker through Whatman No. 41 filter paper and centrifuged for 10 min at 10,000 rpm. This was done in duplicates and absorbance was then measured at 410 nm.

3.3.3 Determination of Invisible Browning

This determination is carried out in the UV region at 287nm.

Reagents

50% ethyl alcohol (ethanol): mix 500ml of ethanol and make up to 1L with water

Procedure

20g of cassava chips were weighed in a beaker after which 40 ml of ethanol was then added and the mixture placed in a blender. This was macerated in a blender for approximately 5 minutes until homogeneous. The slurry was then filtered into another beaker using Whatman No. 41 filter paper and then centrifuged for 10 min at 10,000 rpm. This was done in duplicates and absorbance was measured at 287 nm

3.3.4 Determination of Total Sugars

Principle

Soluble sugars are extracted with hot aqueous-ethyl alcohol and the sugars on treatment with phenol sulphuric acid, produces a stable sensitive golden yellow colour. This method can be applied to simple sugars, oligosaccharides, polysaccharides and their derivatives.

Equipment: 1. Balance 2. Vortex mixer 3. Hot plate 4. Spectronic 21.

Reagents:

1. 80% ethyl alcohol (ethanol): Mix 800ml of ethanol in water and make up to 1L with water.
2. 5%phenol: Dissolve 5g phenol in water and make up to 100ml with water.
3. 96% sulphuric acid (v/v), (use 96% sulphuric acid, specific gravity 1.84, dilute according to the purity).
4. Glucose (w/v) standard: (Stock = 1000 mg/1000 ml). Dissolve 1000 mg glucose in water and make up to 1L.

5. Working standard: Pipette out 10 ml of stock standard into a 100 ml volumetric flask and make up volume to 100 ml (the final concentration will be 100µg/ml)

Procedure

100 mg of cassava chips were weighed in a boiling tube. 30 ml of hot 80% ethanol was added and shaken in a vortex mixer. The material was then centrifuged for 10 min at 10,000rpm. This was then filtered into a beaker through a Whatman No. 41 filter paper. Steps 2-4 were then repeated for complete extraction of sugars 4 times. The material was evaporated on a hot sand bath until the ethanol had evaporated. 10 ml of water was then added to dissolve the contents and transferred to 100 ml volumetric flasks. The contents of the beaker were rinsed 3 time and added to the volumetric flasks and made up to 100 ml with water. 1 ml aliquot from the above was taken and 1 ml water as blank into a test tube. 5% phenol was added and shaken. 5 ml of 96% sulphuric acid was added and shaken vigorously on a vortex mixer and the tubes cooled in water. Absorbance of the golden yellow colour was read at 490nm against the blank. The standards were ran at different concentrations(i.e. 10, 20, 30, 40 and 50 µg of glucose standard) from the working standard, keeping the volume to 1 ml with water and adding reagents as in steps 9 and 10.

Calculation

% Total soluble sugars =

$$\frac{\text{Conc. of Std } (\mu g)}{\text{Absorbance of Std}} \times \text{Absorbance for 1 ml sample extract} \times \frac{1 \text{ (conversion of g)}}{1{,}000{,}000} \times \frac{100 \text{ ml (vol. made up)}}{0.1 \text{ g (sample wt.)}}$$

X 100 (Percentage)

3.3.5 Texture Measurement

This objective measurement was carried out using a penetrometer (Fig 2). Cassava stored under different storage conditions was also tested for change in texture by use of a penetrometer. The bottom of the device has a probe which is pressed on the sample. This results in a tension of a spring which is indicated by the pointer.

Fig 2: Penetrometer

3.3.6 Physical examination

The cassava was also physically examined to assess the visual discolouration of the tubers as a result of different treatments.

3.3.7 Sensory Evaluation

Cassava tubers were also evaluated for acceptability after cooking. The roots were boiled for 30 minutes until soft. After which they were coded and asked to record their reactions on the provided questionnaire.

3.4 STATISTICAL ANALYSIS

Data was analyzed using the GENSTAT version 10.0 for ANOVA and further analysis was done using Microsoft excel to generate graphs. Means were separated the Duncan Multiple test range version 6.0.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 EFFECT OF TEMPERATURE OF STORAGE ON DRY MATTER

The changes in dry matter contents of the three varieties of cassava during storage are shown in Table 3.

Table 3: Mean Dry matter of Stored Cassava varieties at different temperatures*

VARIETY	TEMPERATURE (^{o}C)			
	Ambient	2	4	6
Ex-Ndolo	41.21	41.21	41.91	41.30
KME 1	31.12	31.17	31.29	32.52
Mucherichéri	39.61	39.89	41.06	42.50

The mean dry matter for Ex-Ndolo was 41.41, for KME 1 was 31.53 and finally 40.77 for Mucherichéri variety. At ambient temperature. the mean dry matter for all the three varieties was was 37.32, 37.42 at 2°C, 38.09 at 4°C and finally 38.77 at 6°C.

TABLE OF ANALYSIS OF VARIANCE OF DRY MATTER

Variate: Dry_matter_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season_1 stratum	1	8.889E-05	8.889E-05	0.01	
Season_1.*Units* stratum					
Variety_1	2	1.467E+03	7.334E+02	1.232E+05	<.001
Temp_1	3	2.462E+01	8.205E+00	1378.42	<.001
Variety_1.Temp_1	6	1.656E+01	2.761E+00	463.74	<.001
Residual	59	3.512E-01	5.953E-03		
Total	71	1.508E+03			

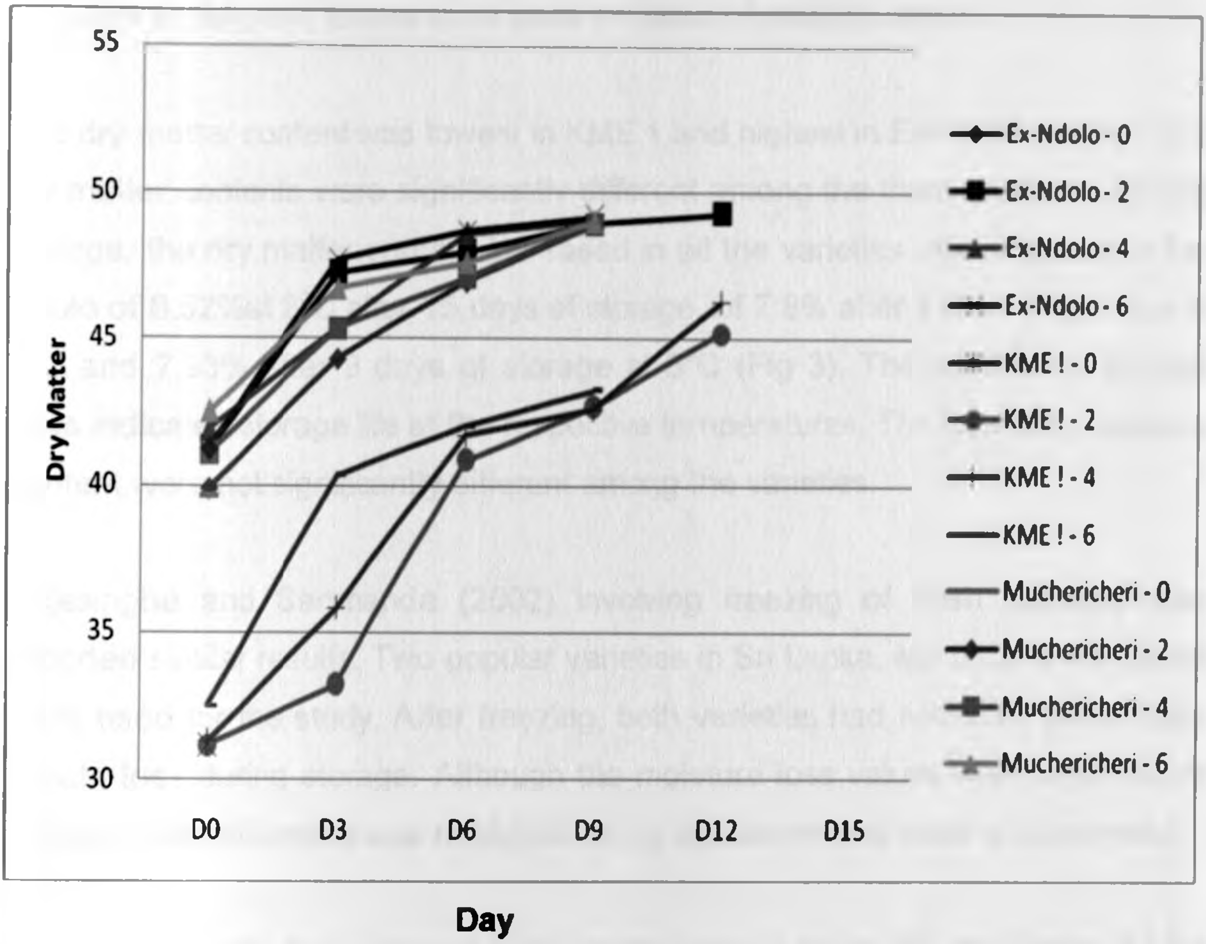

Figure 3: Changes in the dry matter of cassava varieties at different temperatures during storage

The variety being sampled was significant in as far as dry matter was concerned. At the same time, temperature was also significant as well as the interaction between variety and temperature as in the table of analysis above.

The dry matter content was lowest in KME 1 and highest in Ex-Ndolo variety. The dry matter contents were significantly different among the three varieties. During storage, the dry matter content increased in all the varieties with increase in Ex-Ndolo of 8.52%at 2°C after 15 days of storage, of 7.8% after 9 days of storage at 4°C and 7.98% after 9 days of storage at 6°C (Fig 3). The number of storage days indicated storage life at the respective temperatures. The losses in moisture content were not significantly different among the varieties.

Wijesinghe and Sarananda (2002) involving freezing of fresh cassava also reported similar results. Two popular varieties in Sri Lanka, MU 51 and Kirikavadi were used for the study. After freezing, both varieties had minimum percentage weight loss during storage. Although the moisture loss values were significantly different, the difference was negligible as far as commercial scale is concerned.

For Muchericheri, the increases in dry matter were 9.1% at 2°C for 9 days, 9.13% at 4°C for 9 days and 9.17% at 6°C for 9 days. Finally for KME 1, 13.94% at 2°C for 12 days, 15.09% at 4°C for 12 days and 12.05% at 6°C for 9 days. Generally, the losses in water up to the last days of storage life were highest for KME 1 variety, which had the highest initial water content. The final moisture contents, however, did not differ significantly among varieties for all storage temperatures. The loss in water and increase in dry matter was driven by the low relative humidity in the refrigerator which established high vapour pressure deficit between the product and refrigerator environment. This was also seen in the splitting of the roots due to the water stress (Fig 4).

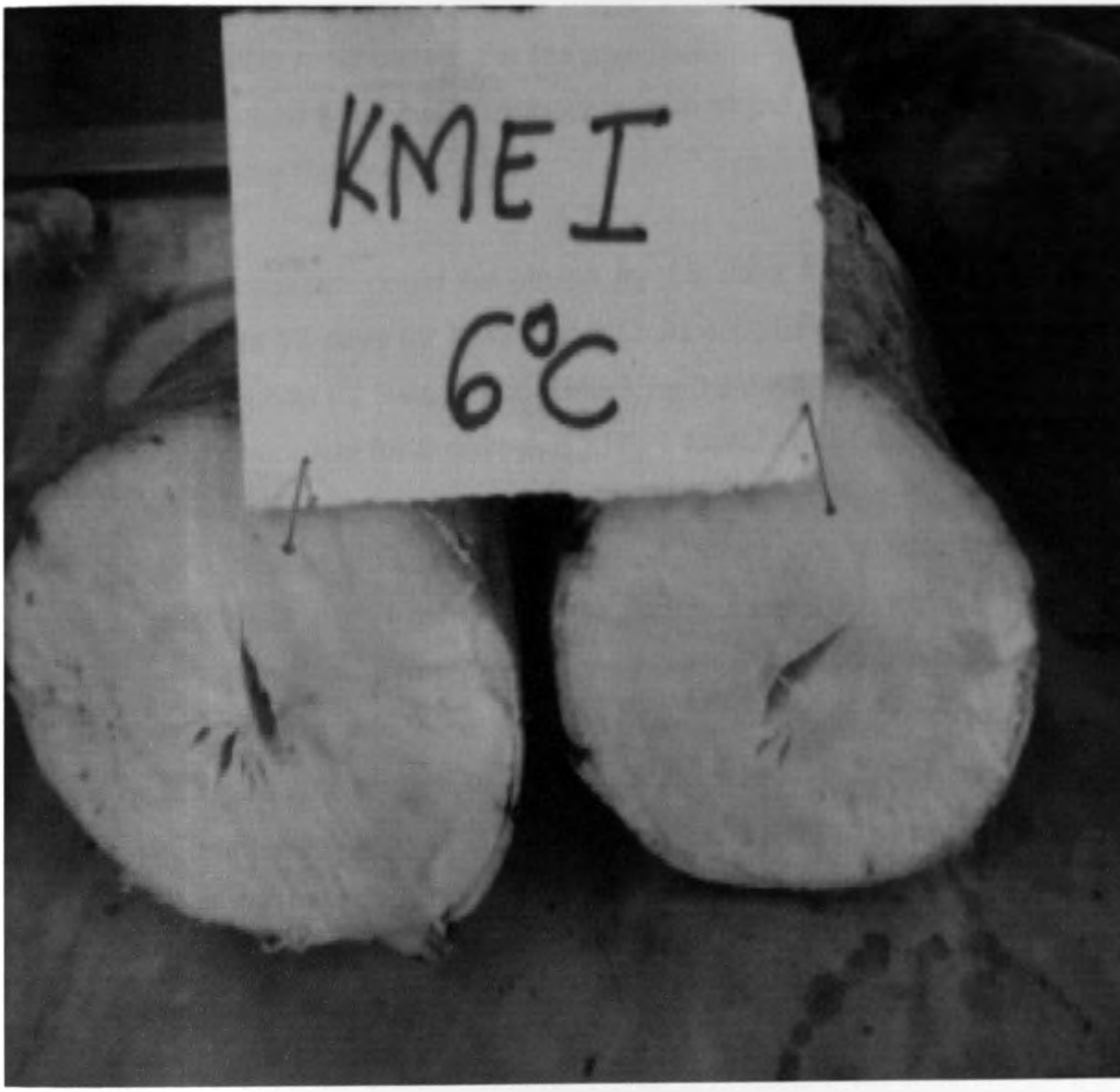

Fig 4: KME 1 variety after six days of storage at 6°C

A study on the changes that occur in cassava during storage by Booth et al (2006) also found increases in the dry matter contents during storage. The study also showed that in most cases, the cassava roots remained of acceptable eating quality over an eight week period although none of the stored roots remained as good as the freshly harvested ones.

In this study, cassava could be stored for 15 days for Ex-Ndolo, 9 days for Muchericheri and 12 days for KME 1 at 2°C. At 4°C, Ex-Ndolo could be store for 9 days, Muchericheri for 9 days and KME 1 for 12 days. At 6°C, Ex-Ndolo stored for 9 days, Muchericheri for 9 days and KME 1 for 12 days (Table 2).

The results indicated that there are varietal differences in storage properties. Other studies have also shown that some varieties can keep for over two months without developing any symptoms of deterioration (N. Morante *et al*, 2008). A study by N. Morante and others in USA which started as a an accident after some cassava roots were left on a shelf for more than two months between the end of 2008 and beginning of 2009, showed that genetic make-up plays a major role. This study involved the use of a cassava clone belonging to a new generation of high-carotene germplasm.

4.2 EFFECT OF STORAGE TEMPERATURE ON VISIBLE BROWNING OF CASSAVA VARIETIES

The change in visible browning of the three varieties of cassava during storage at different storage temperatures is shown in Table 4.

Table 4: Visible Browning (Mean) of Stored Cassava varieties at different temperatures*

VARIETY	TEMPERATURE (°C)			
	Ambient	2	4	6
Ex-Ndolo	0.24	0.21	0.25	0.26
KME 1	0.32	0.33	0.34	0.36
Muchericheri	0.19	0.21	0.22	0.24

The mean visible browning for Ex-Ndolo variety 0.24, 0.33 for KME 1 and lastly 0.21 for Muchericheri variety. The mean visible browning for all the three varieties was 0.25 at ambient conditions, 0.25 at 2°C, 0.27 at 4°C and finally 0.27 at 6°C.

TABLE OF ANALYSIS OF VARIANCE OF VISIBLE BROWNING

Variate: Vsble_brwng_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season_1 stratum	1	0.0033347	0.0033347	7.80	
Season_1.*Units* stratum					
Variety_1	2	0.2158583	0.1079292	252.54	<.001
Temp_1	3	0.0046264	0.0015421	3.61	0.018
Variety_1.Temp_1	6	0.0070528	0.0011755	2.75	0.020
Residual	59	0.0252153	0.0004274		
Total	71	0.2560875			

Variety was significant in as far as visible browning was concerned. This differed from one variety to another. However, Temperature was not significant. There was also no significance in the interaction between temperature and variety.

Visible browning increased with storage time for the different cassava varieties and visible was lowest in Ex-Ndolo and highest in Mucherícheri variety. Visible browning was significantly different for all the three varieties (Fig 5, Fig 6 & Fig 7).

Fig 5: Mucherícheri variety at 2°C after 9 days of storage

Fig 6: KME 1 variety at 2°C after 9 days of storage

Fig 7: Ex-Ndolo variety at 2°C after 9 days of storage

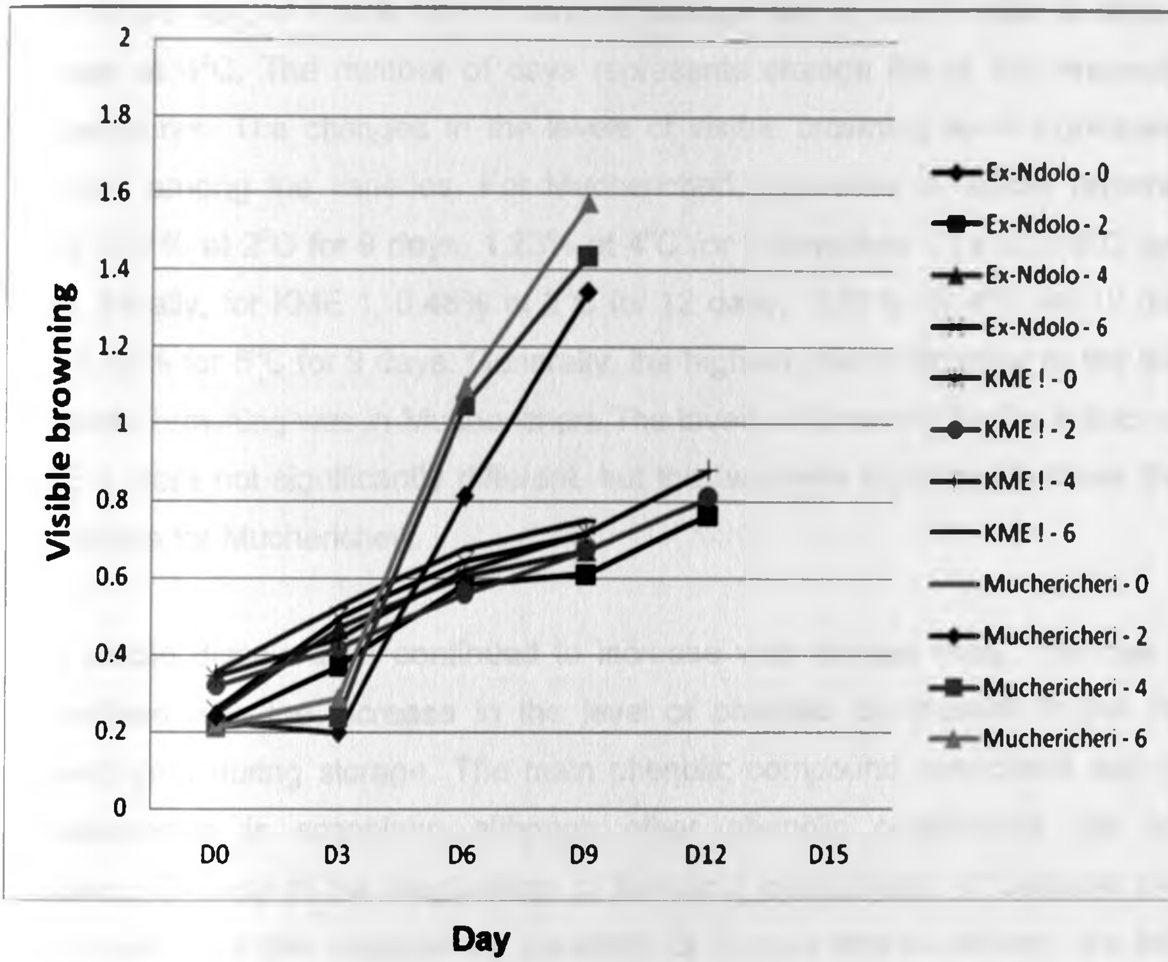

Figure 8: Changes in visible browning of cassava varieties at different temperatures during storage

During storage, visible browning increased in all the varieties (Fig 8) with increase in Ex-Ndolo of 0.43% at 2°C after 15 days of storage, of 0.39% after 12 days of storage, of 0.39% after 9 days of storage and of 0.37% after 6 days of storage at 6°C. The number of days represents storage life at the respective temperatures. The changes in the levels of visible browning were significantly different among the varieties. For Muchericheri, increases in visible browning were 1.37% at 2°C for 9 days, 1.23% at 4°C for 9 days and 1.14% at 6°C for 9 days. Finally, for KME 1, 0.48% at 2°C for 12 days, 0.51% for 4°C for 12 days and 0.36% for 6°C for 9 days. Generally, the highest rate of increase in the level of visible browning was in Muchericheri. The levels of browning for Ex-Ndolo and KME 1 were not significantly different, but the two were significantly lower than the values for Muchericheri.

The visible discoloration continued to increase with storage time. This can be associated with the increase in the level of phenolic compounds in the root parenchyma during storage. The main phenolic compound associated with the discolouration is scopoletin although other phenolic compounds are also involved. A study of the mechanism of the rapid deterioration of cassava roots has shown that this requires the presence of oxygen and scopoletin, the latter acting, apparently, in some autocatalytic fashion (Wheatley *et al.* 1984).This can also be as a result of maillard (non-enzymic) browning pigments which in turn continue to increase with the storage time. This browning renders the cassava unacceptable and results in huge losses. The degree of browning also differed from one variety to another with some browning more than others after the same duration of storage. (Fig 9 and Fig 10)

Fig 9: Muchericheri, KME 1 and Ex-Ndolo varieties on day three at 6°C

Fig 10: Muchericheri, KME 1 and Ex-Ndolo varieties on day nine at 6°C

4.3 EFFECT OF STORAGE TEMPERATURE ON INVISIBLE BROWNING OF CASSAVA VARIETIES

The changes in invisible browning of the three varieties of cassava during storage at different storage temperatures are shown in Table 5. Invisible browning is represents accumulated oxidized substrates in either enzymic and non-enzymic discolouration before their polymerization to form the visible colour of melanoidins. Invisible browning is an indicator for potential for visible browning.

Table 5: Invisible Browning (Mean) of Stored Cassava varieties at different temperatures*

VARIETY	TEMPERATURE (°C)			
	Ambient	2	4	6
Ex-Ndolo	8.47	9.53	10.59	10.66
KME 1	4.76	0.33	0.34	0.36
Mucharicheri	4.83	0.21	0.22	0.24

The mean visible browning for Ex-Ndolo variety 9.81, 5.77 for KME 1 and lastly 5.46 for Muchericheri variety. The mean invisible browning for all the three varieties was 6.68 at ambient conditions, 6.84 at 2°C, 7.35 at 4°C and finally 8.16 at 6°C.

TABLE OF ANALYSIS OF VARIANCE OF INVISIBLE BROWNING

Variate: Invs_Browng_1
Aaqz<

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season_1 stratum	1	0.05611	0.05611	2.84	
Season_1.*Units* stratum					
Variety_1	2	393.56560	196.78280	9950.98	<.001
Temp_1	3	23.94219	7.98073	403.57	<.001
Variety_1.Temp_1	6	15.69159	2.61526	132.25	<.001
Residual	59	1.16674	0.01978		
Total	71	434.42223			

Variety and temperature were highly significant in determining the level of invisible browning. The interaction between variety and temperature was also very significant.

The level of invisible browning was lowest in KME 1 and highest in Muchericheri variety. The level of invisible browning was significantly different among the three varieties. During storage, the level of invisible browning increased in all the varieties with increase in Ex-Ndolo of 2.83% at 2°C after 15 days of storage, of 2.42% after 9 days of storage at 4°C and 2.43% after 9 days of storage at 6°C (Fig 11). The number of days represents storage life at the respective temperatures. The changes in invisible browning were significantly different among the varieties.

For Muchericheri, the increases in the level of invisible browning were 8.64% at 2°C for 9 days, of 9.97% at 4°C for 9 days and of 9.0% at 6°C after 9 days of storage. Finally, for KME 1, 5.10% at 2°C after 12 days of storage, 3.48% at 4°C after 12 days of storage and 3.21% at 6°C after 9 days of storage.

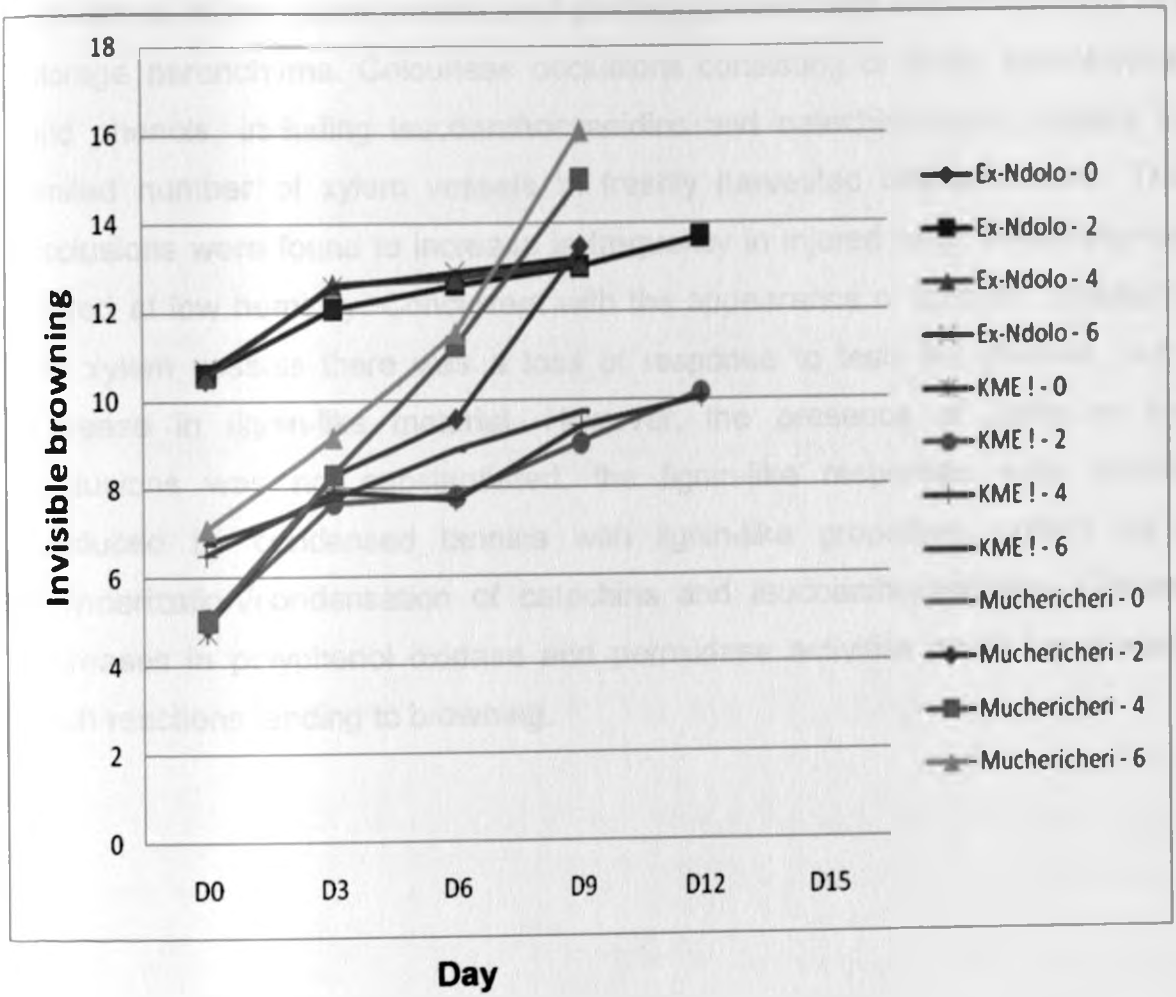

Figure 11: Changes in invisible browning of cassava varieties at different temperatures during storage

A study by Rickard and Gahan (1983) revealed that Cassava roots exposed to physiological stress arising from wounding, respond by forming coloured occlusions in the xylem vessels and producing chemically similar deposits in the storage parenchyma. Colourless occlusions consisting of lipids, carbohydrates and phenols, including leucoanthocyanidins and catechins were present in a limited number of xylem vessels in freshly harvested cassava roots. These occlusions were found to increase in frequency in injured roots especially when stored at low humidity. Concurrent with the appearance of coloured products in the xylem vessels there was a loss of response to tests for phenols, but an increase in lignin-like material. However, the presence of lignin in these occlusions was not substantiated: the lignin-like responses were probably produced by condensed tannins with lignin-like properties formed by the polymerization/condensation of catechins and leucoanthocyanidins. Observed increases in polyphenol oxidase and peroxidase activities could be related to such reactions leading to browning.

4,4 EFFECT OF STORAGE TEMPERATURE ON TOTAL SUGARS OF CASSAVA VARIETIES

The changes in the level of total sugars of the three varieties of cassava during storage are shown in Table 6.

Table 6: Total sugars (Mean) of Stored Cassava varieties at different temperatures*

VARIETY	TEMPERATURE (°C)			
	Ambient	2	4	6
Ex-Ndolo	4.23 (%)	4.27(%)	4.36(%)	4.65(%)
KME 1	3.59(%)	3.75(%)	4.24(%)	4.36(%)
Mucherichermi	2.51(%)	2.61(%)	2.69(%)	3.66(%)

The total mean sugar (%) content for all the varieties was 3.70. The mean total sugars content for Ex-Ndolo variety 4.24; 3.98 for KME 1 and lastly 2.87 for Mucherichermi variety. The mean total sugar content for all the three varieties was 3.46 at ambient conditions, 3.54 at 2°C, 3.69 at 4°C and finally 4.09 at 6°C.

```
TABLE OF ANALYSIS OF VARIANCE FOR TOTAL SUGARS

Variate: Sugar_1

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

Season_1 stratum            1    0.006050    0.006050      4.74

Season_1.*Units* stratum
Variety_1                   2   25.552019   12.776010  10003.78  <.001
Temp_1                      3    4.202717    1.400906   1096.93  <.001
Variety_1.Temp_1            6    3.525525    0.587588    460.09  <.001
Residual                   59    0.075350    0.001277

Total                      71   33.361661
```

As far as the level of total sugars is concerned, variety and temperature were highly significant as well as the interaction between variety and temperature.

The total sugars content was lowest in KME 1 and highest in Ex-Ndolo variety. The total sugars content was significantly different among the three varieties. During storage, the total sugars content increased in all the varieties. This can be attributed to the conversion of starch to sugars during storage. The total sugars increased by 4.02% at 2°C after 15 days of storage, 2.80% at 4°C after 9 days of storage and 2.87% at 6°C after 9 days of storage for Ex-Ndolo variety. The number of days represents storage life at the respective temperatures. The changes in the total sugar levels were not significantly different among the varieties.

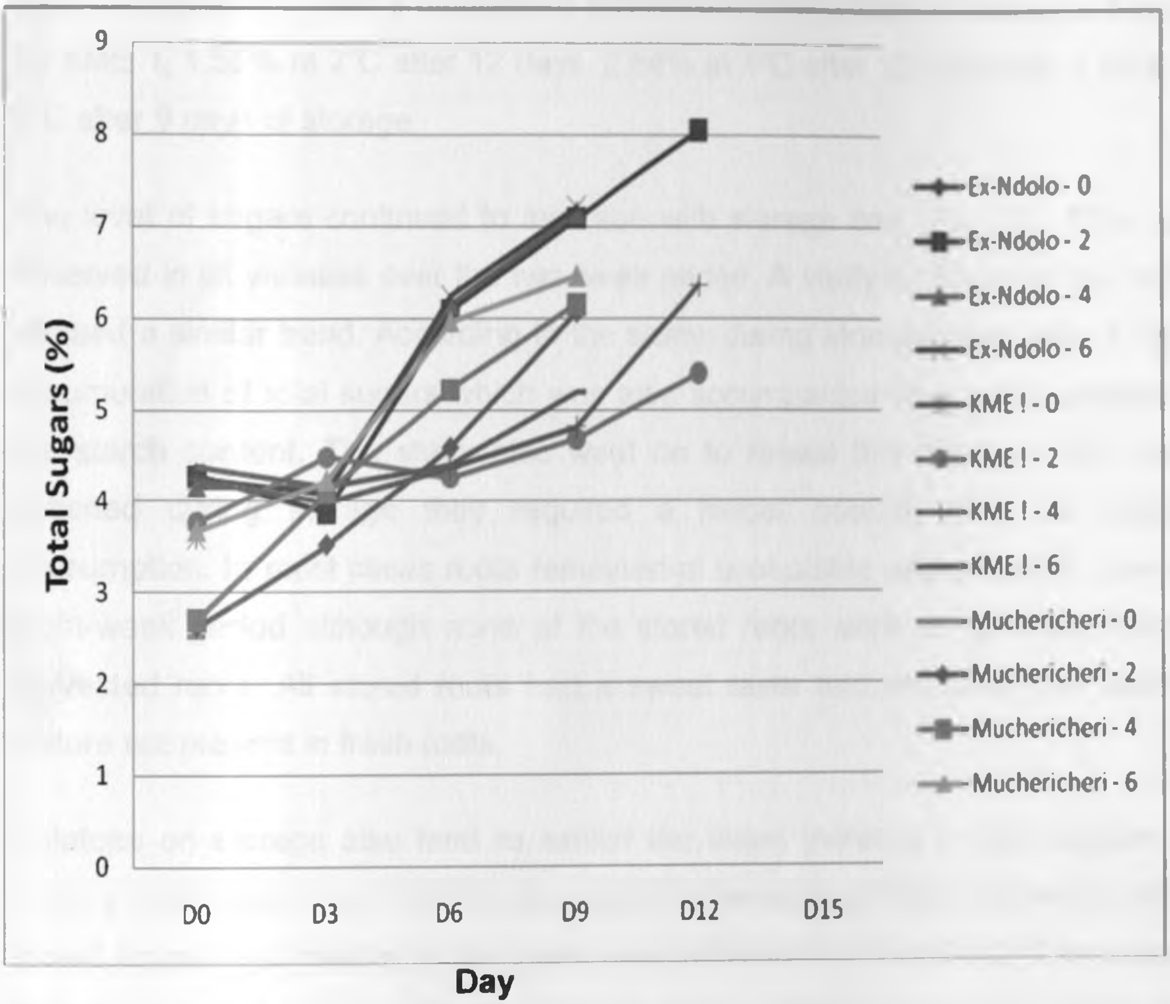

Figure 12: Changes in total sugar levels of cassava varieties during storage at different temperatures

For Muchericheri, the increases in the total sugars were 3.46% at 2°C after 9 days, 3.56% at 4°C after 9 days and 3.80% at 6°C after 9 days of storage. Finally for KME 1, 1.55% at 2°C after 12 days, 2.54% at 4°C after 12 days and 1.39% at 6°C after 9 days of storage.

The level of sugars continued to increase with storage time (Fig 12). This was observed in all varieties over the two week period. A study by Booth *et al* (2006) showed a similar trend. According to the study, during storage there was a rapid accumulation of total sugars which was also accompanied by a small decline in the starch content. The study also went on to reveal that although the roots softened during storage they required a longer cooking time for human consumption. In most cases roots remained of acceptable eating quality over an eight-week period although none of the stored roots were as good as freshly harvested roots. All stored roots had a sweet taste and frequently an uneven texture not present in fresh roots.

Potatoes on storage also tend to exhibit the same increase in total sugars. A study by Hironaka *et al*, (2002) also supports the same. Potato tubers are often stored for several months at temperatures between 4.4°C and 7.2°C to extend their processing season. Since reducing sugar content increases during this storage period, it must be lowered to a more acceptable level in order to produce light coloured French fries or crisps. This is done by storage at elevated temperatures from 15.6°C to 21.1°C, what is commonly referred to as "re-conditioning", which promotes respiration and breakdown of sugars.

4.5 EFFECT OF STORAGE TEMPERATURE ON TEXTURE OF CASSAVA VARIETIES

The change in texture of the three varieties of cassava during storage is shown in Table 7. Texture was measured as hardness in shores using a penetrometer (Fig 4).

Table 7: Mean Texture of Three Cassava Varieties Stored at different Temperatures*

VARIETY	TEMPERATURE (°C)			
	Ambient	2	4	6
Ex-Ndolo	61.53	63.43	63.43	61.30
KME 1	64.51	67.68	66.53	66.20
Muchericheri	58.48	62.26	59.95	59.16

The mean total sugar (%) content for all the varieties was 62.88. The mean total sugars content for Ex-Ndolo variety 62.51; 66.23 for KME 1 and lastly 59.96 for Muchericheri variety. The mean total sugar content for all the three varieties was 61.51 at ambient conditions, 64.46 at 2°C, 63.31 at 4°C and finally 62.22 at 6°C.

TABLE OF ANALYSIS OF VARIANCE FOR TEXTURE

Variate: Texture_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season_1 stratum	1	0.0089	0.0089	0.07	
Season_1.*Units* stratum					
Variety_1	2	478.5433	239.2717	1996.44	<.001
Temp_1	3	89.7739	29.9246	249.69	<.001
Variety_1.Temp_1	6	14.4178	2.4030	20.05	<.001
Residual	59	7.0711	0.1198		
Total	71	589.8150			

Variety and temperature were highly significant to the texture in the respective roots. The interaction between variety and temperature were also highly significant.

Texture was lowest in KME 1 and highest Muchericheri variety. Texture values were significantly different among the three varieties. During storage, texture decreased in all the varieties with a decrease in Ex-Ndolo of 27.0 shores at 2°C after 15 days of storage, of 22.0 shores at 4°C after 9 days and 29.0 shores after 9 days at 6°C (Fig 13). The number of days represents storage life at the respective temperatures. The changes in texture were not significantly different among the varieties.

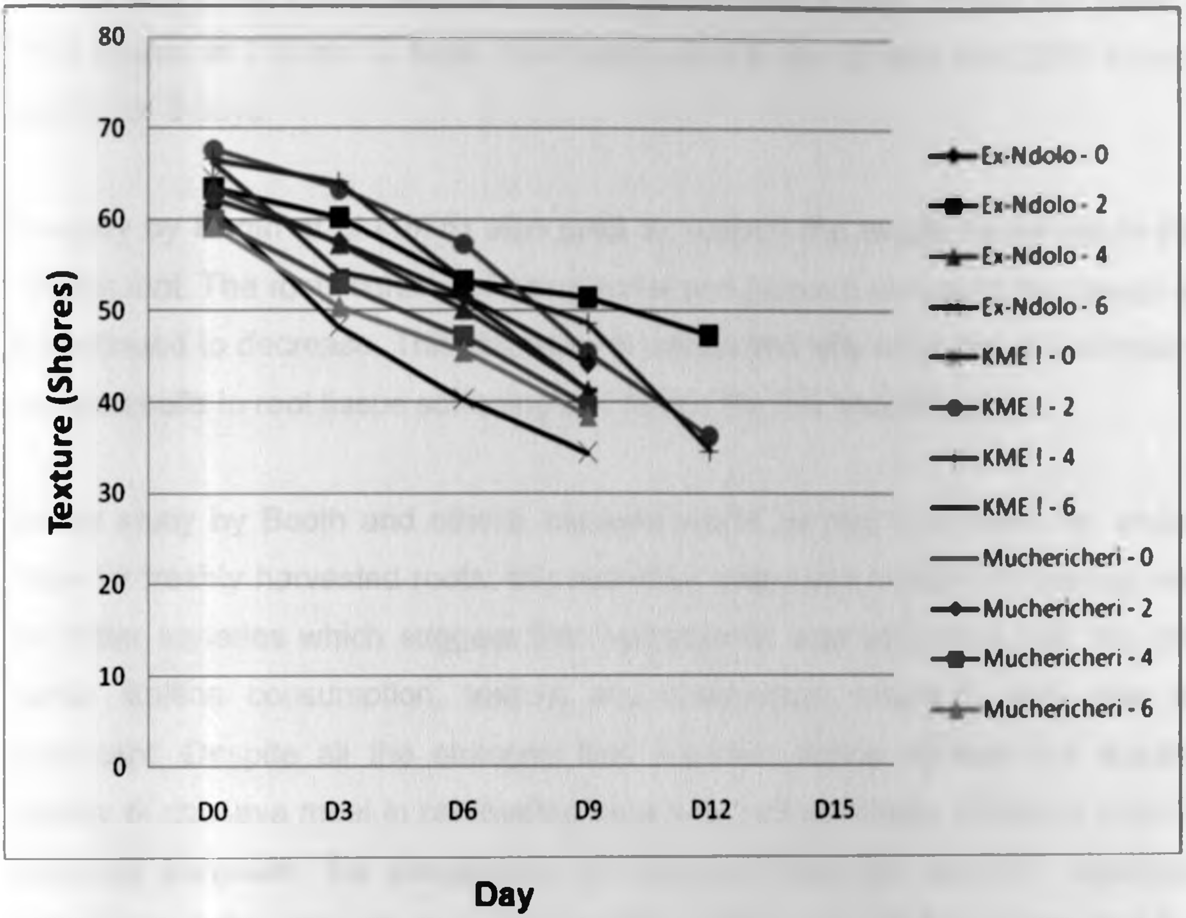

Figure 13: Changes in texture of cassava varieties stored at different temperatures during storage

For Muchericheri, the decrease in texture was 17.6 shores at 2°C for 9 days, 22.5 shores at 4°C for 9 days and 23.5 shores at 6°C after 9 days. Finally for KME 1, 31.0 shores at 2°C for 12 days, 33.0 shores at 4°C for 12 days and 26.0 shores at 6°C for 9 days.

A study by Booth et al (1976) also goes to support the results obtained in this experiment. The roots continued being softer and hence a decline in the levels as it continued to decrease. This decrease is associated with microbial deterioration which results in root tissue softening and hence the low textural values.

In the study by Booth and others, cassava intake by pigs was lower for stored than for freshly harvested roots: this reduction was more marked for sweet than for bitter varieties which suggest that hydrocyanic acid content is not the only factor limiting consumption, texture and organoleptic changes may also be important. Despite all the changes that occurred during storage the feeding quality of cassava meal in rat feeding trials was not noticeably affected, thus for practical purposes the preparation of cassava meal for diets for domestic animals, notably chicken and pigs, might eliminate the limitations observed in texture and eating quality of stored roots.

4.6 EFFECT OF STORAGE TEMPERATURE ON VISUAL DICOLOURATION OF CASSAVA VARIETIES DURING STORAGE

There was no visible discoloration on the roots on day 0 before being placed in the different environmental conditions. Cassava under ambient conditions had developed a considerable degree of browning for all the varieties and hence was unacceptable after day 3 (Table 8). At 2°C, all the varieties had slight browning but were still acceptable. For those roots stored at 4°C, more browning was noted but slightly more than those stored at 2°C. The browning was more advanced in those stored under 6°C as the days of storage continued to advance.

Degree of browning varied from variety to variety. Ex-Ndolo stored at 2°C was still acceptable after 12 days of storage. KME stored at 2°C was still acceptable after 9 days of storage. Muchericheri on the other hand at 2°C, 4°C and 6°C could only be acceptable up to 6 days of storage.

A study by J. Marriot *et al*, 2006 which involved investigation of susceptibility of freshly harvested and stored cassava roots to vascular discolouration also supports the findings of this research. The study involved seven varieties in Colombia and one in Jamaica. The visual discolouration and other changes that follow were retarded but not prevented by storage at 2°C. There is also potential of cassava roots to develop endogenous resistance to vascular discoloration either before or after harvesting in relation to the problems of storage of harvested cassava roots (J. Marriot, 2006).

Table 8: Extent of Visual discoloration with different Storage Temperatures and Time in Ex-Ndolo, Muchericheri and KME 1 varieties.

Days of Storage	Muchericheri				Ex-Ndolo				KME			
	23 ± 3°C	2°C	4°C	6°C	23 ± 3°C	2°C	4°C	6°C	23 ± 3°C	2°C	4°C	6°C
0	–	–	–	–	–	–	–	–	–	–	–	–
3	+++ ++ +++	+	++	+++	+++ ++ +++	+	++	+++	+++ ++ +++	+	++	+++
6	X	++	+++	+++ +	X	+++	+++ +	++++ + +	X	++	+++	+++
9	X	+++ ++ +++	+++ ++ +++	+++ ++ +++	X	+++	+++ ++ +++	++++ + +++	X	+++	+++ ++ +++	++++ +
12	X	X	X	X	X	++++	X	X	X	+++ ++ +++	X	+++ ++ +++
15	X	X	X	X	X	+++ ++ +++	X	X	X	X	X	X

Key

–	-	Shows no visible discolouration
+	-	Represents extent of browning
2x	-	Minimum deteriration
4x	-	Moderate deteriorated
8X	-	Cassava no longer acceptable beyond this day

4.7 CHANGES IN SENSORY PROPERTIES OF CASSAVA ROOTS AT STORED DIFFERENT TEMPERATURES

The change in sensory acceptability of the three cassava varieties at different storage temperatures during storage are shown in Table 9.

Table 9: Variation of Sensory acceptability of stored cassava roots with different Storage in Ex-Ndolo, Muchericheri and KME 1 varieties.

Variety	Muchericheri				Ex-Ndolo				KME			
	23 ± 3°C t	2 °C	4 °C	6 °C	23 ± 3°C	2 °C	4 °C	6 °C	23 ± 3°C	2 °C	4 °C	6 °C
0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	X	✓	✓	✓	X	✓	✓	✓	X	✓	✓	✓
6	X	✓	✓	✓	X	✓	✓	✓	X	✓	✓	✓
9	X	X	✓	X	X	✓	X	X	X	✓	X	✓
12	X	X	X	X	X	✓	X	X	X	X	X	X
15	X	X	X	X	X	X	X	X	X	X	X	X

Key

✓ - cassava acceptable

X - Cassava no longer acceptable beyond this point

From Table 9, the shelf lives of the cassava varieties based on sensory evaluation and stored at different temperatures are summarized in Table 10.

Table 10: Summary of shelf life of the Ex-Ndolo, Muchericheri and KME 1 varieties

Variety	Shelf life (days)			
	Ambient	2°C	4 °C	6 °C
Ex-Ndolo	2	12	6	6
Muchericheri	2	6	9	6
KME 1	2	9	6	9

These results show that contrary to the expectation, not all the varieties stored best at 2°C. Muchericheri stored best at 4°C and KME 1 stored equally well at 2°C and 6°C. Only Ex-Ndolo stored best at 2°C. The temperature of 4°C has been reported as the critical temperature for chilling injury of cassava roots in chilled storage (J. Marriot *et al*, 2006). It is therefore possible that Muchericheri and KME 1 were beginning to show symptoms of chilling injury as well. This would indicate that chilling injury is variety dependent.

The first quality judgement made by a consumer when purchasing a food product is its visual appearance and colour (Dutta *et al*., 2006). Excessive discolouration lowers the market value of the food. Therefore, colour as a tool for sensory evaluation is important and interesting as well. Change in food colour can be associated with its previous exposure to heat, packaging material, method of storage and duration of storage. Various reactions such as pigments destruction, enzymatic browning (Maillard reactions) can occur during processing and therefore affect its colour and visual appearance. (Cornwell and Wrolstad,1981).

Taste and texture are two of the most important sensory parameters when considering a food. Data from a study by Wijesinghe and Sarananda, 2002 showed that fresh cassava has higher values for taste and texture than frozen cassava. There was also no significant difference of frozen cassava in taste and texture according based on the packaging material used. But, there was significant difference between blanched and boiled samples in both varieties of frozen cassava for above two parameters. Taste and texture of boiled cassava were preferred by panelist than blanched cassava. The latter were not completely cooked thereby exhibiting harder structure prior.

Cassava is a tuberous root that store mostly starch with low amounts of protein and lipids (Beleia *et al.*, 2004). As food, the fresh roots can be used after appropriate cooking or boiling. Cassava may have 35-40% total solids, taking longer to cook and having a characteristic texture. Therefore, blanching for 4 minutes prior to freezing and steaming for 5 minutes is not enough to get the favourable taste and texture for cassava (Wijesinghe and Sarananda, 2002).

Boiling starchy tubers results in hydration, gelatinization, increase in cell volume, modification of cell wall and middle lamellae carbohydrates, especially due to pectin solubilzation through elimination and gradual tissue softening (McDougall *et al.*, 1996). Furthermore, cassava requires more cooking time than other tuber crops to soften and become acceptable to consumers (Wijesinghe and Sarananda (2002).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The dry matter content of the cassava varieties subjected to the different environmental conditions did not change significantly among the cassava varieties. Visible browning increased with storage time and was significantly different for the different cassava varieties. Invisible browning was also significantly different among the varieties and continued to increase with storage time. The level of total sugars also increased with storage time was significantly different among the three varieties. Texture decreased in all the varieties and was not significantly different among the varieties.

The shelf life of stored cassava was varietal and storage temperature dependent. Cassava stored for a maximum of 2 days under ambient conditions. Contrary to the expectation, not all the varieties stored best at 2°C. Muchericheri stored best at 2°C and KME 1 stored equally well at 2°C and 6°C. Only Ex-Ndolo stored best at 2°C for 12 days.

5.2 RECOMMENDATIONS

More studies can be conducted to investigate the different responses by the different cassava varieties. This temperature range of the different varieties can be used for storage as recommended storage temperatures and consumers advised on how to lengthen the shelf life of the fresh cassava varieties and reduce losses.

Low cost storage structures can also be designed with the recommended temperatures of storage for farmers to take up and thus reduce post harvest losses.

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******* Analysis of variance *******

Variate: Dry_matter_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season_1 stratum	1	8.889E-05	8.889E-05	0.01	
Season_1.*Units* stratum					
Variety_1	2	1.467E+03	7.334E+02	1.232E+05	<.001
Temp_1	3	2.462E+01	8.205E+00	1378.42	<.001
Variety_1.Temp_1	6	1.656E+01	2.761E+00	463.74	<.001
Residual	59	3.512E-01	5.953E-03		
Total	71	1.508E+03			

* MESSAGE: the following units have large residuals.

Season_1 1	*units* 2	-0.2239	s.e. 0.0698
Season_1 1	*units* 3	0.2361	s.e. 0.0698
Season_1 2	*units* 1	-0.2261	s.e. 0.0698

***** Tables of means *****

Variate: Dry_matter_1

Grand mean 37.9025

Variety_1	Ex-Ndolo	KME !	Muchericheri
	41.4083	31.5300	40.7692

Temp_1	0.00	2.00	4.00	6.00
	37.3194	37.4233	38.0917	38.7756

Variety_1	Temp_1	0.00	2.00	4.00	6.00
Ex-Ndolo		41.2150	41.2083	41.9083	41.3017
KME !		31.1283	31.1700	31.2983	32.5233
Muchericheri		39.6150	39.8917	41.0683	42.5017

*** Standard errors of differences of means ***

Table	Variety_1	Temp_1	Variety_1 Temp_1
rep.	24	18	6
d.f.	59	59	59
s.e.d.	0.02227	0.02572	0.04454

*** Least significant differences of means (5% level) ***

Table	Variety_1	Temp_1	Variety_1 Temp_1
rep.	24	18	6

```
***** Analysis of variance *****

Variate: Invs_Browng_1

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

Season_1 stratum           1    0.05611     0.05611    2.84

Season_1.*Units* stratum
Variety_1                  2  393.56560  196.78280 9950.98  <.001
Temp_1                     3   23.94219    7.98073  403.57  <.001
Variety_1.Temp_1           6   15.69159    2.61526  132.25  <.001
Residual                  59    1.16674    0.01978

Total                     71  434.42223


* MESSAGE: the following units have large residuals.

Season_1 2     *units* 24          0.909   s.e. 0.127


***** Tables of means *****

Variate: Invs_Browng_1

Grand mean  7.261

 Variety_1     Ex-Ndolo          KME ! Muchericheri
                 10.562          5.766          5.455

   Temp_1      0.00      2.00      4.00      6.00
              6.685     6.841     7.355     8.163

    Variety_1   Temp_1      0.00      2.00      4.00      6.00
     Ex-Ndolo               8.47      9.53    10.535    10.657
        KME !              4.755     5.052     6.503     6.753
 Muchericheri              4.828     4.885     5.027     7.078


*** Standard errors of differences of means ***

Table               Variety_1       Temp_1   Variety_1
                                                Temp_1
rep.                       24           18           6
d.f.                       59           59          59
s.e.d.                 0.0406       0.0469      0.0812

*** Least significant differences of means (5% level) ***

Table               Variety_1       Temp_1   Variety_1
                                                Temp_1
rep.                       24           18           6
d.f.                       59           59          59
l.s.d.                 0.0812       0.0938      0.1625
```

***** Stratum standard errors and coefficients of variation *****

Variate: Invs_Browng_1

Stratum	d.f.	s.e.	cv%
Season_1	1	0.0395	0.5
Season_1.*Units*	59	0.1406	1.9

****** Analysis of variance *******

Variate: Sugar_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season_1 stratum	1	0.006050	0.006050	4.74	
Season_1.*Units* stratum					
Variety_1	2	25.552019	12.776010	10003.78	<.001
Temp_1	3	4.202717	1.400906	1096.93	<.001
Variety_1.Temp_1	6	3.525525	0.587588	460.09	<.001
Residual	59	0.075350	0.001277		
Total	71	33.361661			

* MESSAGE: the following units have large residuals.

Season_1 1	*units* 8	-0.1192	s.e. 0.0324
Season_1 2	*units* 7	0.1125	s.e. 0.0324

***** Tables of means *****

Variate: Sugar_1

Grand mean 3.7014

Variety_1	Ex-Ndolo	KME !	Muchericheri
	4.2446	3.9875	2.8721

Temp_1	0.00	2.00	4.00	6.00
	3.4667	3.5483	3.6956	4.0950

Variety_1	Temp_1	0.00	2.00	4.00	6.00
Ex-Ndolo		4.2367	4.2733	4.3583	4.6500
KME !		3.5900	3.7550	4.2367	4.3683
Muchericheri		2.5133	2.6167	2.6917	3.6667

*** Standard errors of differences of means ***

Table	Variety_1	Temp_1	Variety_1 Temp_1
rep.	24	18	6
d.f.	59	59	59
s.e.d.	0.01032	0.01191	0.02063

```
*** Least significant differences of means (5% level) ***

Table             Variety_1      Temp_1   Variety_1
                                            Temp_1
rep.                     24          18          6
d.f.                     59          59         59
l.s.d.              0.02064     0.02384    0.04129


***** Stratum standard errors and coefficients of variation *****

Variate: Sugar_1

Stratum                      d.f.         s.e.         cv%

Season_1                       1      0.01296         0.4
Season_1.*Units*              59      0.03574         1.0


***** Analysis of variance *****

Variate: Texture_1

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

Season_1 stratum           1      0.0089      0.0089     0.07

Season_1.*Units* stratum
Variety_1                  2    478.5433    239.2717  1996.44  <.001
Temp_1                     3     89.7739     29.9246   249.69  <.001
Variety_1.Temp_1           6     14.4178      2.4030    20.05  <.001
Residual                  59      7.0711      0.1198

Total                     71    589.8150


* MESSAGE: the following units have large residuals.

Season_1 1     *units* 18          1.228   s.e. 0.313
Season_1 1     *units* 31          1.061   s.e. 0.313


***** Tables of means *****

*** Standard errors of differences of means ***

Variate: Texture_1

Grand mean  62.875

 Variety_1     Ex-Ndolo        KME ! Mucherricheri
                 62.425       66.233       59.967

   Temp_1      0.00      2.00      4.00      6.00
             61.511    64.461    63.306    62.222
```

Variety_1	Temp_1	0.00	2.00	4.00	6.00
Ex-Ndolo		63.533	61.433	60.433	59.300
KME !		67.517	66.683	64.533	62.200
Muchericheri		62.483	60.267	59.950	57.167

Table	Variety_1	Temp_1	Variety_1 Temp_1
rep.	24	18	6
d.f.	59	59	59
s.e.d.	0.0999	0.1154	0.1999

*** Least significant differences of means (5% level) ***

Table	Variety_1	Temp_1	Variety_1 Temp_1
rep.	24	18	6
d.f.	59	59	59
l.s.d.	0.2000	0.2309	0.3999

***** Stratum standard errors and coefficients of variation *****

Variate: Texture_1

Stratum	d.f.	s.e.	cv%
Season_1	1	0.0157	0.0
Season_1.*Units*	59	0.3462	0.6

******* Analysis of variance *******

Variate: Vsble_brwng_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season_1 stratum	1	0.0033347	0.0033347	7.80	
Season_1.*Units* stratum					
Variety_1	2	0.2158583	0.1079292	252.54	<.001
Temp_1	3	0.0046264	0.0015421	3.61	0.018
Variety_1.Temp_1	6	0.0070528	0.0011755	2.75	0.020
Residual	59	0.0252153	0.0004274		
Total	71	0.2560875			

***** Tables of means *****

Variate: Vsble_brwng_1

Grand mean 0.2629

Variety_1	Ex-Ndolo	KME !	Muchericheri
	0.2404	0.3383	0.2100

Temp_1	0.00	2.00	4.00	6.00
	0.2561	0.2544	0.2672	0.2739

Variety_1	Temp_1	0.00	2.00	4.00	6.00
Ex-Ndolo		0.2400	0.2183	0.2467	0.2567
KME !		0.3367	0.3200	0.3433	0.3533
Mucholicheri		0.1917	0.2250	0.2117	0.2117

*** Standard errors of differences of means ***

Table	Variety_1	Temp_1	Variety_1 Temp_1
rep.	24	18	6
d.f.	59	59	59
s.e.d.	0.00597	0.00689	0.01194

*** Least significant differences of means (5% level) ***

Table	Variety_1	Temp_1	Variety_1 Temp_1
rep.	24	18	6
d.f.	59	59	59
l.s.d.	0.01194	0.01379	0.02388

***** Stratum standard errors and coefficients of variation *****

Variate: Vsble_brwng_1

Stratum	d.f.	s.e.	cv%
Season_1	1	0.00962	3.7
Season_1.*Units*	59	0.02067	7.9