DEVELOPMENT AND EVALUATION OF A CASSAVA *(Manihot esculenta)* STORAGE CUM PACKAGING SYSTEM

By

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(2012 - 18 - 105)

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TAVANUR - 679573, MALAPPURAM

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THESIS

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Department of Post-Harvest Technology and Agricultural Processing

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TAVANUR - 679573, MALAPPURAM

2014

DECLARATION

I, hereby declare that this thesis entitled **"Development and evaluation of a cassava (*Manihot esculenta*) storage cum packaging system"** is a bonafide record of research done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Development and evaluation of a cassava (*Manihot esculenta*) storage cum packaging system"** is a record of research work done independently by **Ms. Chinthana.D.T (2012-18-105)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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EXTERNAL EXAMINER

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Chinthana, D.T

Dedicated to

My loving family

And

Profession

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SYMBOLS AND ABBREVIATIONS

ANOVA	-	Analysis of variance
AOAC	-	Association of Official Agricultural Chemists
ºC	-	ºCelcius
cm	-	centimetre
CO2	-	Carbon dioxide
et al.,	-	and others
etc.	-	etcetra
ºF	-	Degree Fahrenheit
Fig.	-	figure
g	-	gram
g^{-1}	-	per gram
h	-	hour (s)
ha	-	hectare
HCN	-	Hydrogen cyanide
HDPE	-	High density poly ethelene
i.e.	-	that is
KAU	-	Kerala Agricultural Engineering
K.C.A.E.T	-	Kelappaji College of Agricultural Engineering and Technology
kCal	-	kilo calorie
kg	-	kilogram

$kJ/ kg^o C^{-1}$	-	Kilo joule per kilogram degree celcius
LDPE	-	Low density poly ethylene
m	-	meter
ml	-	millilitre
m^2s^{-1}	-	Meter square per second
mg	-	milligram
min	-	minute (s)
mm	-	millimetre
N	-	Newton
PPD	-	Post harvest Physiological Deterioration
RH	-	Relative Humidity
SPSS	-	Statistical Package for the Social Sciences
Viz.,	-	namely
$W/m. K^{-1}$	-	Watt per meter per kelvin

Introduction

CHAPTER 1

INTRODUCTION

Food production and storage are the main activities of the mankind from time immemorial. Different storage techniques adopted for different items at different countries show the equal importance given to food storage by the people from the ancient times.

The total world food production has increased in the recent years and it is estimated to be enough and surplus to feed all mouths and there is no reason for hunger and malnutrition on this planet Earth. The world food production in the year 2013 was 2306.6 MT of which India's contribution was 261 MT (FAO, 2014). Deficient and insufficient food producing countries of Africa, Asia and Latin America are under the mercy of food exporting countries such as USA. It is pointed out that out of 128 countries of the world under FAO surveillance, still 55 Countries are classified as LIFDC (Low Income Food Deficiency Countries) for the year 2014. India is included under these 55 countries in spite of the successful implementation of Green Revolution and surplus food production in the Country. The main reason for this issue of challenging human dignity and right to healthy food of an individual are low income of a section of population to buy the expensive food grains. In this backdrop a study on low cost staple foods other than food grains and their storage for increased shelf life gain significance.

Cereals provide half of the calories consumed by humans globally; root and tuber crops are second in importance to cereals as a global source of carbohydrates, with particularly high production potential in humid regions that are not suitable for cereal production (Balagopalan, 2000).

Root crops and tuber crops such as cassava, yam, potato, sweet potato and taro can play an important role in reducing hunger and malnutrition in low income and deprived population of the world.

Cassava (*Manihot esculenta*) is grown in developing countries of Africa, Asia and Latin America where the poorer sections of population use this as an affordable, nutritional staple food. There are around 10,000 varieties in this tuber crop with different characteristics (Andres and Dimuth, 2011). Approximately 500 million people depend on it as a major carbohydrate source, in part because it yields more energy per hectare than other major crops (Sharkawy, 2003). Average yield of cassava crops worldwide was 12.5 t/ha, with an average yield of 34.8 t/ha in India (FAO, 2010). The estimated total world cassava production in 2012 was 256 million tone (FAO, 2013), which is an increase of 40% since 2000. Africa represents the continent with the largest cassava production of more than 50% of the annual world production. The crop is one of the most important staple foods with about 93% of the production used for human consumption (Nweke *et al.*, 2002).

Cassava is an important root crop grown in 13 states of our country. However the main production and consumption is concentrated to the southern states of India (Kerala, Tamil Nadu, Andhra Pradesh, and Karnataka). In addition to the use as a low cost staple food, it is also used as a raw material for industrial productions of Starch and Sago in the states of Tamil Nadu and Andhra Pradesh. This crop can be grown in most type of soils where the temperature is around 25-30^{0}C, annual rainfall of around 800 mm and where there is no water logging or frost. Cassava cultivation demands only minimum labour input and it is free from most of the pests and diseases (Coversey and Haynes, 1970).

For more than a century cassava has played an important role in the food habits of the people of Kerala State. It has played an important role in mitigating the food problem of Kerala state during the period of Second World War and the great famine that struck India during that period as the import of rice from Burma was banned by the British regime (Edison *et al*., 2006).

Now due to the increased availability of other cereal food grains and in view of the increased per capita income of the people in Kerala state the use of this tuber crop is declining day by day and hence the area of cultivation has also come down considerably. Now in most part of the Kerala state it has replaced to the status as an inter crop. However Kerala still holds the top slot with 1.04 lakh ha under cassava cultivation which is 43.33% of cassava area in India and the maximum production here goes for human consumption, followed by Tamil Nadu. Tamil Nadu has an area of 95,000 ha (40% to 60% of cassava produced is utilized industrially to produce starch, sago and other value added products (Edison *et al*., 2006).

Cassava root is essentially a storage organ of the plant and not a propagule with reproductive function. Hence, biologically there is no wound healing response in this root, which is the main reason for the low shelf life of cassava (Reilly *et al*., 2004). Due to this character of cassava various studies and experiments have been conducted world over to increase the shelf life and preserve the nutritional values of the same.

According to studies, a unique phenomena known as Physiological Post harvest Deterioration (PPD) or Primary Post harvest Deterioration sets in immediately after the harvesting of the crop. This is linked to oxidative burst and enzymatic stress response to wounding (Beeching *et al*., 2002). The development of dark bluish, brownish and black radical veins or streaks found as a ring around the inner part of the pith signals the same and the deterioration of nutritional values, colour and taste of the same follows. This PPD loss of cassava is estimated to be 10 % in Asia, 8% in Caribbean and 29% in African countries (Andres and Dimuth, 2011). The crop is not marketable after 48 to 72 hours as the process of deterioration starts minutes after harvesting the same and thus adversely affecting the farmers, consumers and processors alike (Reilly *et al*., 2007). It is also confirmed by studies that the increased levels of carotene cells in the root decreased the PPD levels.

More experiments have also been done with chemical processing to reduce oxidation burst and also with wax treatments of the roots. These have given good results with increased shelf life. However, given the fact that this is essentially a low cost staple food of developing countries used by economically weaker sections of the society, these high cost methods which increase the cost of the root substantially will not be of much use and not sustainable.

It is the ancient wisdom and traditional methods of cassava storage which are more economical and sustainable. A common method practiced throughout the world is the storage of cassava roots within the ground after cutting the stems. This method can increase the shelf life to considerable long time and is very popular among the farming community in our country and also around the globe. Pruning of the plants a few weeks prior to harvest is one of the most effective and low cost measure to reduce Physiological post harvest deterioration (PPD), although the cellular mechanism involved is still unclear (Hirose *et al*., 1984). Though economical and sustainable, these methods have disadvantages such as wastage of cultivable lands for a longer duration and storing of harvested roots within the same ground that involve increased labour inputs on frequent intervals.

For the small and marginal growers who cultivate the plants for their own consumption, PPD is not a problem as cassava can be harvested and consumed when required after keeping them within the ground for a longer time after maturity of the crop. The increased demand from urban poor population and the requirements of retailers have made it necessary to extend the shelf life of cassava beyond 72 h.

Hence an attempt is made to study and synthesis the use of ancient wisdom as well as modern knowledge to increase the shelf life of cassava by adopting low cost storage methods which could be handy and cost effective and within the reach of the common man. These studies are for the benefit of the poorer sections of the rural population as well as retailers. It is reported that increasing the storage life of cassava roots to a minimum of 2 weeks can save an estimated 90% of PPD losses (Oirschot *et al*., 2000). Mechanical damages which takes place during harvesting is a critical factor in deciding PPD losses (Aristizabal and Sanchez, 2007) as these damages will increase oxidation process due to over exposure and microbial attack by pathogens responsible for rotting. Due care taken during harvesting is also an added factor to increase the shelf life of cassava roots.

Hence an attempt was made to study the storage of cassava roots by using different filler materials under various conditions of humidity and ventilations, which are readily and locally available to the small growers, consumers, processors and retailers, which will be of some use to the common man in increasing the shelf life of cassava roots and there by mitigating the problem of hunger and malnutrition at least to some extent.

Considering the facts and situations, the present study was undertaken to develop a low cost improved cassava storage system by using readily available low cost materials with the following objectives:

- Development of a cassava (*Manihot esculenta*) storage cum packaging system.
- Performance evaluation of the developed storage cum packaging system using different filler materials.
- Study of the characteristics of cassava roots before and after storage.
- Economic analysis of the storage cum packaging system.

Review of literature

CHAPTER 2

REVIEW OF LITERATURE

A critical comprehensive review of literature is inevitable for any scientific investigation. A brief report of research works carried on the storage studies of cassava roots are presented in this chapter. This chapter provides the background information on the issues to be considered in the present research work and to focus the relevance of the present study.

2.1 Cassava (*Manihot esculenta)*

2.1.1 Origin and Distribution

Different views about the origin of this plant may not exactly pin point a single place of its origin. However, all agree and surely point towards South American continent as the place of origin of this root plant. Cassava (*Manihot esculenta*) was introduced from Brazil to the tropical areas of Africa, the Far East and the Caribbean Islands by the Portuguese during the 16^{th} and 17^{th} centuries. The Portuguese grew the crop around their trading ports, forts and castles. By the second half of the 18^{th} century, cassava had become the most widely grown and used crop of the people of the coastal plains (Korang *et al*., 1987).

Edison *et al*. (2006) stated that the efforts of Sri Visakham Thirunal the King of Travancore of Kerala state, was laudable in popularizing this crop in Kerala, who brought different varieties of cassava from Malayasia and other countries that fits into the climatic conditions of this state.

2.1.2 World production and trade:

Of the other root crops, cassava occupies first position in terms of area and production globally. It is found as staple food for people living in several tropical countries of South America and Africa. Cassava can produce more dry matter per hectare than other root and tuber crops like potatoes, sweet potatoes or yams (Scott *et al.,* 2000).

The estimated total world cassava production in 2012 was 256 MT which is an increase of 40% since 2000 (FAO, 2013). Cassava is grown in an area of 18.51 million ha producing 202.65 MT with a productivity of 10.95 t/ha. It is reported to be grown in 102 countries of the world. Edison *et al*. (2006) reported that African continent is having a lion's share both in terms of area of cultivation as well as production in the world, 53.37% of world production with 66.21% of area under cultivation. Asian continent is the second largest in terms of area (19%) and production (29%) of cassava with a productivity of 16.76 t/ha (FAO, 2005).

Sreenivas and Anantharaman (2005) indicated that in India, the cultivation is spread over more than 13 states but the major production is from the southern states of Kerala, Tamil Nadu and Andhra Pradesh contributing 93% of area and 98% of production in the country. In Kerala, where it is used mainly as a food crop, accounts to 50% of area and is mainly grown in the rain fed areas of the state (Edison *et al*., 2006).

2.1.3 Varieties

Several varieties of cassava have been identified in farming systems (Fregene *et al*., 2003; Manu *et al*., 2005), and they are often grouped into bitter and sweet varieties. Varieties differ in colour of rind and flesh, size of tubers, colour of stem, leaf and petiole, branching pattern, duration of crop and resistance to mosaic disease. High amount of cross-pollination results in heterozygous nature. Vegetative method of propagation resulted in development of a number of polyploidy varieties and hybrids.

2.1.3.1 Common varieties in Kerala

The following are the common varieties of cassava grown in Kerala (Edison *et al*., 2006).

H-97 is a hybrid between a local variety 'Manjavella' and a Brazilian seedling selection. The plants are medium tall, branched with light brown emerging leaves. The tubers are conical shaped and stout, yielding 25-35 t ha^{-1}. The tuber flesh is white with 27-29 % starch content and matures in 10 months.

H-165 is a hybrid between two indigenous cultivars viz.,'Chadayamangalam Vella and a clone similar to a common variety grown in Kerala known as Kalikalan. The plants are predominantly unbranched with the mature leaves showing a drooping nature. The tubers are relatively short and conical, yielding 33-38 t ha^{-1}. The variety is comparatively early maturing in 8-9 months.

H-226 is a hybrid between a local cultivar 'Etthhakka Karuppan" and the Malayan introduction M4. Plants are tall, occasionally branching and leaves with a characteristic green colour. The tuber yield is 30-35 t ha^{-1} and the crop duration is ten months. Both H-165 and H-226 are the predominant varieties cultivated in Tamil Nadu and Andhra Pradesh for their industrial potential.

Sree Visakham (H 1687) is a hybrid between an indigenous accession and a Madagascar variety S-2312. The female parent is unbranched with light yellow tuber flesh, while the male parent is a heavy yielder with good culinary qualities. It is predominantly a non branching type of variety having compact tubers with yellow flesh due to high carotene content (466 IU/100 g). Tuber skin is brown and rind is cream in colour. The crop duration is ten months and the tuber yield is 35-38 t ha^{-1} with 25-27% starch.

Sree Sahya (H 2304) is a hybrid involving five parents of which two are exotic and three indigenous. Plants are tall, generally non-branching with dark brown and a predominant spiny, stipular mark. The tubers are long necked with light brown skin, cream coloured rind and white flesh. Tuber yield is 35-40 t ha^{-1}. Both Sree Visakham and Sree Sahya are improved varieties for table purpose having better palatability than the former three hybrids and are popular in southern Thiruvananthapuram and western Kanyakumari districts.

Sree Rekha (TCH 1): Top cross hybrid of cassava *viz* TCH 1 was released for general cultivation in Kerala under the name ‘Sree Rekha’. The average yield and starch content are 48.0 t ha^{-1} and 28% respectively. Tubers cook well and give good yields both under upland and lowland conditions.

Sree Prabha (TCH 2): Top cross hybrid of cassava *viz* TCH 2 was released for general cultivation in Kerala under the name ‘Sree Prabha’. The average yield and starch content are 42.0 t ha^{-1} and 26% respectively. Tubers cook well and give good yields both under upland and lowland conditions.

Sree Harsha: This is a triploid clone developed by crossing a diploid with an induced tetraploid clone of ‘Sree Sahya’, plants are stout, erect and non-branching with tubers of good cooking quality and high starch content (38 to 41%) and yield 35- 40 t ha^{-1} in 7 to 8 months.

M-4: This is a non-branching variety with excellent cooking quality; susceptible to mites; yielding 18-23 t ha^{-1} in 10 months

Nidhi: A short duration variety (5-6 months), yielding (25.1 t ha^{-1}). It is tolerant to mosaic disease.

2.1.4 Morphological and physiological characteristics

Many cultivars or varieties of cassava are cultivated in the subtropical and tropical countries of the world. They can be distinguished by their morphological characteristics such as leaf size, color, branching habit, plant height, color of stem and petiole, tuber shape and color, maturity period and yield.

The cassava plant is made up of a shoot system and a root system. The shoot system consists of stem, leaves, and flowers and the root system consists of feeder roots and tubers (Anon, 1990).

Cassava roots are usually circular in cross-section, fattest at the proximal end and tapers slightly towards the distal portion. It is connected to the stem by a short woody neck and ends in a tail similar to a regular fibrous root. The central pith constitutes the bulk of the root and is primarily a storage parenchyma harboring a multitude of xylem vessels (Mpoko, 1999).

2.1.5 World Cassava Utilization and consumption:

Cassava is one of the most important staple foods with about 93% of the production used for human consumption (Nweke *et al*., 2002). Cassava roots are an important carbohydrate source which is eaten both fresh and as processed products. It has been observed that cassava utilization patterns vary considerably in different parts of the world. As per International Food Policy Research Institute (IFPRI), the total world cassava use is expected to increase from 172.7 MT to 275 MT in the period 1993–2020.

Oluwole *et al*. (2004) have estimated the production of cassava for human consumption to be 65% of cassava products, while 25% is for industrial use, mostly as starch (6%) or animal feed (19%) and 10% is estimated to be lost as waste. In Africa the majority of cassava produced (88%) is used for human food, with over 50 % used in the form of processed products. In Latin America, animal feed is far more important accounting for approximately one-third of consumption, and human food represents only 42% of production (Edison *et al*., 2006).

The situation in Asia is greatly influenced by the export of cassava chips by Thailand to the European Community for use as animal feed. If Thailand is excluded, then it is seen that human consumption of fresh roots is the most important use of the crop (46% of production), starch is relatively important (10% of production) and animal feed and export are other minor uses (Westby, 2002).

2.1.6 Nutritive value

Cassava roots are a rich source of carbohydrate. Most of the carbohydrate is present as starch which is 31% of fresh weight with smaller amounts of free sugars (less than 1% of fresh weight). Cassava roots are low in protein (0.53%), although higher concentrations of 1.5% have been reported by Ekpenyong (1984), and fat (0.17%). Protein from other sources is therefore needed if cassava is to be part of a balanced diet. Cassava is generally considered to have a high content of dietary fiber, magnesium, sodium, riboflavin, thiamin, nicotinic acid and citrate (Bradbury and Holloway, 1988).

Cyanide is the most toxic factor restricting the consumption of cassava roots and leaves. Cassava leaves have a cyanide content ranging from 53 to 1,300 mg/kg of Dry weight and cassava root parenchyma has a range of 10 to 500 mg/kg of Dry weight (Siritunga and Sayre, 2003).

2.2 Post Harvest Management of Cassava

2.2.1 Tuber Deterioration

Cassava tubers are highly perishable and after harvesting, cassava roots are susceptible to spoilage and begin to deteriorate 48 hours after harvesting if no preservation measures are taken.

According to Cock (1985), postharvest deterioration of cassava is related to two separate processes such as physiological changes and microbial changes. Physiological deterioration often start within 24 hours after harvest, while microbial deterioration usually beings within a week.

Wenham (1995) observed that major visual symptom of post harvest physiological deterioration is vascular streaking, resulting from occlusions in the vascular parenchyma by oxidized phenolics. There will be considerable variation in degree of development and severity of postharvest physiological deterioration among different cassava varieties and also within the same variety. PPD is also initiated by mechanical damage, which typically occurs during harvesting and progresses from the proximal site of damage to the distal end, making the roots unpalatable within 72 hour of harvesting (Buschmann *et al*., 2000).

Apel and Hirt (2004) reported that reactive oxygen species (ROS) production as one of the earliest events in the deterioration process. In plants, ROS are continuously produced as by-products of aerobic respiration. Sanchez *et al*. (2005) found that cassava cultivars that had high levels of b-carotene (which quenches ROS) were less susceptible to PPD.

Reilly *et al*. (2004) observed that PPD response was an enzymatically mediated oxidative process in which ROS appeared to play a dual role as both a signaling molecule that induces programmed cell death as part of a more general wound response and in oxidizing phenolic compounds to produce the visible symptoms of PPD in cassava, with wound repair and antioxidant defenses being too late or inadequate to contain these effect.

2.2.2 Actual losses Worldwide due to postharvest physiological deterioration (PPD)

PPD restricts the storage potential to only a few days, reducing the development of cassava as a commercial crop. Worldwide it is calculated that losses caused by postharvest deterioration of cassava roots after harvesting are up to 25% (Jansen and Wheatlley, 1985).

Wenham (1995) remarked that small-scale farmers suffer economic losses due to PPD by reduction in root quality while large-scale processors are affected by the risk involved in the reliable supply of cassava as a raw material.

Increasing the storage life of cassava roots to a minimum of two weeks will have a substantial effect on cassava utilization and solve an estimated 90% of the deterioration constraints associated with current cassava marketing and utilization practices (Oirschot *et al*., 2000). In Nigeria delaying of PPD of cassava roots for several weeks reduced the economic losses by US$2.9 billion (Rudi *et al*., 2010).

2.2.3 Storage of cassava roots

The basic concept of storage is to extend the shelf life of products by storing them in appropriate conditions to maintain their availability to consumers and processing industries in their usable form. They can either be stored naturally in the field, or in built storages (Pantastico *et al*., 1975; Raghavan and Gariepy, 1985).

2.2.4 In ground storage of cassava roots

A common way of avoiding root losses due to PPD is to leave the roots un harvested in the soil after the period of optimal root development, until the roots can be immediately consumed, processed or marketed.

Early studies undertaken by Ingram and Humphries (1972) estimated that it could cost three quarters of a million hectares of agricultural land to keep all cassava tuberous roots in the soil and also observed that there was extra losses due to increasing possibility of pathogen attacking when tuberous roots remained in ground for a longer duration.

Cassava roots stored in ground by removing large roots from individual plants and leaving small roots in the ground to enlarge, the roots remained in the ground for 7 -12 months and sometimes even longer (Smit and Matengo, 1995).

Wenham (1995) conducted a study to determine the quality of cassava roots by keeping roots unharvested in the ground after 10 -12 months of planting. The study revealed that the roots increased in size and they became more woody and fibrous, palatability was decreased whereas cooking time was increased.

This strategy has disadvantages because large areas of land are used by the standing crop, and those areas are unavailable for additional agriculture production.

2.2.5 Storing fresh cassava roots in crates

Freshly harvested cassava roots can be stored in wooden crates. The crates are lined with a layer of filler material and the spaces between the roots are filled with filler.

Rickard and Coursey (1981) conducted an experiment by storing cassava roots in wooden crates using sawdust as filler. They observed that if the sawdust was too dry the roots deteriorated quickly if it was too moist promoted the formation of mould and rot. A storage period of 4 weeks was attained with crates by this method.

In Ghana this method of storage was modified and the crates were replaced by large baskets. The baskets were lined with fresh banana leaves which also served as a cover for the stored produce. Before storing the roots were subjected to three days of curing. Storage periods in Ghana using this method reached 2 months (Osei, 1990).

In Uganda this storage method was tested in combination with the lining of box with plastic and using sawdust as a filler material (Nahdy and Odong, 1995). The study indicated that 75% of the roots remained healthy with 15% moisture content lost after four weeks in store, provided the roots were packed immediately on the day of harvest. With a delay of one day only 50% of the roots were rated as acceptable.

Udoudoh (2011) conducted an experiment by storing cassava tubers using moist saw dust in sealed boxes and some cassava tubers exposed as control. Results revealed that exposed cassava root used as control had profuse microbial growths on the surface of tubers on the 4^{th} day and were completely soften due to fermentation of the tissues on the 7^{th} day. Tubers on moist sawdust had no microbial growth but developed secondary roots on the third day of storage. The sawdust acted as soil for the tubers while the different gases and heat evolved by the tubers in the sealed boxes had a curing effect on the tubers. The study hence recommended that storage of cassava tubers in moist saw dust upto 3 weeks of storage duration.

2.2.6 Storing fresh cassava roots in clamps and pits

This method involves the storage of cassava roots under in-field conditions in pits, clamps, trenches or boxes. This method is carried out after harvest of cassava roots.

Booth and Coursey (1974) evaluated the storage life of cassava roots in clamps. They found that clamp storage performed less well during the hot season. The temperature inside the clamp easily reached 40ºC, and heavy losses resulted after 1 month of storage.

Ravi *et al*. (1996) conducted a study on extending the shelf life of fresh cassava roots by using pits in sandy soils. The study revealed that this method prolonged the shelf life of cassava roots for more than two months but the roots became very sweet and had poor cooking qualities leading to its only use as cattle feed.

It was noticed that during storage of cassava roots in clamps the bruised or otherwise injured roots tend to undergo a wound-healing response that prevented vascular discoloration (Wheatley and Schwabe, 1985).

Research work on the storage of cassava roots in pits containing sand and soil at 15% moisture content has been conducted in India (Balagopalan, 2000). Results showed that after 2 months of storage 80–85% of roots were recovered undamaged. Roots lost 15–20% of their starch content after 2 months of storage, which was equivalent to one week of storage under ambient conditions. There were also significant reductions in root cyanogens content.

Osunde and Yisa (2000) conducted a study on storing yam tubers in barns with and without fan. Results showed that tubers stored in the barn with fan had the least sprout weight and least weight loss. At the end of a 3 month period, the tubers in the ventilated barn showed 4.7% less weight loss compared to the barn without fan. The difference in sprout weights and weight loss between the structures was statistically significant at $P \leq 0.05$. Also, tubers stored in the barn with fan had the least percentage of rotten tubers (1.85% of stored tubers) compared to the tubers stored in the barn without fan (12.03%). A reduction of some of the nutritional content was also observed during the six months of storage period. From these results it was concluded that intermittent air flow on stored yam tubers reduces sprouting, weight loss and rot development, thus reducing the overall loss in stored yam tuber.

Ofor (2012) found successful storage of cassava roots in field clamps for up to eight weeks, the clamp consisted of a layer of straw laid on a dry floor covered by a heap of 300-500 kg of roots followed by a layer of straw and a final layer of soil. Openings were left at the bottom of the heap to provide some ventilation. This storage method was found to be difficult to manage where seasonal variations in climate made it difficult to either limit or increase ventilation and during a wet season, to ensure that the floor of the clamp remained dry.

2.2.7 Pruning

It is a traditional practice to overcome PPD, which consists of the removal of all leaves and stems of the cassava plant approximately 40- 50 cm above the soil level approximately 2-3 weeks prior to harvest

It has been observed by Marriott *et al.* (1979) that pruning of cassava plants by removing the top of the plant and leaving a short (20 cm) leafless stem 2 to 3 weeks before harvest resulted in roots resistant to primary deterioration even if the roots are severely damaged. In accordance with this hypothesis were the findings of Wheatley and Schwabe (1985) that pruning reduced scopoletin accumulation in the roots but not the response to exogenous scopoletin.

Correa *et al*. (1987) found that pruning the aerial parts to 20-30 cm above the soil 2-3 weeks before harvesting did not reduce tuber production but improved the keeping qualities.

Kato *et al*. (1991) observed that pruning cassava stems 10–20 cm above the ground two weeks before harvest reduced susceptibility to PPD but, unfortunately negatively affected eating and starch qualities.

Orischot *et al*. (2000) conducted a study on the effect of pre-harvest pruning of cassava upon root deterioration and quality characteristics. Six cultivars with varying intrinsic susceptibility to PPD, were assessed at pruning harvest intervals of 0, 2, 4, 6, 8, 10, 15, 20, 25, 28 and 39 days. After harvesting, the roots were analyzed. The study revealed that the unpruned plants had a low susceptibility to coincide with low dry matter content and high sugar content. Analysis of the cassava roots showed a relationship between the combined sugar and starch contents and the interval duration, and that sugar and starch contents were inversely related to each other. The sugar content increased with the interval period, probably as a result of starch hydrolysis. It was concluded that sugar/starch ratio of cassava roots had positively relation to resistance to post-harvest physiological deterioration.

Aguiar *et al*. (2011) conducted a research on the influence of pruning dates on productivity of cassava. Two experiments were carried out in two regions having two different soils. The experiments were carried out from September 2008 to June 2010, and harvest was done after two growing seasons (22 months). The experimental design was a randomized block design, with four replicates. Ten treatments, nine monthly pruning dates, between April and December, and a control cultivated without pruning were evaluated. Pruning dates were statistically analyzed by orthogonal contrasts, in comparison to the control, and by regression. Results showed that pruning during the rest period did not alter dry matter content and root yield. However, when performed at the end of the first cycle or after the start of the second cycle, pruning reduced dry matter content and root yield.

2.3 Modern methods of storing fresh cassava roots

2.3.1 Storage at low temperature

While storing tuber crops the first priority is to maintain the quality of the product. Low temperature storage is one of the most commonly adopted methods to maintain the root crop quality. For successful storage it is necessary to efficiently control the temperature throughout the storage period.

Bradbury and Holloway (1988) conducted a study by storing cassava roots in cold storage. They found that recommended temperature for maximizing cassava storage life was 2°C (36°F), and reported a shelf life of 4 to 5 months for sound roots.

Ravi *et al*. (1996) found that at temperatures above 4ºC roots developed the PPD symptoms more rapidly and spoiled after 2 weeks of storage. An alternate study was conducted by him by storing entire roots or pieces of root frozen under deep-freeze conditions in polyethylene bags and found that it was able to keep for a further 4 days.

Oirschot *et al.* (2000) observed that cassava roots can be stored for 2 weeks between 0 to 4ºC without any internal deterioration and found that favorable temperature for storing fresh cassava roots was 3ºC for 4 weeks and further research indicated that after 5-6 months of storage between 0 to 4ºC, the part of the root without decay was in excellent condition and was suitable for human consumption.

Bezerra *et al*. (2002) conducted a study on the effect of refrigerated storage and blanching of cassava roots. The results revealed that refrigerated storage and blanching led to an increase in cooking time, but preserved its cooking quality. Blanching for 30 minutes did not inactivate polyphenol oxidase and peroxidase enzymes whereas darkening of the roots was effectively controlled until the 15th day of storage and the roots became unacceptable for consumption because of its appearance. Refrigerated conditions contributed to an increase of 66.6% in the shelf life of cassava roots.

Wijesinghe and Sarananda (2008) investigated the utilization of cassava through freezing. Two popular varieties MU 51 and Kirikavadi were used for the study. Heat treatments of blanching and boiling together with packing materials of Low-density polyethylene (LDPE) and Low-density polyethylene and Nylon (LDPE+N) were tested in completely randomized design. Results showed that both varieties had a minimum percentage weight loss during storage. Microbiological study showed that all samples were safe for consumption up to 3 months at freezer storage. Cyanide levels were significantly reduced by boiling before freezing. Variety Kirikavadi had significantly lower cyanide levels than variety MU 51. Quick freezing using a modification in a normal freezer showed superior quality of frozen product compared to those of stored in a normal freezer.

2.3.2 Storage by coating

Surface coating has been used to restrict moisture loss from root crops through evaporation, transpiration and respiration.

Knoth (1993) observed that dipping the roots in molten paraffin wax at 51.5ºC to 52.5°C (125°F to127°F) for one second added a smooth thick surface coating to the root. This coating helped reducing root moisture loss and extended market life for up to 2 month. The reasons for the use of wax as a coating are that they extend product shelf life by controlling oxidation and respiration reactions (Park *et al.*, 1994).

Sargent *et al*. (1995) found that waxing of cassava roots and holding at 0 to 5ºC (32 to 41 °F) extended shipping time to more than 30 days with minimal occurrence of vascular streaking. It is observed by Guilbert *et al.* (1996) that wax coating to cassava roots added to texture and sensory characteristics and was environmental friendly and also found that wax coating improved the external appearance of the root and reduced discoloration of the vascular tissue.

Westby (2002) conducted a study by dipping cassava roots in 2.2% of aqueous emulsion of fungicidal wax with 17% triethanolamine and 5% o-phenyl phenol for 1 min.The results showed that there was a acceptable loss of 10% after 2-10 days and further results showed that roots dipped in paraffin wax during 45 sec at 90-95ºC was acceptable for a period of 1 month

Qiuping and Wenshui (2007) found that cassava roots can be preserved for a period of 2 months by coating cassava roots in food grade wax which may or may not be supported with a fungicide.

Ezeocha and Oti (2013) studied the effect of different waxing materials (bee wax, palm wax and paraffin wax) on some physico-chemical parameters of *Dioscorea dumetorum* tubers for a storage period of 2 months. The results revealed that all the waxing materials retained the nutrient contents more than the un-waxed tubers and concluded that, palm wax performed better than the other waxing materials in terms of weight after storage, nutrient and functional properties after storage.

2.3.3 Storing cassava roots in plastic bags

The use of plastic bags to preserve cassava roots have been a consistent extension of traditional storage methods which serve the purpose of avoiding the loss of moisture and water stress. When the roots are packed airtight, the oxygen content in the bags is reduced creating a preserving effect (Rickard and Coursey, 1981).

International Tropical Agriculture Center, Colombia (CIAT, 1984) developed a methodology that consisted of packing the cassava roots in plastic bags and treating them immediately with a thiabendazole based fungicide. The environment within the bags was characterized by high temperature and moisture conditions. The results revealed that roots were being found fresh stored for two weeks. Best (1990) reported that storage duration of more than 14 days was reached in Columbia using this method.

A series of on-farm storage trials was carried out by Bancroft and Crentsil (1995) in Ghana to determine whether the application of water or fungicide (thiobendazole) to freshly harvested cassava roots prior to or during storage in either polyethylene bags or recycled rice sacks (woven polyethylene) to prolong the storage life of the produce. Results indicated that, if applied early enough, under ambient conditions the surroundings engendered by these treatments were sufficient to prolong the storage life of the roots from 3-5 days to 2-3 weeks. Water treatments alone in combination with either bags or sacks helped to maintain the storage potential of the cassava for at least 7 days provided that microbial infection was avoided. Thiobendazole was found to not only suppress fungal rots but also enhanced the storability of the roots to an even greater extent than water alone.

Ravi *et al*. (1996) found that cassava root stored in polyethylene bags after harvest at high RH remained fresh up to 4 weeks, and concluded that the successful conservation of cassava roots in polyethylene bags depends on the quality of the roots (with minimal damage), protection from sunlight, treatment with fungicide, and packing within three hours after harvest.

Mussury *et al*. (2012) found that roots stored in a cold chamber and packaged in plastic bags, had a good appearance and without signs of wilting up to 30 days of storage.

2.4 Physicochemical changes during the storage of cassava roots

2.4.1 Moisture content

Cassava roots are highly sensitive to moisture content and high reduction in moisture content of the roots during storage is attributed due to the respiration and transpiration processes. Linssen and Roozen (1994) found that the most important factor encouraging mould contamination of garri is the initial high moisture content and the relative humidity (R.H) of the air within and around the commodity during storage.

Processing the tuber into a dry form reduces the moisture content and converts into a more durable and stable product with less volume which makes it more transportable. Emmanuel and Samuel (2001) observed decreasing levels of moisture in D. dumetorum tubers after harvest and found that roots underwent a process of rapid dehydration immediately after harvest, leading to the hardening phenomenon.

Karim *et al*. (2009) observed a decrease in moisture content of cassava roots stored in polyethylene bag, jute bag, trench and storage box for 14 days of period. The short shelf-life of the cassava roots after harvest was due to their high water content (65%) and resulting bulkiness (Ceballos *et al*., 2012).

Adebola *et al.* (2014) observed an increase in initial moisture content of cassava roots stored in different packaging materials for a period of eight months. The highest increase in moisture content was in fertilizer bags followed by polythene bags, plastic buckets at the end of the storage period.

2.4.2 Starch content

The carbohydrate fractions of plants are a very diverse category of compounds, that generally include non-cell wall compounds simple sugars involved in intermediary plant metabolism, and storage compounds such as starches and fructans, and cell wall compounds include structural carbohydrates such as pectin, hemicelluloses, cellulose and lignin. Pillai *et al*. (1970) observed an increase in sugar and decrease in starch on storage of tubers in soil.

Kawabata *et al*. (1984) found an increase in the amount of glucose and a decrease in the amount of sucrose during storage at ambient temperature. Akingbala *et al*. (2005) found decrease in starch content of cassava roots stored at ambient temperature 30°C in trench and polyethylene bags for 21 days.

Silim *et al*. (1992) found an decrease in starch content in cassava roots stored in three plant based storage media namely wooden shavings, wet saw dust , coffee husks. Sanchez *et al*. (2005) studied the change in starch content of cassava roots of variety (HMC-1) and 31 tolerant

(AM 206-5) during storage in ambient conditions. They observed a 1 % starch loss per day of root storage.

Priscila *et al.* (2013) conducted a study on the spatial and temporal distribution of starch accumulation in cassava roots of cassava, variety IAC 576-70 with 90 and 120 days after planting. The results revealed a concentration of starch around the secondary xylem vessels of the cassava tuberous roots and concluded that the accumulation was due to the movement of organic solutes in the xylem vessels, water flow and the occurrence of the symptoms of the physiological deterioration in these roots.

2.4.3 Cyanide content:

Cyanide is present in cassava roots in two forms, bound cyanide present as the cyanogenic glucoside and free cyanide present as the cyanohydrin, that is free hydrogen cyanide which is a gas above 26ºC under alkaline conditions and as cyanide ion, CN- (Bradbury and Holloway, 1988).

Cyanide content in cassava roots can be reduced by a treatment which enhances linamarin-linamarase contact by thorough disintegration of the cell structure. This can be done by crushing, grating or by microbial cell-wall degrading enzyme activity. A second treatment is to degrade the cyanohydrins formed and to volatilize the HCN. This can be done by heating or drying at an adequate PH (Hahn, 1989).

Alexander *et al*. (1996) conducted a study to analyze linamarin levels in sun-drying cassava root pieces. Results showed that linamarin levels decreased exponentially parallel with the moisture loss and stabilized when moisture levels reached about 15%.

Bainbridge (1998) conducted a study on the role of tissue disruption in the removal of cyanogens during cassava root processing. Results revealed that crushing cassava root pieces prior to drying was found to significantly improve the efficiency of cyanogen removal by on average 22% during laboratory experiments and 12% during field trials. Pounding cassava to small pieces in a traditional pestle and mortar prior to drying was the most efficient, providing 90% removal of cyanogens.

Vasconcelos *et al*. (2007) investigated the detoxification of cassava during the preparation of garri. The results showed that the most important processing stages, with regard to elimination of cyanide, were the initial grating of the cassava and the final roasting of the product. The breakdown of linamarin was dependent primarily on the presence of endogenous linamarase and the lactic acid bacteria present during the fermentation.

2.4.4 Fibre

Crude fibre consists of cellulose, variable proportion of hemicelluloses and highly variable proportion of lignin along with some minerals. Earlier studies reported very high increase in the fibre levels during prolonged storage of D.rotundata and D. dumetorum tubers (Treche, 1996). During vascular streaking fiber content of the roots increases due to condensed tannins from leucoanthocyanidins and cathechin (Rickard, 1985).

Ezeocha and Oti (1985) experimented the effect of different waxing materials (bee wax, palm wax and paraffin wax) on some physico-chemical parameters of *Dioscorea dumetorum* tubers for a storage period of 8 weeks and reveled an increase in fibre content during storage. Emmanuel *et al*. (2001) observed slight increase in fibre content of Dioscorea dumetorum yam tubers harvested and stored in cold room condition at 4ºC for 72 h.

Enidiok *et al*. (2008) observed that upon fermentation of MM 96/5280 variety of cassava tubers fibre content increased upto 32%. Karim *et al*. (2009) found an increase in fibre content of cassava roots stored for a period of 14 days in polyethylene bag, jute bag, trench and storage box.

2.4.5 Texture

The understanding of the textural properties of the tubers and analyzing their behavior under mechanical force will help in the design of appropriate post harvest machineries for processing.

Rickard and Coursey (1981) conducted a study to analyze the textural changes of cassava roots during freezing. Results showed that freezing of cassava roots changed the texture and made it somewhat spongier.

Wheatley and Gomez (1985) studied the textural behavior of cooked cassava roots of M Col 22 and CM 342-170 variety. Results showed that cassava roots had a soft texture and good taste from 6 to 10 months maturity followed by a decline in quality of roots having 12 months maturity.

Beleia *et al.* (2005) conducted a study on sensory and instrumental texture analysis of cassava roots. Two cassava varieties at three harvesting ages, 6, 12 and 24 months, were analyzed for sensory flavor and texture development. Maximum shear force, Texture Profile Analysis (TPA) and water absorption during cooking were determined at various sampling times. Results revealed that the 24-month-old roots had higher variability and never reached optimum texture or flavor development. Maximum shear force was 111 N for raw samples and 8.1 N for samples that cooked in less than 25 min. Samples that required longer cook time had on the average a maximum shear force of 19 N.

Sajeev *et al*. (2010) conducted a study which aimed at analyzing and modeling the textural, dynamic rheological and gelatinization properties of selected cassava varieties (‘*Venjaramoodan’, ‘Kaliamanja’, ‘Koliakodan’, ‘Adukkumuttan’, ‘Narayanakappa’, ‘Sree Rekha’, ‘Sree Prabha’, ‘H152’ and ‘H740’*). The thermal softening behavior was analyzed by linear regression and fractional conversion techniques, rheological properties of the gelated starch by Maxwell and power law models. The varieties were classified based on their physico-chemical, texture profile, rheological and gelatinization properties by multivariate analysis. The results showed that textural, rheological and gelatinization properties varied considerably among the varieties and besides the physico-chemical properties, interaction between them and structural make up of the tuber parenchyma had a great influence on cooking quality and rheological properties.

Materials and methods

CHAPTER 3

MATERIALS AND METHODS

This chapter deals with the details of the materials and the methodology followed during the course of the present investigations.

3.1 Development of the cassava storage cum packaging system

The storage cum packaging system was initially developed using wooden boxes. Wood is a natural packaging material and it is easily available and widely used all over the world. Tomatoes, oranges, grapes and other fruits are commonly packed in wooden boxes with sufficient ventilation. Hence it was decided to use wooden boxes for the study.

A wooden box of known dimension which can store 6 kg of cassava roots with filler materials was developed. Based on convenience, the thickness of the box was taken.

3.2 Experimental outline

Experiment was conducted in three stages. First two experiments were conducted with nine different filler materials in nine wooden boxes with two different varieties of Cassava (*M-4 & Muttechi*). Based on these results, best three filler materials were selected and the third experiment with nine boxes made up of three different materials was conducted for *Muttechi* variety.

3.3 Experimental Materials

3.3.1 Procurement of Raw materials

Cassava roots were collected from two different farms for different stages of experiments. For first experiment cassava variety *M4* of maturity 11 months was procured from a local farm near Kuttipuram in Malapuram District. For second and third experiment cassava variety *Muttechi* of maturity 10 months was collected from local farm near Kolathur in Malapuram District.

3.3.2 Description of filler materials and arrangement in wooden box

Filler materials are the packing materials to cover the cassava roots to provide an environment nearly natural and almost nearer to the ancient practice of keeping the roots inside the grounds. Selection of filler materials is done to provide a natural environment to the roots coupled with increased air circulation, humidity etc., and thus create artificially favorable environmental conditions to the cassava roots to survive for a longer duration.

The study was undertaken to make use of the different filler materials which are readily and locally available to the small growers, consumers, processors and retailers, under various conditions of temperature and humidity. The experiments were conducted in months of October, January, and March. Temperature and relative humidity varied considerably during this various seasons in Kerala.

3.3.3 Filler materials used for first and second experiment.

The following nine filler materials were used for the first and second experiment

1. **Cassava leaves (F1):** Cassava (*Manihot esculenta*) leaves contain a high level of crude protein (29.3-32.4% dry weight). It is composed of Dietary fiber in the range of (26.9-39% dry weight) and Tannin (29.7 mg/g). It is also comprised of cyanide content potential in the range (5.1-12.6 mg/100 g dry weight) (Awoyinka *et al*., 1995).

Plate 3.1 Cassava leaves

For the study, Cassava leaves harvested from fresh cassava plants were used for the study.

2. **Sand (F2)**: It is a soil made of a greater proportion of bigger particles and since these particles cannot fit closely together, there are larger spaces between them. Naturally, these gaps are filled with air. In sand, water absorption is very high as the water passes quickly through these gaps. This soil is light, well aerated and dry.

Plate 3.2 Sand

For the study, sand was collected from the Bharatapuzha.

3. **Clay (F3):** Clay contains relatively high proportion of fine particles. There is very less space between particles. Clay can hold more water, as the particles are smaller in size, water is trapped in the tiny gaps between them.

Plate 3.3 Clay

For the study clay was collected from K.C.A.E.T farm.

4. **Sponge (Foamed plastic polymer) (F4):** The sponge is a basic synthetic material which has porous surface that retains more moisture with the water absorption capacity of 50-51%. It is manufactured artificially in factories. It was selected for the study for the reason that it is easily available in the market, easy to pack, and it can absorb moisture.

Plate 3.4 Sponge

5. **Laterite soil (F5):** This soil is almost a mixture of clay and sand, hence have the properties of both of them. It retains more water and there is less air circulation when compared to sand. However when compared to clay it has more air circulation and lesser water retention qualities.

Plate 3.5 Laterite soil

For the study Laterite soil was collected from K.C.A.E.T farm.

6. **Plastic cuttings (F6):** This is an artificial material which is commonly used in our day to day life in one form or the other. It is transparent, and flexible. Density range of Low density polyethylene (LDPE) is 0.910–0.940 g/cm^3 and the size selected for the study purpose was approximately 2×2 cm.

Plate 3.6 Plastic cuttings

7. **Coconut fibre (F7):** Coconut fibre is extracted from the husk of coconut. It is found between the hard internal shell and the outer coat of a coconut. Shredded coconut fibers have high water-holding capacity (42- 45%), some cation exchange capacity, and are often used in hydroponics. It is a common material available in Kerala.

Plate 3.7 Coconut fibre

For the study coconut fibres were collected from an oil mill near Tavanur.

8. Sawdust (F8): Sawdust is the by-product of cutting, grinding, drilling, sanding, or otherwise pulverizing wood with a saw or other tools. It is composed of fine particles of wood. It has good water absorption (21-27%), aeration, and evaporation capacity.

Plate 3.8 Sawdust

For the study sawdust was collected from carpentry shop near Tavanur.

9. Wooden shavings (F9): These are the waste materials obtained while working in wood industry. These are produced while planing the wood through machine tools and while manufacturing certain semi finished products (single ply, veneer, lath, thin paneling etc.) in the wood industry. Particles have better water absorption (22-29%), aeration, and evaporation capacity.

Plate 3.9 Wooden shavings

For the study wooden shavings were collected from carpentry shop near Tavanur.

3.4 Methodology:

The experiments were conducted in the Food Engineering Laboratory under Department of Post Harvest Technology & Agricultural Processing (PHT&AP) at K.C.A.E.T, Tavanur. About 60 kg of cassava was used for each experiment. Soon after harvest, cassava roots were shifted to nine wooden boxes in the lab. 6 kg of cassava was weighed and arranged with different filler materials in each box. Cassava roots were kept in layers and filler materials were kept around each layer of cassava roots. All the physical and chemical properties of cassava fresh roots were measured and analyzed. Initial moisture and final moisture content of filler materials were determined by oven dry method. A known amount of water was sprinkled daily to all the boxes in order to maintain moist environment. Initial moisture content of all the filler materials and the moisture content after addition of moisture was noted and maintained.

Plate 3.10 Freshly harvested cassava roots

Plate 3.11 Experiment setup

3.4.1 In first and second experiment following were the experimental setup with cassava roots. For first experiment *M4 variety* and for second experiment *Muttechi* variety were used.

- Wooden box (M1) + Cassava leaves (F1)
- Wooden box(M1) + Sand (F2)
- Wooden box(M1) + Clay (F3)
- Wooden box(M1) +Sponge (F4)
- Wooden box(M1) + Laterite soil (F5)
- Wooden box (M1)+ Plastic cuttings (F6)

- Wooden box(M1) + Coconut fibre (F7)
- Wooden box(M1) + Sawdust (F8)
- Wooden box(M1)+ Wooden shaving (F9)

3.4.2 Third experiment

The first two experiments were conducted in wooden boxes. It was decided further to explore the impact of the material used for making boxes, as the material of the box is in direct contact with cassava and there can be some direct impact of the material on the cassava roots . Hence the study was further extended using other boxes made of plastic and plywood along with wooden boxes in order to find that impact**.** In the third experiment filler materials that gave good results in first and second experiments were used in the study. Boxes made up of different materials wood (M1), plastic (M2) and plywood (M3) were used for the study.

Following was the experimental setup of third experiment with cassava roots of *Muttechi* variety

- Wooden box (M1) + wooden shavings (F9)
- Wooden box (M1) + Sawdust (F8)
- Wooden box (M1) + Coconut fibre (F7)
- Plastic box (M2) + Wooden shavings (F9)
- Plastic box (M2) + Sawdust (F8)
- Plastic box (M2) + Coconut fibre (F7)
- Plywood box (M3) + Wooden shavings (F9**)**
- Plywood box(M3) + Sawdust (F8)
- Plywood box (M3)+ Coconut fibre (F7)

3.5 Storage conditions

Temperature and relative humidity in each experiment were recorded by Digital thermo-hygrometer. This displays Temperature to an accuracy of +/- Fahrenheit.

3.6 Physical chemical characteristics estimation

The methods of estimating various attributes of cassava roots for the study are

briefly described below

3.6.1 Moisture content

Moisture content of cassava roots was determined using the method of Association of Analytical Chemists (AOAC, 1992). About 5 g of each sample was dried in an air oven at 105ºC for 24 h. Drying continued until the final weight of the sample became constant. The initial moisture content on wet basis was calculated by following formula:

$$X_0 = \frac{W_1 - W_2}{W_1} \times 100$$

Where, X_0 = Moisture content on wet basis (%)

W_1 = Initial weight of sample

W_2 = Final weight of sample after drying

3.6.2 Crude fibre content

Crude fibre consists of cellulose, variable proportion of hemicellulose and highly variable proportion of lignin along with some minerals. It was estimated by the method suggested by AOAC (1976). About 2 g of the dried sample (W) was ground and boiled with 200 ml H_2SO_4 for 30 minutes. Then the sample was filtered through muslin cloth and washed with hot water for 2 - 3 times so that the washings were not acidic. The residue obtained was boiled with 200 ml NaOH and filtered through muslin cloth again and washed with 25 ml of 1.25% H_2SO_4, 350 ml of water and 25 ml alcohol. Then the residue was transferred to ashing dish (W1) and dried for 2 h at 130 ± 2°C. Weight of the dish and the residue (W2) was taken after cooling in the desiccator. Again the dish was ignited for 30 minutes at 600 ± 15°C and weighed after cooling (W3)

$$\text{Crude fiber content (\%)} = \frac{(W_2 - W_1) - (W_3 - W_1)}{W} \times 100$$

3.6.3 Carbohydrate content

The total saccharides moiety in a sample was estimated by the anthron method by Gerhardt *et al*. (1994). Which is a simple colorimetric method with relative insensitivity to interferences from the other cellular components. The first step in total carbohydrates measurement is to hydrolyze the polysaccharides and to dehydrate the monomers by the process of digestion with sulphuric acid addition and heat treatment. The 5-carbon (pentoses) and 6-carbon (hexoses) sugars are converted to furfural and hydroxymethylfurfural, respectively. When anthrone which is an aromatic compound is added it reacts with these digestion products to give colored compound. The amount of total carbohydrates in the sample is then estimated via reading the absorbance of the resulting solution against a glucose standard curve.

Materials and chemicals used were

- One ml pipettes (glass or acid-durable pipettes)
- Ice buckets (to keep everything chilled all throughout the experiment),
- Spectrophotometer.
- Anthron reagent Anthron ($C_{14}H_{10}O$), [9(10-H)-Anthracenone]
- Glucose D-(+)-Glucose anhydrous
- Reagent-grade H_2SO_4.

First Glucose standard curve was calibrated. From this standard calibration curve the total carbohydrates of the cassava samples in mg /ml was determined.

3.6.3.1 Preparation of the solutions

For the Glucose standard curve 75% H_2S0_4, Glucose Standard Solution, Anthron Standard solutions were prepared.

- **75 % H_2S0_4**: For 25 ml of water 75 ml of H_2S0_4 added and the solution was cooled by keeping the solution in ice bath.
- **Anthron reagent**: 0.1g of anthron reagent was weighed and was dissolved properly by stirring it with 5 ml of ethanol. For this solution 50 ml of 75% H_2S0_4 added to make it up to 50 ml.
- **Glucose standard solution:** 0.1g of glucose reagent was weighed and dissolved in 100 ml of water in volumetric flask.

Aliquots of 0.2, 0.4, 0.6, 0.8, and 1 ml glucose was taken in five test tubes and volumes of aliquots were made up to 1 ml by addition of distilled water. One ml of distilled water was taken as blank. One ml of H_2S0_4 and 4 ml of anthron reagent was added to each test tube and was heated for 15 min for 100^0C in a boiling water bath. Absorbance of the cooled purple solutions was measured at 578nm in spectrophotometer. After that a standard graph was plotted with concentration of the standard on the x axis and the absorbance on the y axis as shown in section 4.4.3. From the graph carbohydrate present in cassava samples was determined

3.6.3.2 Carbohydrate determination for cassava extract

Five gram of cassava tuber was cut into small cubes and extract was made up to 150 ml by addition of distilled water. From that 1ml aliquot was taken and diluted 10 fold and from that 1ml aliquot was taken and methodology was repeated as described above for color development and concentration in mg/ml was obtained from standard graph using spectrophotometer. Carbohydrate content was calculated using following formula

$$\text{Carbohydrate \%} = \frac{\text{Concentration} \times 10 \times 150}{5000} \times 100$$

3.6.4 Cyanide content

Cassava contains cyanide in the leaves and roots which are harmful for human consumption. Cyanide in cassava is mainly present as cyanogenic glycosides, linamarin, and a small amount as a closely related compound, lotaustralin. Cyanide content in cassava roots in terms of mg/kg was determined by acid hydrolysis method (Bradbury *et al.,* 1991).

Reagents and materials used were 0.1 N H_3PO_4, 4 N H_2SO_4, 3.6N NaOH, 0.2N phosphate buffer pH 6, Chloramine T solution, pyridine and barbituric acid, 0.2 N NaOH. First cyanide standard curve was calibrated. From this standard calibration curve the total cyanide content of the cassava samples in mg /kg was determined.

3.6.4.1 Cyanide standard curve calibration

A stock solution of HCN was prepared by dissolving 75 mg in 0.2 N NaOH and made up to 100 ml with 0.2 N NaOH. It was diluted tenfold using 0.2 N NaOH, and six different aliquots (0, 1.5, 3.0, 4.5, 6.0, 7.5 and 9.0 ml) were diluted to 10 ml in volumetric flasks and filled to the mark with a pre-prepared mixture of 20 ml 0.1 N H_3PO_4, 20 ml 4 N H_2SO_4. This was heated for 50 min in boiling water bath and cooled. To cool solution 50 ml 3.6 M NaOH was added and mixed well and the solution was filtered. The solution was allowed to stand for 5-10 min to ensure complete reaction.

One ml aliquot of the mixture (blank) and 1 ml aliquots of the five solutions containing cyanide were each added to 7 ml portions of 0.2 N phosphate solutions. To aliquots 0.4 ml 5g litre $^{-}$1 chloramin T solution was added. The tubes were cooled in ice for 5 min, and 1.6 ml pyridine and barbituric acid solution was added .The purple colour was allowed to develop for

60-90 min. The absorbances of the purple solutions were measured at 583 nm against the blank solution. A linear graph of absorbance v/s concentration of cyanide was obtained shown in section 4.4.4. From which the cyanide concentration of the cassava samples was determined.

3.6.4.2 Cyanide determination from cassava extract

A 20 g disc of cassava tuber was cut into small cubes and blended with 30 ml 0.1 N H_3PO_4, in a household blender for 2-3 min. The mixture was filtered using suction through a Whatman No 1 filter paper and washed twice with 0.1 N H_3PO_4. The filtrate was made up to 50 ml with the same acid in a volumetric flask. A 2.0 ml of the aliquot was taken from 50 ml solution, 2.0 ml of 4 N H_2SO_4 was added to this solution and was heated in a boiling water bath for 50min and cooled. To the cold solution 5.0 ml of 3.6 N NaOH was added with shaking to ensure proper mixing, and then the solution was filtered. The solution was allowed to stand for 5-10 min to ensure complete reaction. Aliquots (1.0 ml) of the solution were added to each test tube containing 7.0 ml of 0.2 N phosphate buffer (pH 6.0). To one aliquot was added 1 ml of water for use as a blank, further the methodology was followed as described above for cyanide standard.

$$\text{Cyanide (mg/kg)} = \frac{\text{Concentration}\times 2\times 50\times 1000}{20}$$

3.6.5 Texture analysis

This important quality parameter which affects the consumer acceptability of cassava root was determined using Texture Analyzer (Stable Micro Systems, UK; Plate 3.13). The instrument had a micro processor regulated texture analysis system interfaced to a personal computer. The instrument consists of two separate modules; the test-bed and the control console (keyboard). Both are linked by a cable which route low voltage signal and power through it. The texture analyzer measures force, distance and time and hence provide a three-dimensional product analysis. Forces may be measured to achieve set distances and distances may be measured to achieve set forces. The sample was kept on the flat platform of the instrument and was subjected to double compression by a cylindrical probe with 5 mm diameter. The test was conducted at a speed of 10 mm/s using 50 N load cells. The sample was allowed for a double compression of 40% with trigger force of 0.5 kg during which various textural parameters were determined. From the force deformation curve, the firmness or hardness (peak force), and toughness (area under the curve) were determined.

Plate 3.12 Textural Analyzer

3.6.6 Physiological loss in weight (PLW):

Physiological loss in cassava weight was calculated according to the method of Ayodele and Iwhiwhu (2007). Each tuber was weighed before the treatment and at intervals of observation, the mean weight of each of the three replicates was obtained and the percentage loss in fresh weight was determined and calculated thus:

$$\text{Loss in fresh weight} = \text{Initial weight} - \text{Final weight}$$

$$\text{Loss in fresh weight (\%)} = \frac{\text{Loss in fresh weight}}{\text{Initial weight}} \text{ X } 100$$

3.6.7 Determination of Rotten percentage:

Rotten percentage of cassava roots in different treatment was calculated according to method of Ayodele and Iwhiwhu (2011). Physical observations were made for an interval of 5days to note the number of decayed tubers in each treatment. Percentage (%) rot incidence was calculated using the following formula.

$$\text{Rotten (\%)} = \frac{\text{Number of tubers rotted (kg)}}{\text{Total number of tubers in treatment (kg)}} \times 100$$

3.6.8 Cooking time (min)

Cooking time was calculated according to method of Wheatly and Gomez (1985). The central region of the peeled root was quartered longitudinally and the fibrous central vascular bundle removed. Each quarter was cut into portions approximately 6 to 8 cm long, thereby obtaining cassava pieces of similar geometry and origin to those commonly cooked by housewives in India. Four pieces from each root were placed in a beaker (600ml) containing 250 ml of boiled simmering unsalted water. Cooking time was determined to the nearest minute by ease of penetration with a household fork**.**

3.6.9 Sensory analysis

Sensory evaluation of cassava with respect to appearance, color, texture, flavor, and overall acceptability was adjudged on a nine point hedonic scale (Ranganna, 1986) by a panel of 12 untrained judges. The nine point hedonic scale used for the sensory evaluation is shown below.

Table 3.2 The nine hedonic scale used for the sensory evaluation

Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like nor dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

The evaluation session was carried out at every 5 to 7 days interval of storage. The samples were arranged in tables with specific codes. The scale was easily understood by each of the panelist and their response was converted to numerical values for computation purposes. Final results were obtained by calculating the average of the points given by all panelists.

3.6.10 Cost analysis

The cost of developed storage cum packaging system along with cassava roots was determined using standard procedures. The estimation of cost is given in Appendix IX.

3.6.11 Statistical Analysis

The results obtained during the course of experiments were subjected to the one-way Analysis of Variance (ANOVA). The statistical analysis of data was carried out by using software SPSS.

Results and discussions

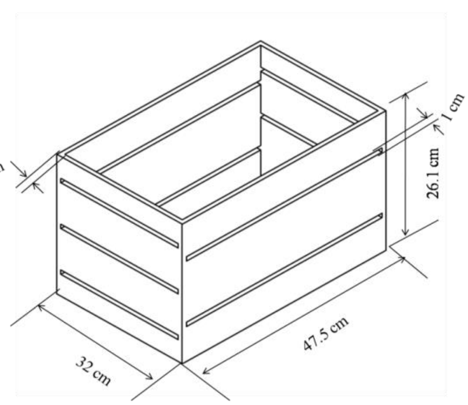
CHAPTER 4

RESULTS AND DISCUSSION

The results of the study, ***Development and evaluation of a cassava (Manihot esculenta) storage cum packaging system*** to extend the shelf life of cassava are detailed in this chapter. The results of the performance evaluation of the developed system and experiments conducted to study the post harvest behavior of cassava roots stored using different filler materials are also discussed.

4.1 Developed cassava storage cum packaging system

A wooden box of known dimension 47.5 cm × 32 cm × 26.1 cm which can store 6 kg of cassava roots with filler materials was developed. The volume of the wooden box was calculated for keeping 6 kg of cassava roots along with filler materials. The volume of the box was found to be 0.039 m^3.



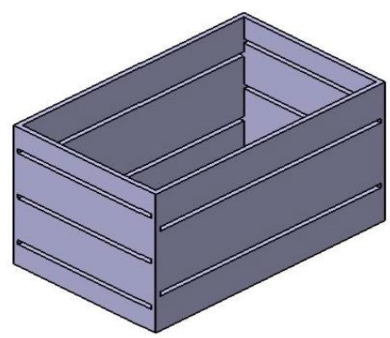
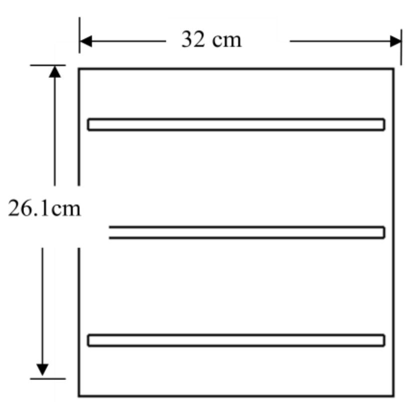


Fig. 4.1 Developed wooden box **Plate 4.1 Wooden storage system for cassava**



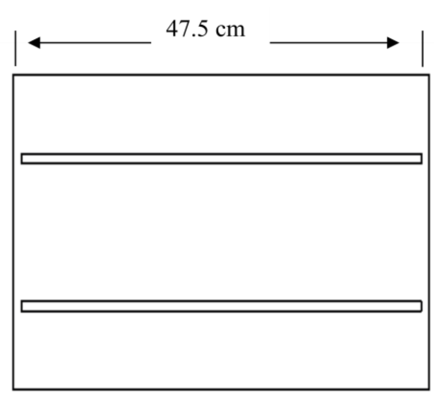


Fig 4.2 Front view **Fig 4.3 Side view**

Plank thickness of the box was taken as 1cm, as this is the standard thickness used in packaging boxes.

The Dimensions of the box is summarized in table 4.2

Table 4.1 Specifications of the developed wooden box

Specifications	**Dimensions**
Volume	0.039 m^3
Inner width	32cm
Height	26.1cm
Length	47.5cm
Thickness	1cm
Ventilation gap	1cm

4.2 Effect of moisture content of filler materials on cassava storage.

As described in section 3.4, Cassava leaves (F1), Sand (F2), Clay (F3), Sponge (F4), Laterite (F5), Plastic cuttings (F6), Coconut fibre (F7), Sawdust (F8), Wooden shavings (F9) were used as filler materials for studying storage characteristics.

The shelf life of cassava is highly dependent on storage moisture condition. However, the packing filler material must be moist but not wet. Physiological deterioration occurs if the material is too dry and microbial decay accelerates when it is too wet (Nahdy and Odong, 1995). Hence it was essential to add extra water into the filler materials in order to maintain moist condition for better storage. Therefore certain amount of water was added to all the filler materials during the experiments.

Table 4.2 Initial moisture content of filler materials of *M4* variety used in first experiment, *Muttechi variety* used in second and third experiment

Filler materials	***M4* variety** (first season) **(%) *wet basis***	***Muttechi* variety** (Second season) **(%) *wet basis***	***Muttechi* variety** (Third season) **(%) *wet basis***
Cassava leaves (F1)	70.12	65.10	68.10
Sand (F2)	16.30	16.10	16.50
Clay (F3)	21.22	23.20	20.10
Sponge (F4)	-	-	-
Laterite (F5)	18.36	18.30	17.80
Plastic cutting (F6)	-	-	
Coconut fibre (F7)	13.61	13.70	13.12
Sawdust (F8)	15.20	15.90	15.40
Wooden shavings (F9)	14.60	14.4	13.90

Table 4.2 shows that maximum initial moisture content was observed in filler cassava leaves (F1) followed by filler clay (F3) used in three experiments. Whereas minimum initial moisture content was observed in filler coconut fibre (F7) followed by filler wooden shavings (F9).

4.3 Physical and chemical characteristics of fresh cassava roots

Physical and chemical properties of fresh cassava roots vary according to agro-climate of the area, traditional farming practices and often the local cultural heritage. The physical and chemical composition of raw cassava roots were determined and are given in Table 4.3

Table 4.3 Physical and chemical characteristics of fresh cassava roots

Variety	***M4* variety** (First season)	***Muttechi* variety** (Second season)	***Muttechi* variety** (Third season)
Moisture content (%) *wet basis*	58.29	57.25	56.46
Carbohydrate content (%) *wet basis*	26.76	22.31	21.06
Cyanide content mg/kg	71.81	51.92	51.12
Fiber content (%)	1.06	1.20	1.21
Firmness N	92.09	98.10	91.10
Toughness N/sec	115.37	122.96	114.19

From the Table 4.3 it can be observed that the *M4* variety had maximum initial moisture content, carbohydrate content and cyanide content compared to *Muttechi* variety used in second and third season. Whereas fibre content, firmness and toughness of *Muttechi* variety used in study in second and third season had maximum initial content compared to *M4* variety. The variation in physical and chemical characteristics of cassava roots is due to diverse environmental conditions.

4.4 Post harvest behavior of cassava roots during its storage period

According to Eka (1998), Storage of root and tuber crops could result in variation in nutrient content. Thus, post harvest behavior during storage of cassava roots using different filler materials were evaluated by finding the quality parameters as described (section 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.4.6, 4.4.7,4.4.8). The results of analysis are discussed below.

It was found that cassava roots of *M4* variety of first season stored in fillers clay (F3), laterite (F5), and plastic cuttings (F6) spoiled after 10days of storage period and in fillers, cassava leaves (F1) and sponge (F4) spoiled after 15days of storage period. In case of *Muttechi* variety of next season cassava roots stored in fillers clay (F3), laterite (F5) and plastic cutting (F6) spoiled after 12 to 17 days of storage period. Whereas in the third study, cassava roots of *Muttechi* variety kept in three different filler materials in nine boxes made up of three different materials, it was observed that cassava roots stored in all the three filler material in box made of plywood (M3) material spoiled after 10 days of storage period.

Statistical analysis were conducted up to 15 days of storage in first variety, 17days in second variety and 10 days in third study according to availability of data and rest of data after this period are explained graphically.

4.4.1 Moisture content

Cassava roots are highly sensitive to moisture content and high reduction in moisture content of the roots during storage is attributed due to the respiration and transpiration processes

4.4.1.1 Change in moisture content of *M4* variety

The moisture of the *M4* variety cassava roots in filler materials (F1, F2, F5, F7, F8, and F9) showed significant moisture content decrease. There was no drastic decrease in moisture content of cassava roots as small amount of moisture was sprinkled daily to all filler materials. Statistical analysis up to 15 days of storage in *M4* variety revealed that mean difference in moisture content was significant at 0.05 levels as shown in Appendix I.

The minimum decrease in moisture content was observed in cassava roots stored in saw dust (F8) filler material as shown in Fig. 4.4 with the mean value of 51.17% from an initial moisture content of 58.2% followed by wooden shaving (F9) (40 days) and coconut fibre (F7) (35days) filler materials. The minimum decrease in trend of cassava roots stored with sawdust (F8) filler material is explained by the equation 4.1.

$$y = -0.190x+57.61 \ (R^2 = 0.922) \qquad \text{….. 4.1}$$

Where x=storage days.

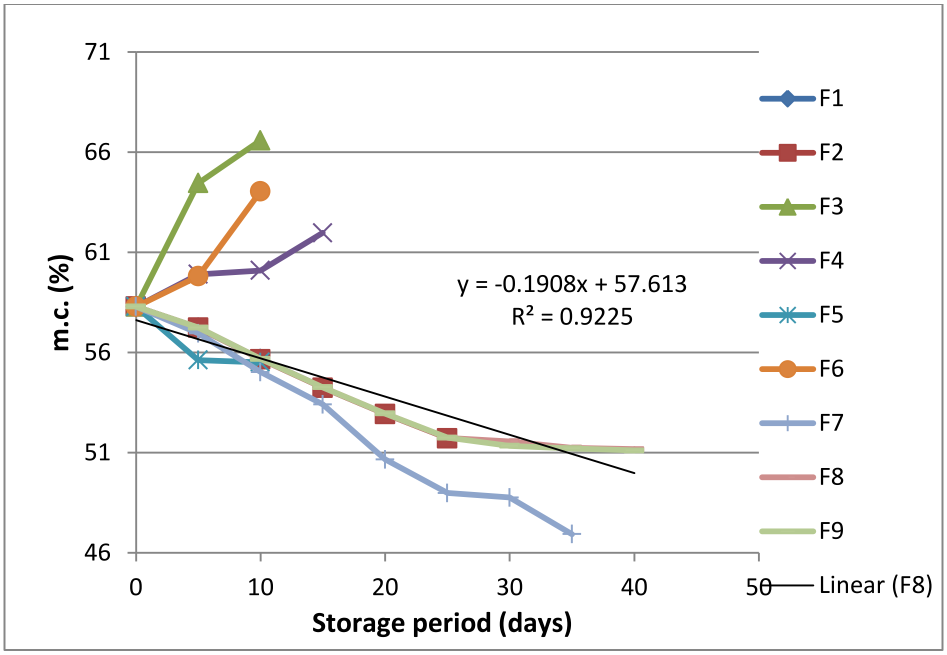


Fig. 4.4 Change in moisture content of *M4* variety

4.4.1.2 Change in moisture content of *Muttechi* variety

Cassava roots in filler materials (F1, F2, F4, F5, F7, F8, and F9) showed significant moisture content decrease. Statistical analysis up to 17 days of storage revealed that mean difference in moisture content was significant at 0.05 levels and was observed in cassava roots stored in plastic cutting (F7) filler material followed by sand (F2) and cassava leaves (F1) as shown in Appendix II. The minimum decrease in moisture content was observed for cassava roots stored in coconut fibre (F7) filler material up to 27 days with the mean value of 51.734%, from an initial moisture content of 57.25% followed by sand (F2) and wooden shavings (F9) (37 days) filler materials as shown in Fig. 4.5. The minimum decreasing trend of cassava roots stored with coconut fibre (F7) filler material is explained by the equation 4.2.

$$y = -0.211x+57.9 \ (R^2=0.955) \qquad \text{….4.2}$$

Where x = storage days

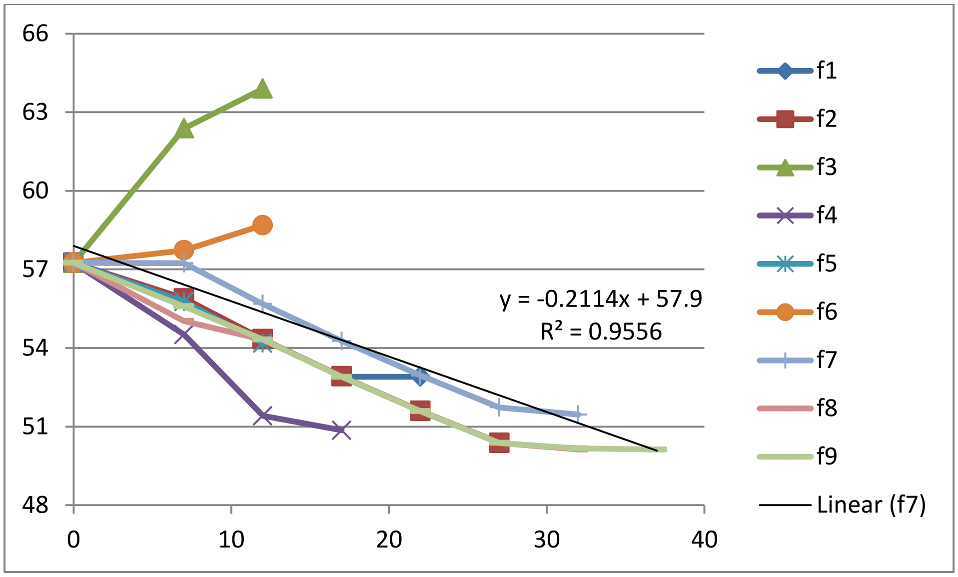


Fig. 4.5 Change in moisture content of *Muttechi* variety

4.4.1.3 Change in moisture content in cassava roots of *Muttechi* variety stored in three different filler materials in nine boxes made up of three different materials

Statistical analysis revealed a significant difference in mean value up to 0.05 level in cassava roots stored in different filler materials in different material boxes up to ten days of storage as shown in Appendix I. Cassava roots stored in filler wooden shavings (F9) had a minimum decrease in moisture content followed by sawdust (F8) and coconut fibre (F7). In case of material boxes, cassava roots stored in boxes made of material plastic (M2) had minimum decrease in moisture content followed by wood (M1) and plywood (M3) as shown in Fig.4.6, 4.7 and 4.8.

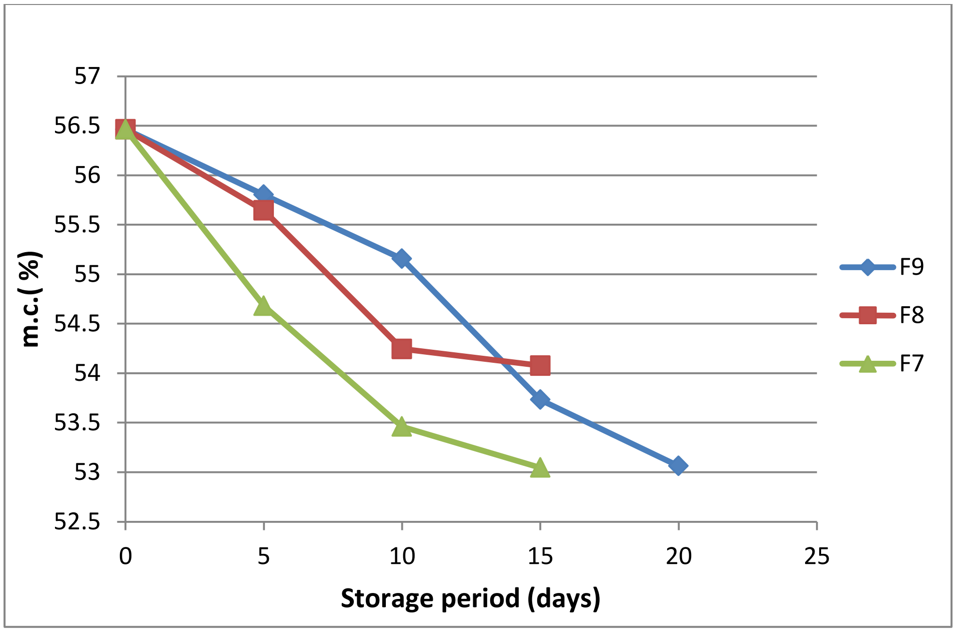


Fig. 4.6 Change in moisture content of *Muttechi* variety stored in wooden box

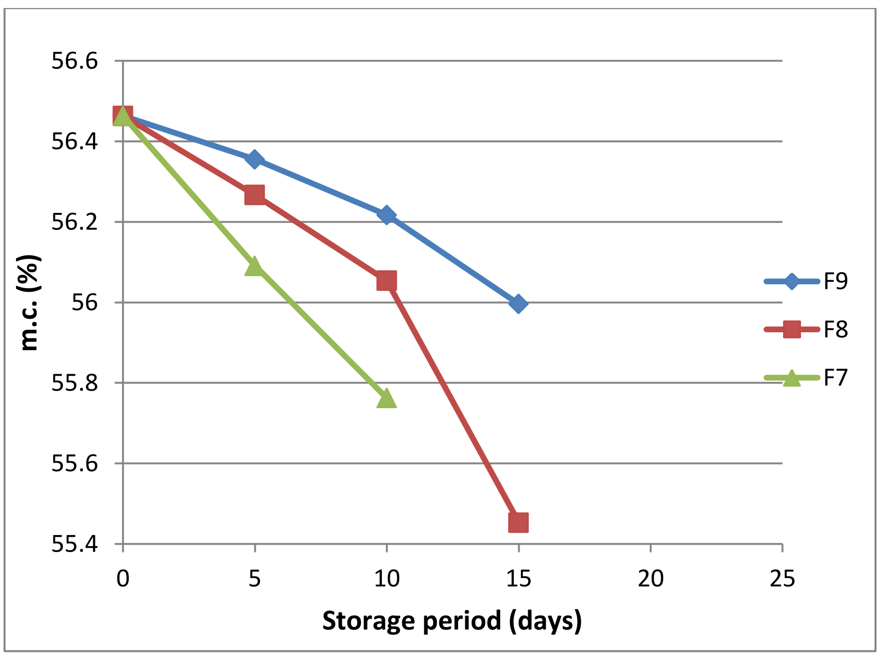


Fig. 4.7 Change in moisture content of *Muttechi* variety stored in plastic box

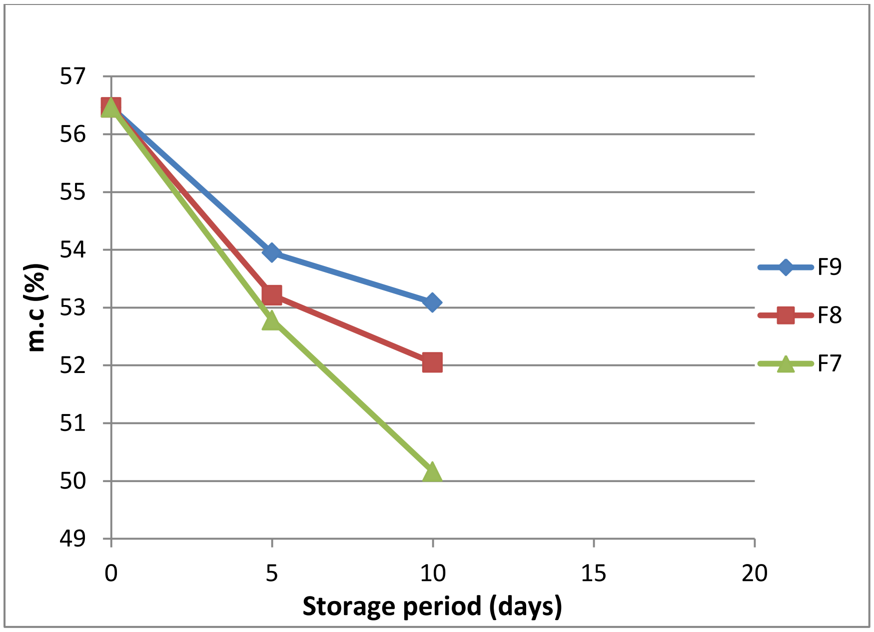


Fig. 4.8 Change in moisture content of *Muttechi* variety stored in plywood box

The decrease in moisture content in cassava roots during storage is due to evaporation, transpiration and respiration. Furthermore, as reported by Karim (1995) other factors like starch hydrolysis, equilibrium of roots and atmospheric moisture might have affected the moisture content of the roots.

In first experiment minimum decrease in moisture content was observed in cassava roots stored in sawdust (F8) up to 40 days, and in second experiment in coconut fibre (F7) up to 27 days. In first experiment sawdust (F8) filler might have retained moisture in cassava roots due to characteristic nature of this filler to retain moisture and to maintain respiration, evaporation, transpiration of cassava roots to a minimum level. Evaporation of moisture is mainly due to heat of the surrounding environment. It may be coconut fibre (F7) is a bad conductor of heat did not conduct external heat into the surroundings of the roots, Hence there was less evaporation of the moisture in cassava roots stored in this filler material in second experiment. The decreasing trend of moisture content was in line with the observation made by Nahdy and Odong (1995).

There was also marginal increase in moisture content of cassava roots in some filler materials in first and second experiment. The maximum increase in moisture content was observed in cassava roots stored in clay (F3) filler with mean value of 66.5% from initial mean value of 58.2% followed by plastic cutting (F6) and sponge (F4) filler materials in first experiment. And in clay (F3) filler with a mean value of 63.8% from an initial mean value of

57.2% followed by plastic cutting (F6) in second experiment. It might be due to the characteristics of these filler materials to absorb moisture and not to evaporate or aerate moisture and deterioration occurred at faster rate for cassava roots stored in these filler materials. Thus water sprinkled was absorbed by roots, and vaporization did not take place. Deterioration at faster rate of the tubers was also encouraged by the high moisture content (Udoudoh, 1998) as mesophilic bacteria easily grew on the tubers with high moisture content (Okaka, 2001). Though, moisture loss did not occur, the shelf life of roots was minimized due to lack of air circulation and maximum moisture . It is also observed that out of these three filler materials two filler were inorganic substances. When these results were compared with the results of organic substances connected to plants as filler materials, Coconut fibre (F7), sawdust (F8), wooden shavings (F9) it was observed that organic substances related to plant kingdom were good in maintaining the moisture content naturally at the desired level without making the cassava roots wet.

In third experiment the minimum decrease in moisture content was obtained with cassava roots stored with filler materials in box made of material plastic (M 2) . This might be due to the nature of plastic (M2) material to retain moisture for longer duration with almost no air circulation, thus providing moist environment to roots stored in this material.

4.4.2 Fibre content

Crude fibre consists of cellulose, variable proportion of hemicelluloses and highly variable proportion of lignin along with some minerals. Usually fibre content does not exceed 1.5% in fresh root and 4% in root flour (Gil and Buitrago, 2002).

4.4.2.1 Change in fibre content of *M4* variety

It was observed that fibre content of cassava roots increased during storage period. Statistical analysis showed a significant increase with a mean difference at 0.05 levels up to 15days of storage as shown in Appendix II. Minimum increase in fiber content in *M4* variety was observed in cassava roots stored sawdust (F8) filler material followed by wooden shavings (F9) and plastic cutting (F7) filler materials up to 15 days of storage period. There was a change in this tendency after 15 days. It was observed that cassava roots stored in coconut fibre (F7) filler material (up to 35days) had a minimum increase with a mean value of 1.40% from the initial fiber content of 1.06%. Beyond 40 days cassava roots stored in sawdust (F8) and wooden shaving (F9) had satisfactory results as shown in the Fig. 4.9. The minimum increasing trend of cassava roots stored with coconut fibre (F7) filler material is shown by the equation 4.3

$$y = 0.006x + 1.216 \ (R^2 = 0.528) \quad \ldots\ 4.3$$

Where x= storage days

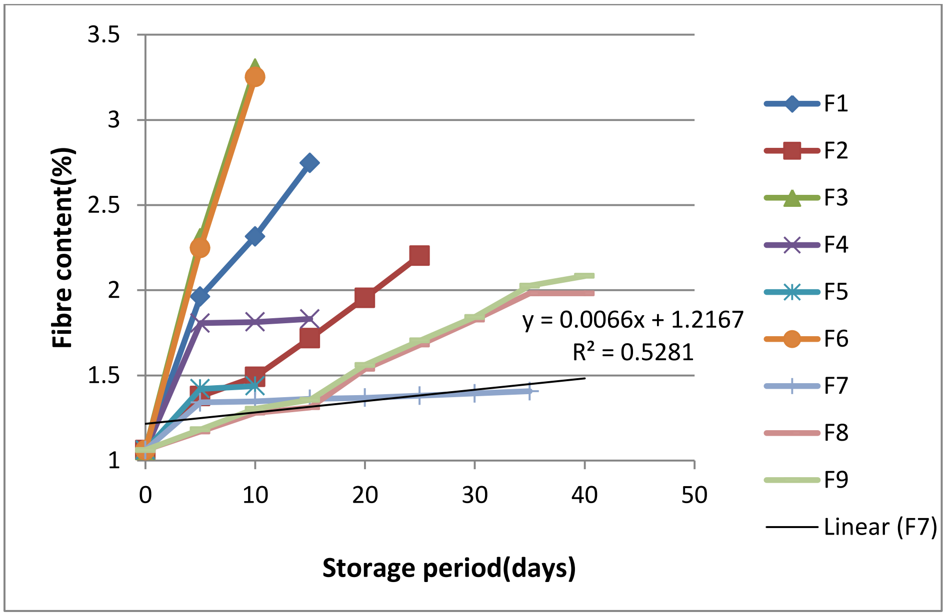


Fig. 4.9 Change in fiber content of *M4* variety

4.4.2.2 Change in fiber content of *Muttechi* variety

It was observed that fiber content of cassava roots increased during storage period. Statistical analysis showed a significant increase with a mean difference at 0.05 level. The minimum increase in fibre content was observed in cassava roots stored in sand (F2) filler material, followed by wooden shavings (F9) and coconut fibre (F7) up to 17days of storage period shown in Appendix II. After 17 days, minimum increase was observed in cassava roots stored in coconut fibre (F7) filler material (up to 27days) with a mean value of 1.88% from the initial fiber content of 1.2% followed by wooden shavings (F9) (37days) and sawdust (F8) (32 days) as shown in the Fig. 4.10 . The minimum increase in trend of cassava roots stored with coconut fibre (F7) filler material is shown by the equation 4.4.

$$y = 0.026x + 1.204 \ (R^2 = 0.968) \quad \ldots\ 4.4$$

Where x= storage days

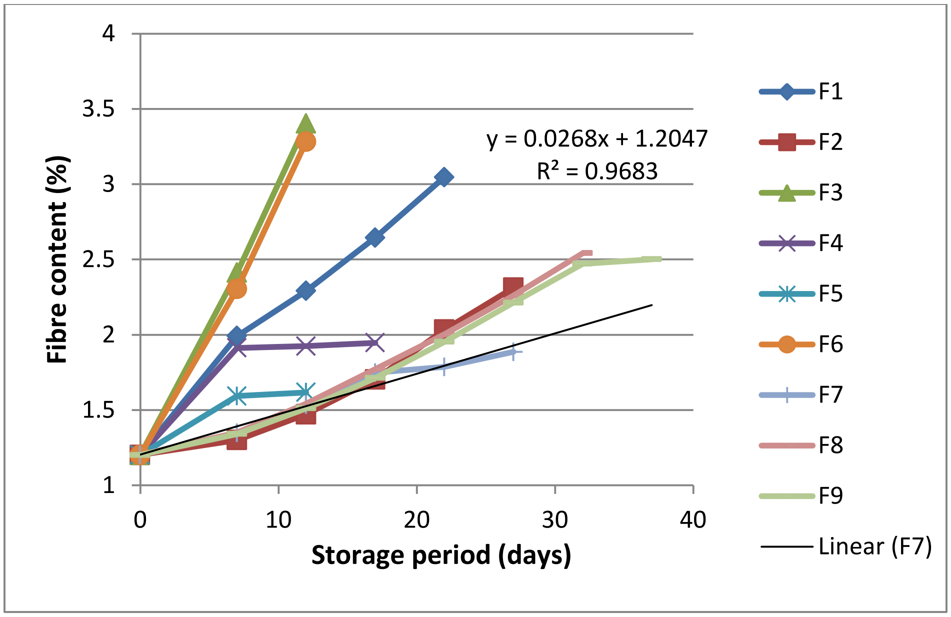


Fig. 4.10 Change in fiber content of *Muttechi* variety

4.4.2.3 Change in fibre content of cassava roots of *Muttechi* variety stored in three different filler materials in nine boxes made up of three different materials

Change in fiber content of cassava roots kept in three different filler materials in nine boxes made up of three different materials are shown in Fig.4.11, 4.12 and 4.13. Statistical analysis up to ten days of storage revealed that minimum increase in fiber content was observed in cassava roots stored in wooden shavings (F9) filler material in box made of wood (M1) material followed by plastic (M2) and plywood (M3). After 10 days of storage, results followed almost the same pattern.

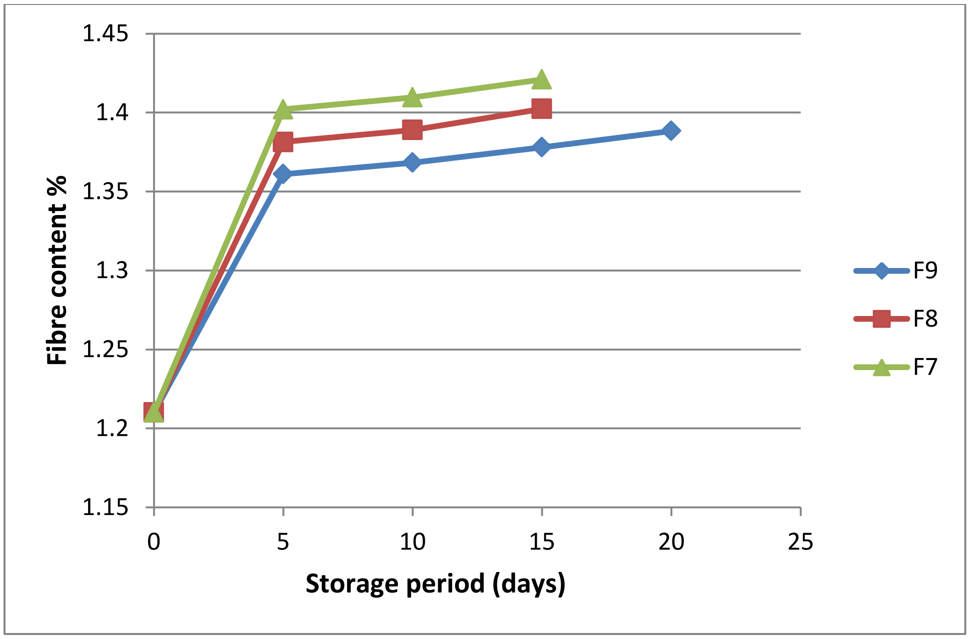


Fig. 4.11 Change in fiber content of *Muttechi* variety stored in wooden box

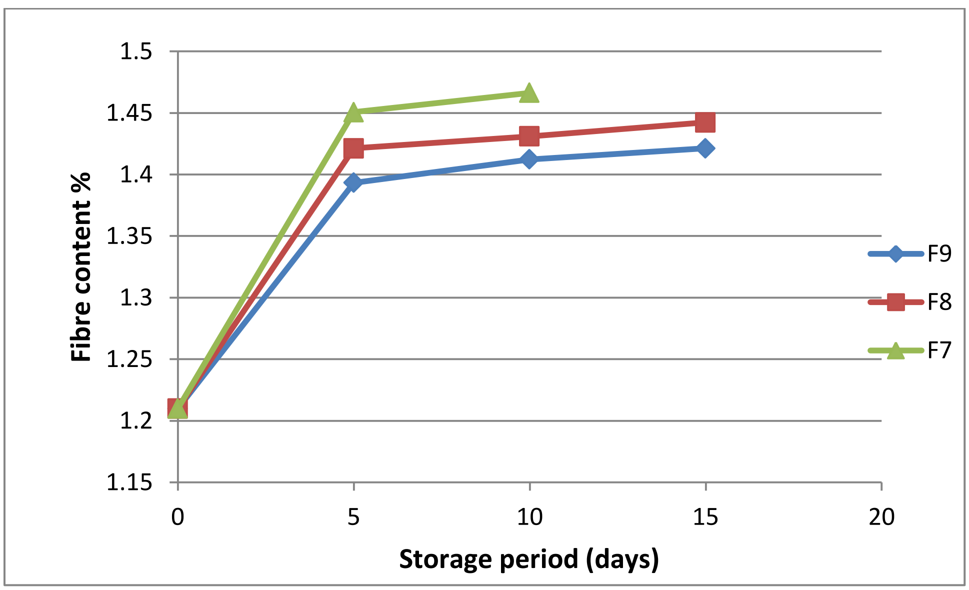


Fig. 4.12 Change in fiber content of *Muttechi* variety stored in plastic box

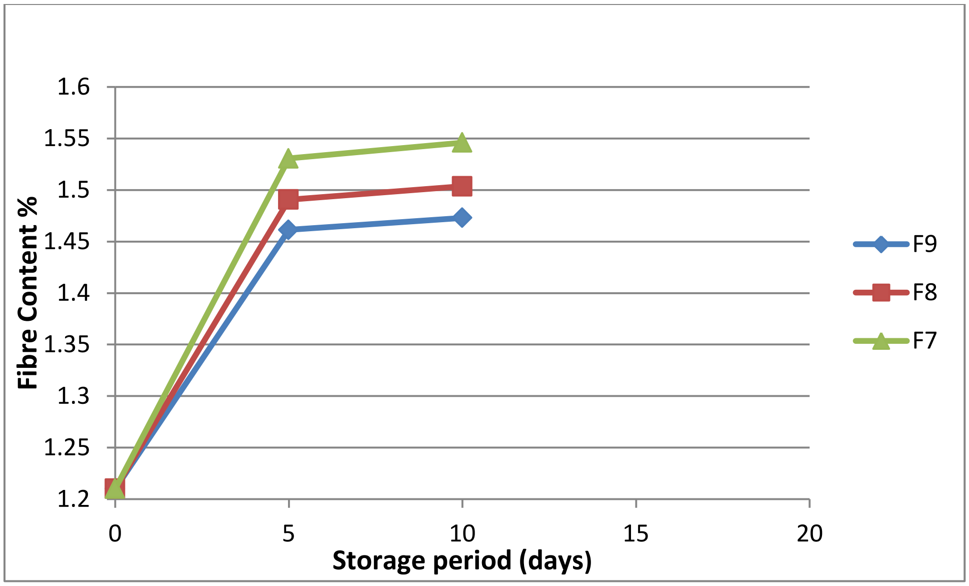


Fig. 4.13 Change in fiber content of *Muttechi* variety stored in plywood box

In all the experiments there was increase in fibre content of the cassava stored in boxes with filler material. This increasing trend was in conformity with the results of many other studies (Akingbala *et al*., 2005; Ezeocha and Oti, 2013). Increase in fiber content of roots may be due to condensed tannins from leucoanthocyanidins and cathechin during vascular streaking as observed by similar studies (Wheatly, 1984; Rickard, 1985). The increase in fiber content of the cassava is a negative parameter and the quality is regarded as poor for consumption purposes. This might be due to the effect of other physical and chemical parameters other than fiber content of the roots. Increase in fiber content indicates the natural aging of the roots and loosing consumer appeal. It may also be due to the decreasing nutritional and moisture content from within the roots. In the third experiment wooden boxes gave better results along with wooden shavings (F9) as a filler material. Wooden box appears to have given the roots almost natural environment to cassava roots to survive for a longer duration.

4.4.3 Carbohydrate content

The carbohydrate fractions of plants are a very diverse category of compounds, that generally include non-cell wall compounds simple sugars involved in intermediary plant metabolism, and storage compounds such as starches and fructans, and cell wall compounds include structural carbohydrates such as pectin, hemicelluloses, cellulose and lignin. The main use of cassava is to supplement carbohydrates into our dietary system**.** In the beginning Glucose standard curve was calibrated. From this standard calibration curve the total carbohydrates of the cassava samples in mg /ml was determined.

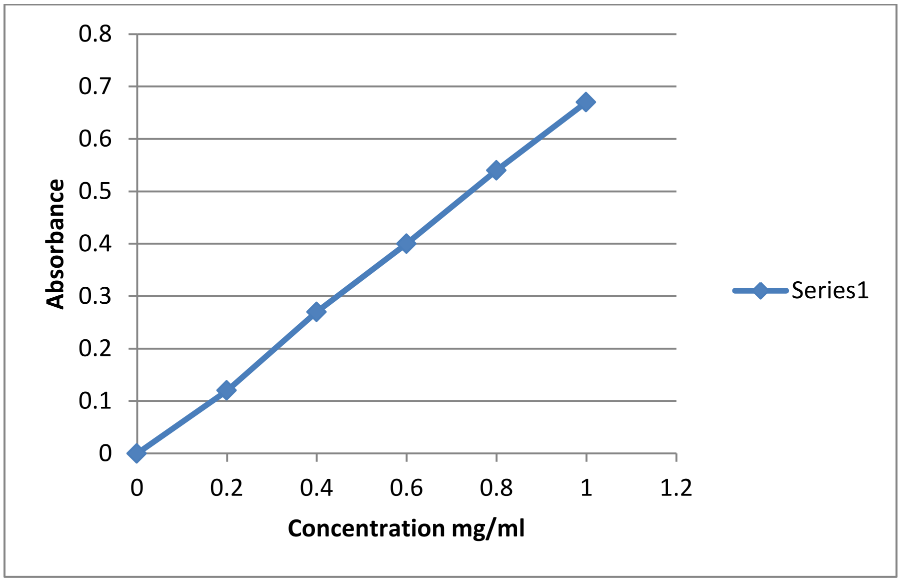


Fig. 4.14 Standard curve for carbohydrate estimation

4.4.3.1 Changes in carbohydrate content of *M4* variety

The below shown figure 4.12 indicates that carbohydrate content of cassava roots decreased during storage period in all the filler materials. Among the filler materials, cassava roots stored in filler wooden shavings (F9) had a minimum decrease in carbohydrate content with a mean value of 21.07% (from initial value of 26.7%) followed by sawdust (F8) up to 40 days of storage. The minimum decreasing trend of cassava roots stored with wooden shavings (F9) filler material is shown by the equation 4.5

$$y = -0.121x+25.16 \ (R^2 = 0.832) \qquad \text{.....4.5}$$

Where x= storage days.

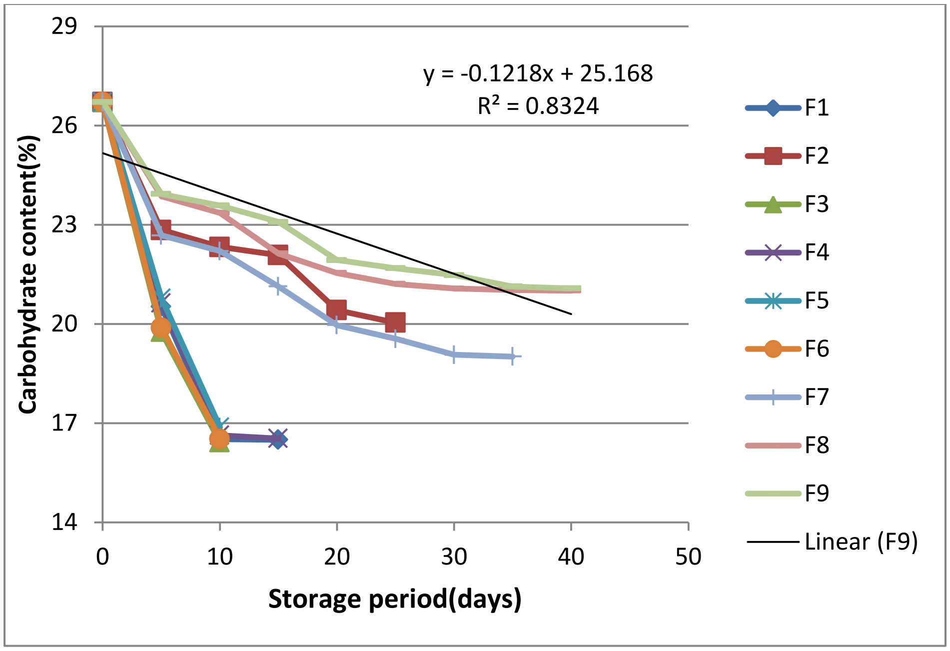


Fig. 4.15 Change in carbohydrate content of *M4* variety

4.4.3.2 Change in carbohydrate content of *Muttechi* variety

Carbohydrate content decreased during storage period in all the filler materials. Among the filler materials, cassava roots stored in filler wooden shavings (F9) had a minimum decrease in carbohydrate content with a mean value of 16.75% (from an initial value of 22.31%) up to 32 days of storage. The minimum decreasing trend of cassava roots stored with wooden shavings (F9) filler material is shown by the equation 4.6

$$y = -0.135x+21.18 \ (R^2 = 0.883) \qquad \ldots.4.6$$

Where x= storage days.

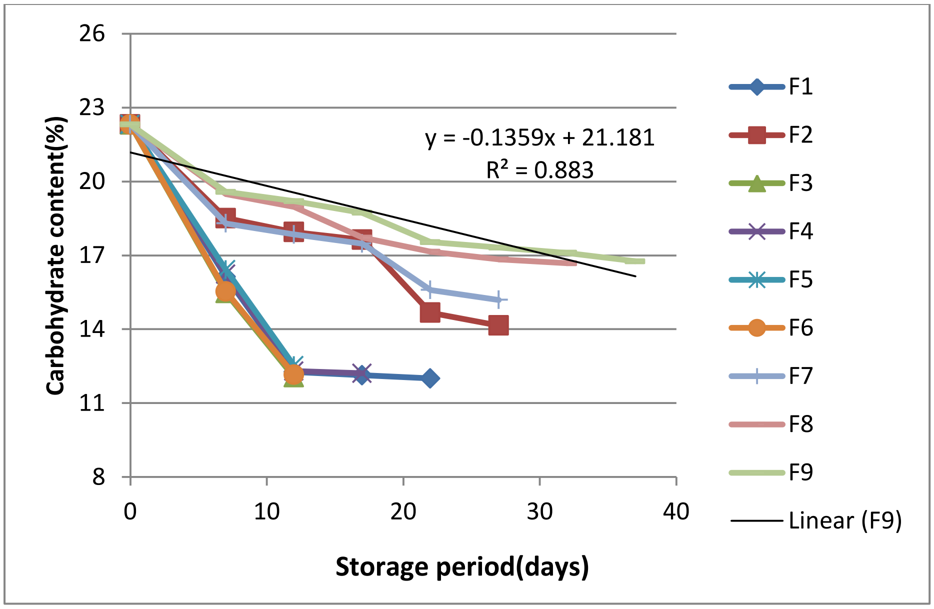


Fig. 4.16 Change in carbohydrate content of *Muttechi* variety

4.4.3.3 Change in carbohydrate content of cassava roots stored in three different filler materials in nine boxes made up of three different materials

Change in carbohydrate content of cassava roots stored in three different filler materials in nine boxes made up of three different materials are represented in Fig. 4.17, 4.18 and 4.19. Statistical analysis up to 10 days of storage revealed a marginal decrease in carbohydrate content of cassava roots stored in wooden shaving (F9) filler material stored in box made of material wood (M1) followed by plastic (M2) and plywood (M3) show in Appendix III. After 10 days of storage, results followed the similar trend in M1 – F9 combination.

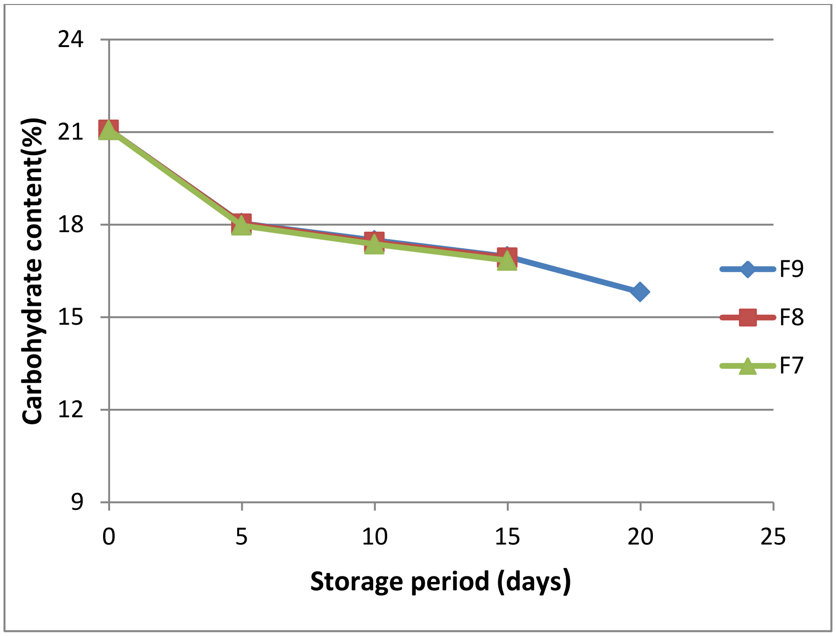


Fig. 4.17 Change in carbohydrate content of *Muttechi* variety stored in wooden box

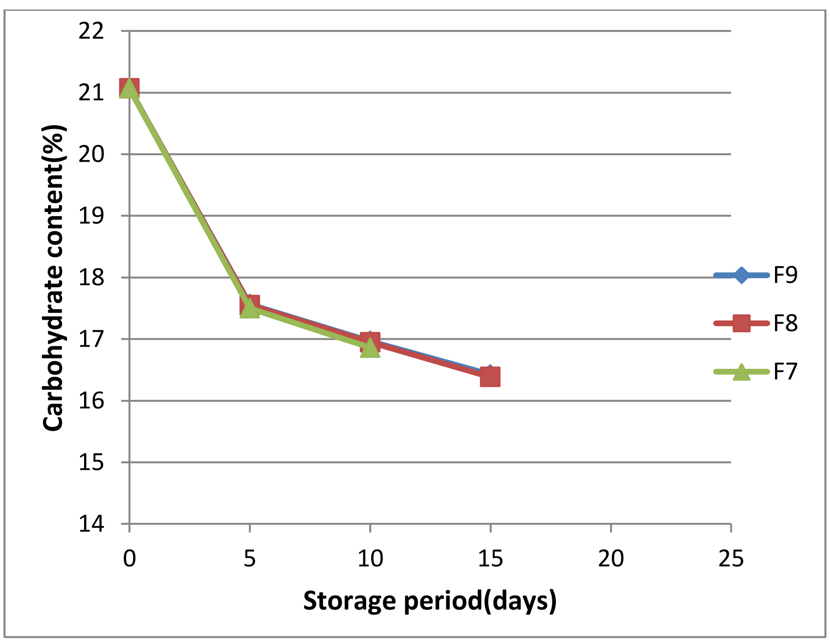


Fig. 4.18 Change in carbohydrate content of *Muttechi* variety stored in plastic box

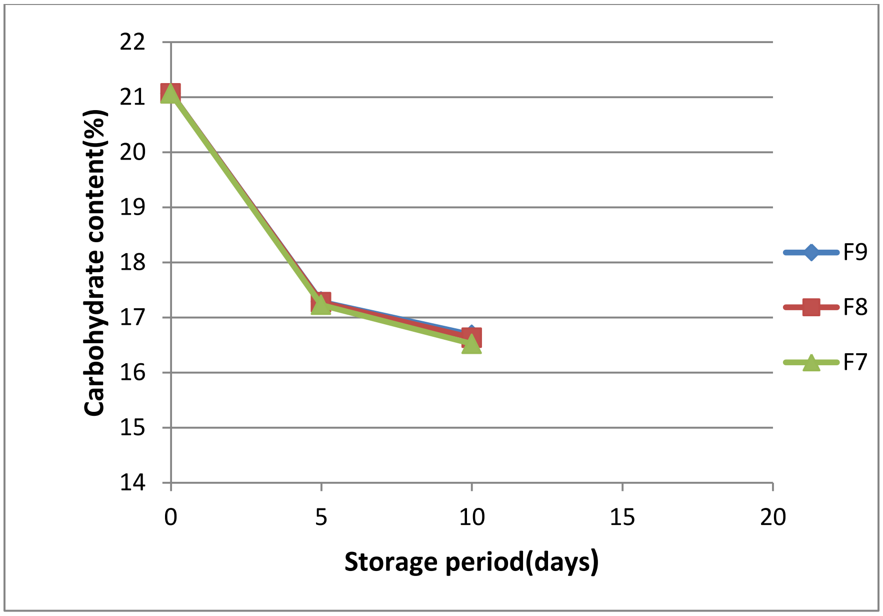


Fig. 4.19 Change in carbohydrate content of *Muttechi* variety stored in plywood box

Carbohydrate content of cassava roots stored in different filler materials showed a significant difference during storage period. The decrease in starch in cassava roots is due to the rapid deterioration in quality during storage of cassava roots (Wenham, 1995). Enzymatic hydrolysis of the starch, decreases utilization quality of cassava roots (Ihedioha *et al*., 1996). It is also reported that starch content of cassava roots decrease during storage due to conversion of starch to sugar and respiratory losses (Sahore *et al*., 2007). Decrease in carbohydrate content indicates falling nutritional value and non usability of the roots for consumption. The carbohydrate content being the major nutritional value of the cassava roots, the decrease of the same at minimum level is a welcome trend. Hence the minimum loss of this nutrient during storage is important to make the root as an economical and acceptable supplier of carbohydrate.

The results of the present study on carbohydrate content of cassava roots, on fresh weight basis with grinding, was in accordance with the observations of many other studies (Montagnac, 2009; Zvinavashe *et al*., 2011). The decreasing trend of carbohydrate content during storage was also in sequence with the findings observed in similar studies (Akingbala *et al*., 2005; Silim *et al*., 1992; Sanche *et al*., 2013).

The filler material wooden shavings (F9) gave excellent results in all the experiments. It appears that minimum retention of moisture and good air circulation in cassava roots stored in wooden shavings (F9) filler in wooden storage box have given the cassava roots an environment congenial and nearly natural to survive for a longer duration. The carbohydrate content decreased from 26.71% to 21.01% for a storage period of 40 days in wooden boxes filled with wooden shavings for M4 variety. The similar results were observed by Karim *et al*. (2009) who found that carbohydrate content decreases up to 25% from initial content of 35% (Fresh weight basis with grinding) for the roots stored in different material boxes (plastic box, jute bag, polyethylene bag, trench box) using sawdust as a filler material.

4.4.4 Cyanide content

Cyanide is a toxic content present in leaves and roots of cassava and it is dangerous for consumption. Cassava roots are essentially storage organs of the cassava plant and hence the presence of cyanide content appears to be a natural protective cover to the roots from bacterial activities.

Cyanide is present in cassava roots in two forms, bound cyanide present as the cyanogenic glucoside and free cyanide present as the cyanohydrin, that is free hydrogen cyanide which is a gas above 26ºC under alkaline conditions and as cyanide ion (Bradbury and Holloway, 1988). The total cyanide content of cassava parenchyma is dependent on the cultivar, the environment and various other factors (Balagopalan, 2000). In the beginning cyanide standard curve was calibrated. From this standard calibration curve the total cyanide content of the cassava samples in mg /kg was determined.

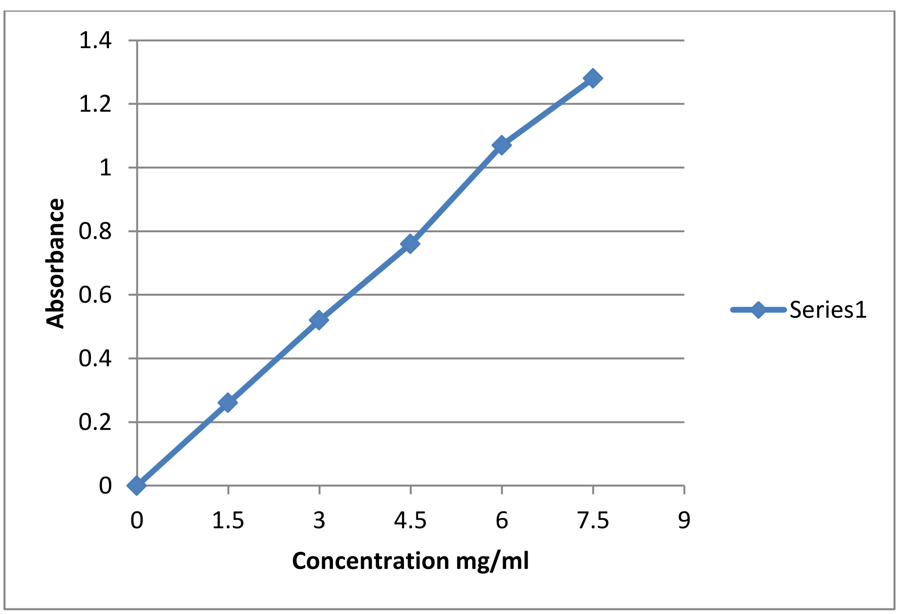


Fig. 4.20 Standard curve for cyanide estimation

4.4.4.1 Change in cyanide content of *M4* variety

Variety *M4* used for first study had high amount of cyanide when compared to variety *Muttechi* used for second and third study. Cyanide content of cassava roots of *M4* variety did not show a significant difference during the storage period. Maximum decrease in cyanide content was observed in cassava roots stored in filler sand (F2) up to 15 days with the mean value of 67.53 mg/kg (from initial value of 71.81 mg/kg) followed by cassava leaves (F1) and wooden shavings (F9). A steep decrease of cyanide content was observed (after 15 days up to 35 days) in cassava roots stored in coconut fibre (F7) filler with a mean value of 59.23 mg/kg (from an initial value of 71.81 mg/kg), followed by wooden shavings (F9) and sawdust (F8) as shown in the Fig. 4.21 here under. The decreasing trend of cassava roots stored in coconut fibre (F7) filler material is shown by the equation 4.7

$$y=-0.367x+72.70 \ (R^2 = 0.980) \qquad \ldots. \ 4.7$$

Where x=storage period

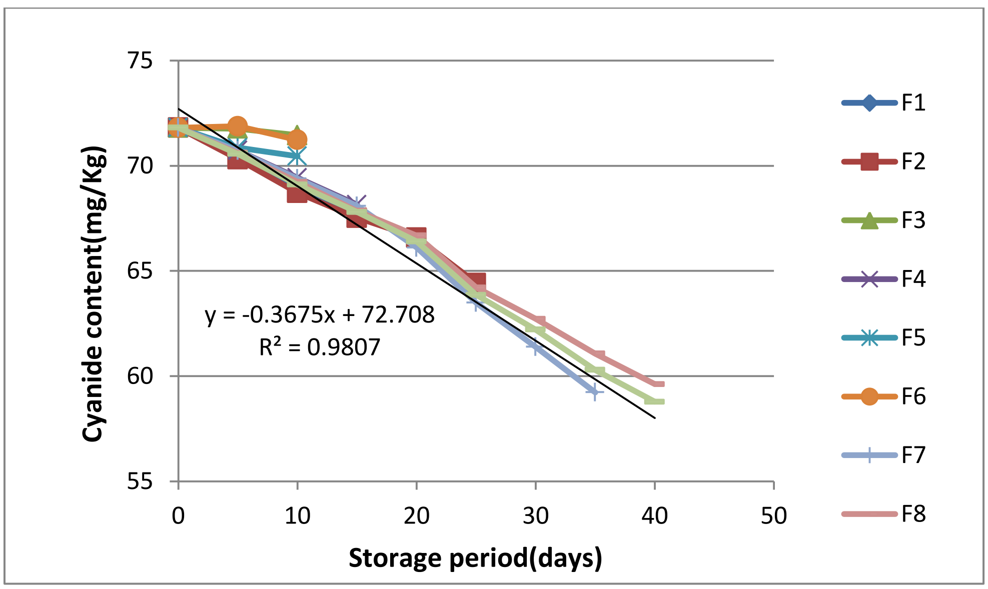


Fig. 4.21 Change in cyanide content of *M4* variety

4.4.4.2 Change in cyanide content of *Muttechi* variety

There was a significant difference in cyanide content in cassava roots of *Muttechi* variety stored in different filler materials up to 17 days of storage. Maximum decrease in cyanide content was observed in cassava roots stored in filler sawdust (F8) followed by wooden shavings (F9) as shown in Appendix IV. After 17 days of storage, the decrease in trend followed a same trend till 37 days. Cassava roots stored in filler sawdust (F8) had a maximum decrease with a mean value of 44.54 mg/kg from initial value of 51.8 mg/kg (up to 32 days) followed by wooden shavings (F9) (upto 37days) as shown in the Fig. 4.22. The decreasing trend of cassava roots stored in sawdust (F8) filler material is explained by the equation 4.8.

$$y=-0.215x+51.22 (R^2 = 0.965) \quad \text{.... 4.8}$$

Where x=storage period

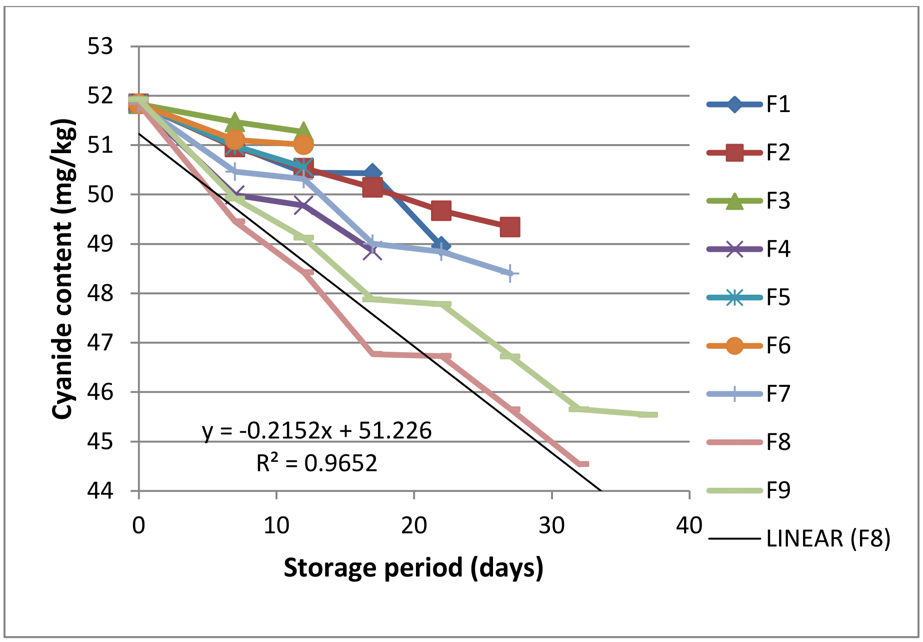


Fig. 4.22 Change in cyanide content of *Muttechi* variety

4.4.4.3 Change in cyanide content of cassava roots of *Muttechi* variety stored in three different filler materials in nine boxes made up of three different materials

Significant difference in cyanide content of cassava roots was observed for a storage period of 10 days of cassava roots kept in nine boxes made up of three different materials containing three different filler materials. Maximum decrease in cyanide content was observed in cassava roots stored in filler coconut fibre (F7) followed by sawdust (F8) and wooden shavings (F9) in box made of plywood (M3) material, followed by wooden (M1) and plastic (M2) material boxes. The results followed the similar trend up to 15 days of storage as shown in the Fig. 4.23, 4.24 and 4.25.

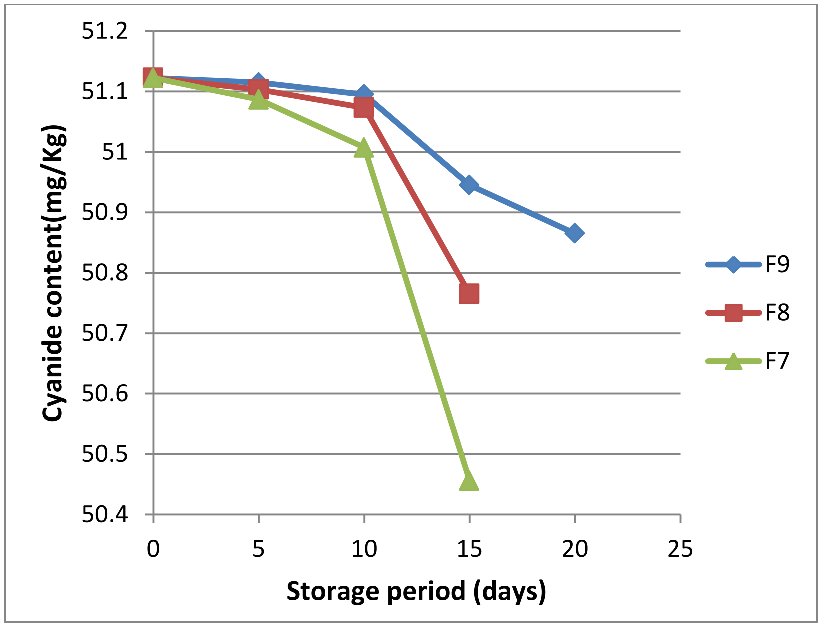


Fig. 4.23 Change in cyanide content of *Muttechi* variety stored in wooden box

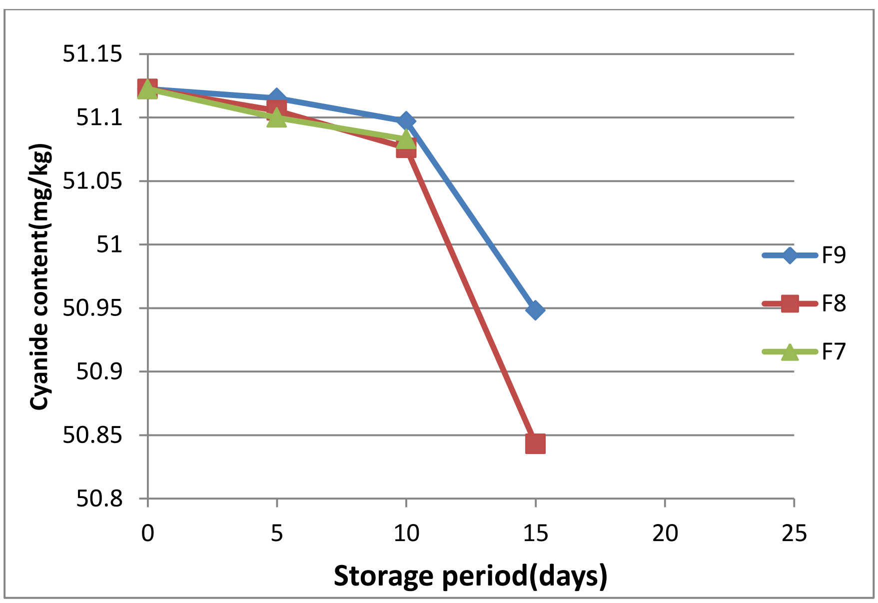


Fig. 4.24 Change in cyanide content of *Muttechi* variety stored in plastic box

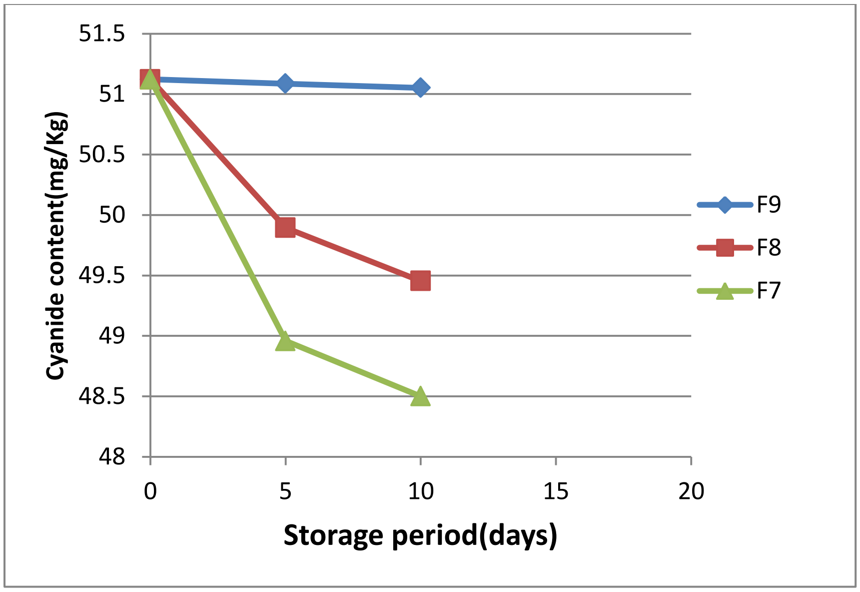


Fig. 4.25 Change in cyanide content of *Muttechi* variety stored in plywood box

In all the experiments it was found that the cyanide content decreased during storage period along with reduction in moisture content thereby showing that cyanide content can remain in higher levels when there is more moisture content. Presence of cyanide in large percentage is not good from the consumption point of view and hence it appears that cassava roots stored for longer periods are better for consumption when compared to freshly harvested roots as far as cyanide parameter is concerned.

The decreasing trend was in line with the observation made by Karim *et al*. (2009). Similar ranges of cyanogenic potential (31 to 630 mg/kg) in the root (fresh weight) were found in larger collections of varieties at the International Institute of Tropical Agriculture (IITA) in Nigeria (851 genotypes) and in 560 genotypes at the Centro International de Agricultural Tropical (CIAT) in Colombia (Bokanga, 1994).

The decrease of cyanide content was more in cassava roots stored in coconut fibre (F7) in *M4* variety, saw dust (F8) in *Muttechi* variety as a filler. It was observed that cassava kept in boxes made of plywood (M3) material gave better results than cassava kept in other boxes. The trend observed was that more decrease in cyanide content in cassava roots stored in coconut fibre (F7) followed by sawdust (F8) and wooden shavings (F9). Decreasing trend of cyanide content was also in line with the decreasing value of moisture content in the roots and hence it may be concluded that cyanide has reduced with the decrease in moisture content in the roots.

4.4.5 Firmness and toughness

Firmness is the characteristic of a material expressing its resistance to permanent deformation. Toughness is the resistance to fracture of a material when stressed or the amount of energy that a material can absorb before rupturing, and can be found by finding the area underneath the stress-strain curve. Firmness and toughness of cassava roots is an indicator of good edible quality of the roots with more consumer appeal.

4.4.5.1 Change in firmness and toughness of *M4* variety

Both firmness and toughness decreased during the storage period. The decreasing trend in the firmness and toughness during the storage period is shown in the Fig. 4.26. For storage period up to 40 days, Maximum retention of firmness was observed in cassava roots stored in wooden shavings (F9) filler material with the firmness value of 86.17367 N (from the initial value of 92.09 N) followed by sawdust (F8) and coconut fibre (F7) (up to 35days). The decreasing trend of cassava roots stored in wooden shaving (F9) filler material is explained by the equation 4.9

$$y=-0.170x+92.89 \ (R^2 = 0.941) \qquad \ldots.4.9$$

Where x=storage period

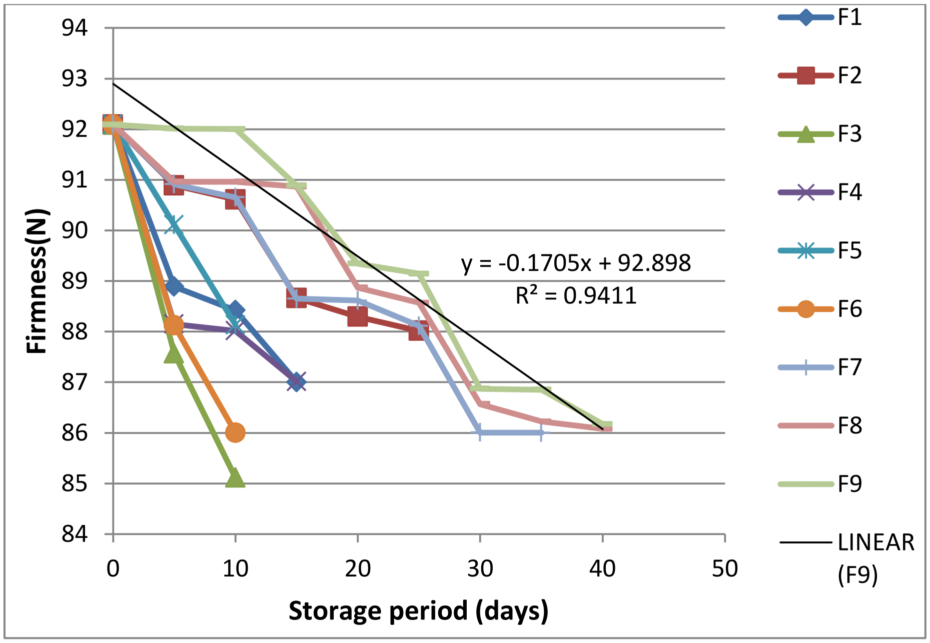


Fig. 4.26 Change in firmness of cassava roots of *M4* variety

Toughness of cassava roots of *M4* variety showed a significant difference during the storage period. Statistical analysis up to 15 days of storage revealed that in case of *M4* variety of cassava roots stored in wooden shaving (F9) filler had retained maximum toughness followed by sawdust (F8) and coconut fibre (F7) fillers as shown in Appendix VI.

Between 15 days and 40 days of storage, cassava roots stored in wooden shavings (F9) filler had retained maximum toughness with a value of 106.12 N/sec (from initial value of 115.37 N/sec) followed by cassava roots stored in sawdust (F8) and coconut fibre (F7) filler materials. The decreasing trend of cassava roots stored in wooden shaving (F9) filler is shown by the equation 4.11

$$y=-0.266x+115.7 \ (R^2 = 0.921) \qquad \text{..... 4.11}$$

Where x=storage period

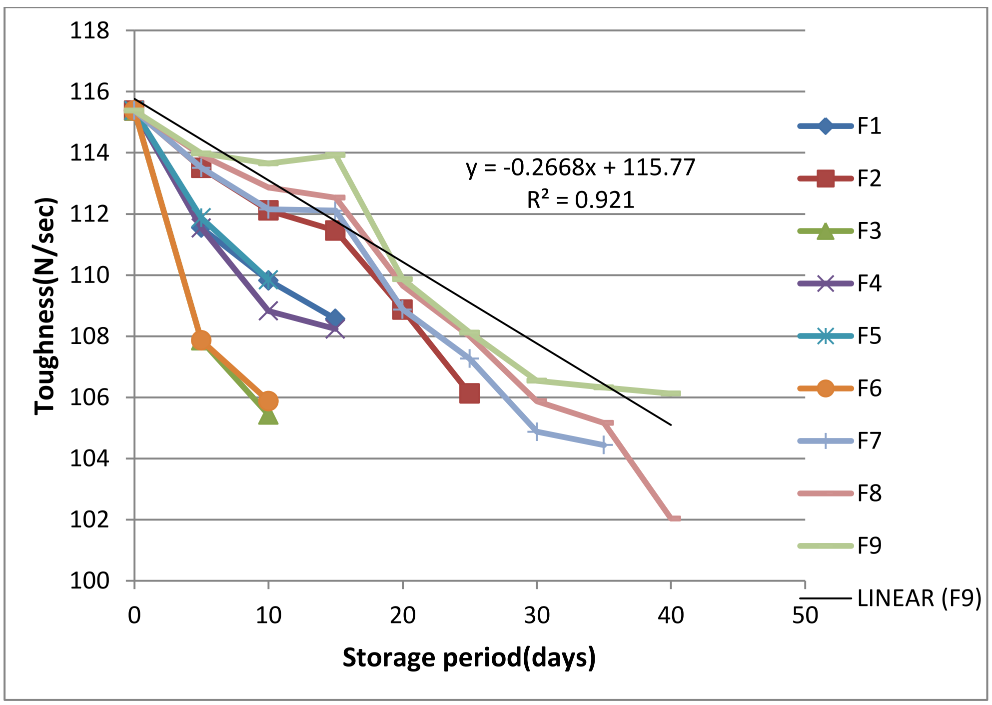


Fig. 4.27 Change in toughness of cassava roots of *M4* variety

4.4.5.2 Change in firmness and toughness of *Muttechi* variety

Firmness and toughness in the *Muttechi* variety decreased during the storage period and statistically mean difference was significant at 0.05 levels up to 17days of storage period and is shown in Appendix V & VI. Maximum retention of firmness up to 17 days of storage was observed in cassava roots stored wooden shaving (F9) filler material followed by sawdust (F8) and coconut fibre (F7) filler materials. Between 17 days and 32 days of storage, cassava roots stored in sawdust (F8) filler with a firmness value of 92.44 N (from initial value of 98.10 N) had retained the maximum firmness followed by wooden shaving (F9) (up to 37 days). The decreasing trend of cassava roots stored in sawdust (F8) filler is explained by equation 4.10

$$y=-0.172x+98.20(R^2 = 0.966) \quad \text{…. 4.10}$$

Where x=storage period.

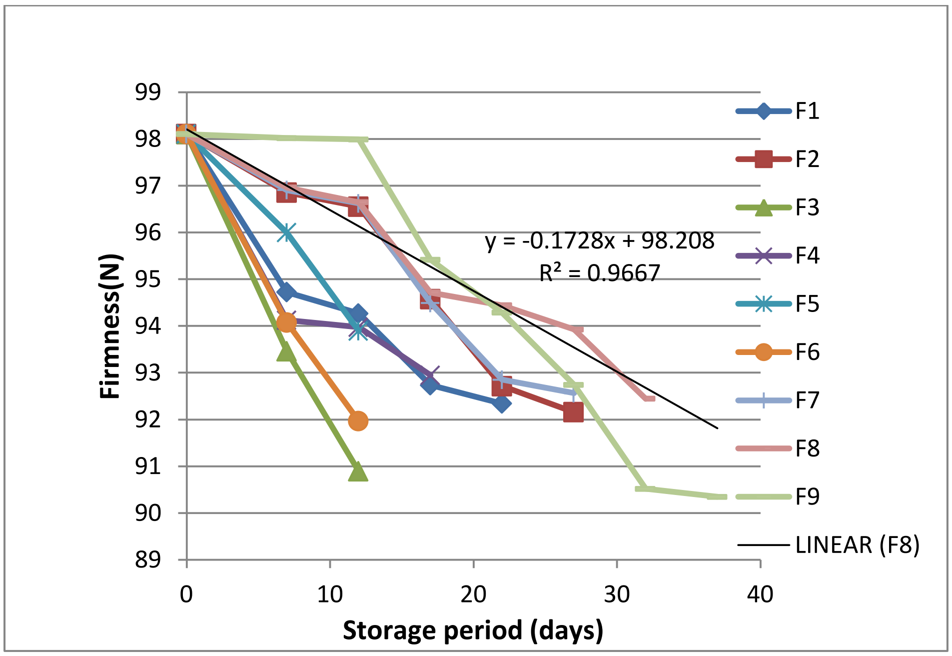


Fig. 4.28 Change in firmness of cassava roots of *Muttechi* variety

Cassava roots stored in filler sawdust (F8) had retained maximum toughness followed by wooden shaving (F9) sand (F2) fillers up to 17 days of storage as shown in Appendix VI. Between 17 days and 32 days of storage, cassava roots of variety *Muttechi* stored in sawdust (F8) filler with decreasing value of 113.76 N/sec (from a initial value of 122.96 N/sec) had retained maximum toughness followed by wooden shavings(F9) and sand (F2). The decreasing trend in toughness of cassava roots stored in sawdust (F8) filler is explained by the equation 4.12.

$$y = -0.296x+123.7(R^2 = 0.959) \quad \text{….4.12}$$

Where x=storage period

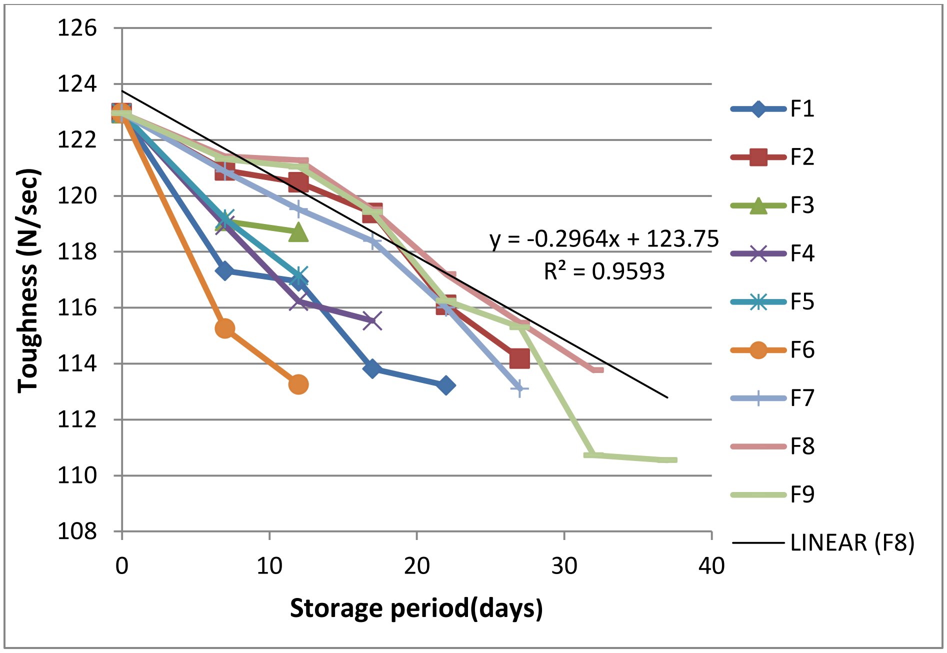


Fig. 4.29 Change in toughness of cassava roots of *Muttechi* variety

4.4.5.3 Change in firmness and toughness of cassava roots of *Muttechi* variety stored in three different filler materials in nine boxes made up of three different materials

Change in the trend of toughness and firmness of cassava roots were almost similar in third experiment as shown in figures below. Maximum retention of firmness and toughness was observed in cassava roots stored in filler wooden shavings (F9) stored in wooden box (M1) material with a firmness value of 90.748N from initial value of 91.106 N, toughness value of 112.78 N/s from initial value of 114.19 N/s upto 20 days followed by sawdust (F8) and coconut fibre (F7) fillers. With regard to the materials of boxes, maximum firmness and toughness was retained by cassava roots stored in box made up of wooden (M1) material followed by plastic (M2) and plywood (M3) material boxes which is shown in the below figures.

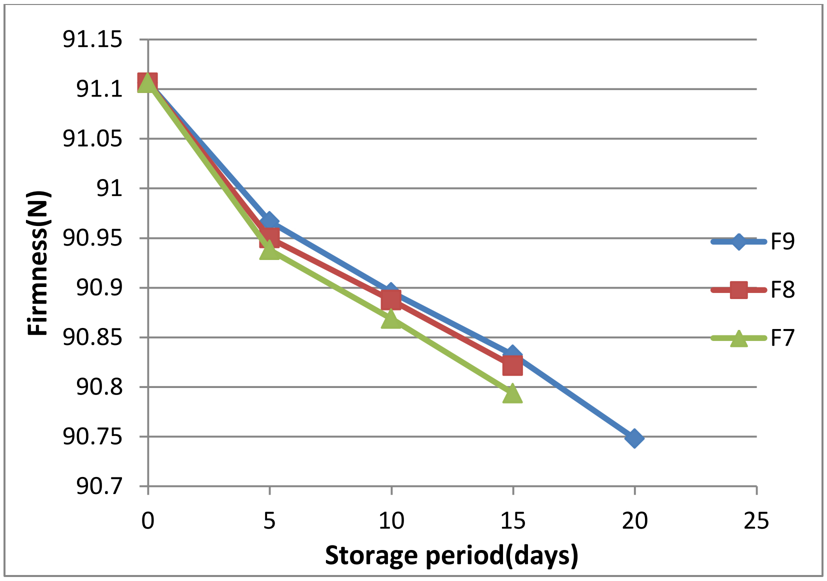


Fig. 4.30 Change in firmness of *Muttechi* variety stored in wooden box

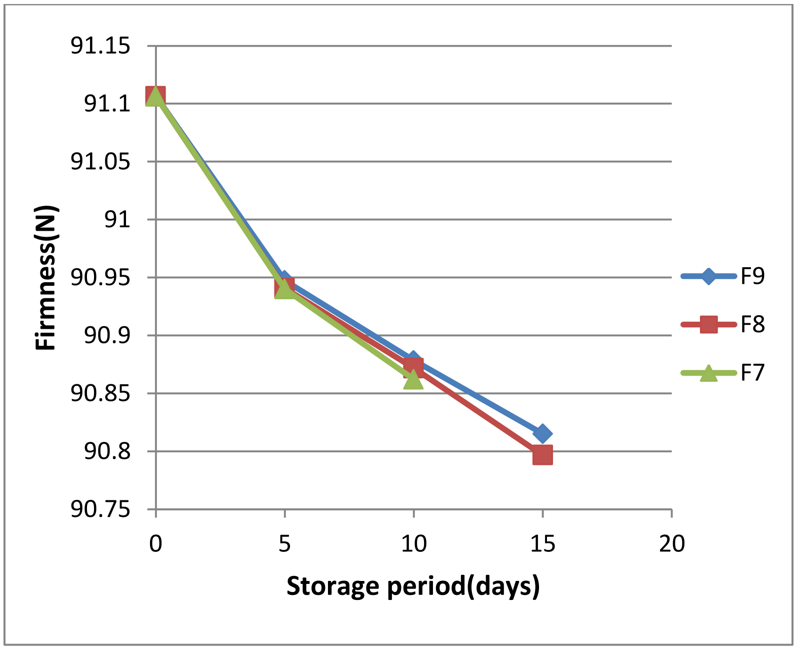


Fig. 4.31 Change in firmness of *Muttechi* stored in plastic box

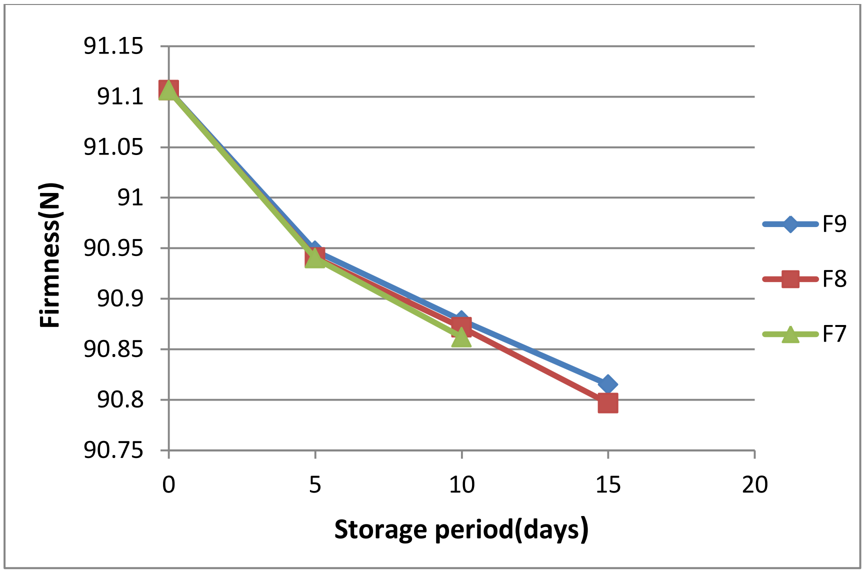


Fig. 4.32 Change in firmness of *Muttechi* variety stored in plywood box

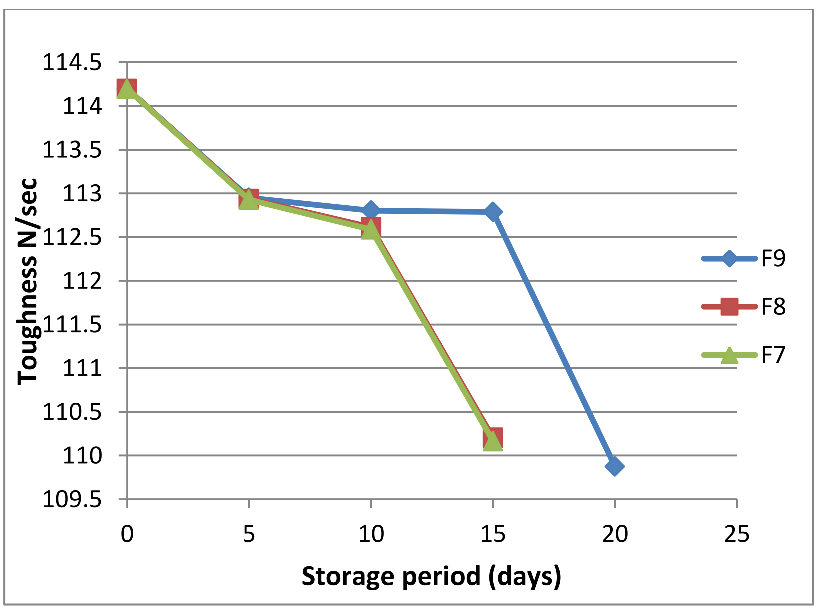


Fig. 4.33 Change in toughness of *Muttechi* variety stored in wooden box

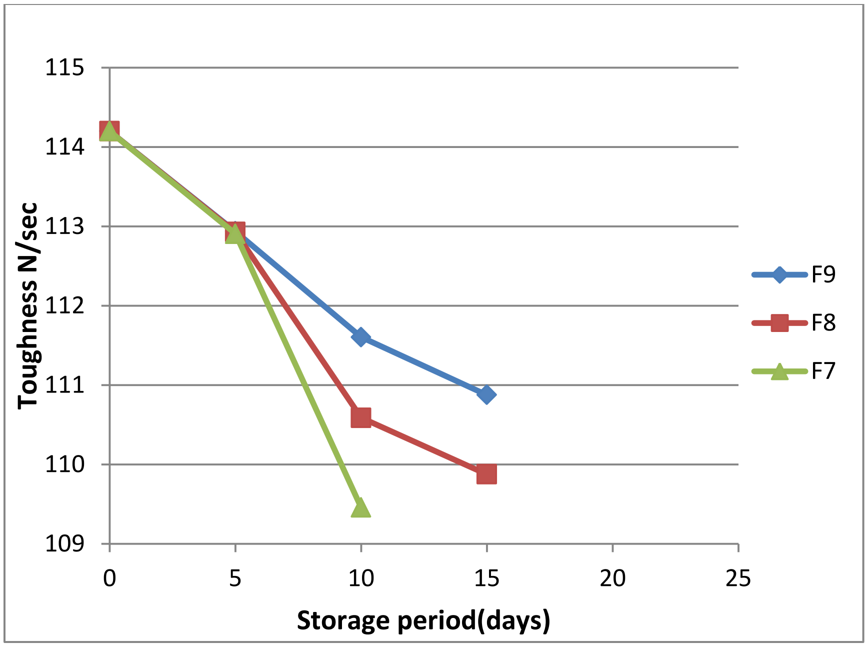


Fig. 4.34 Change in toughness of *Muttechi* variety stored in plastic box

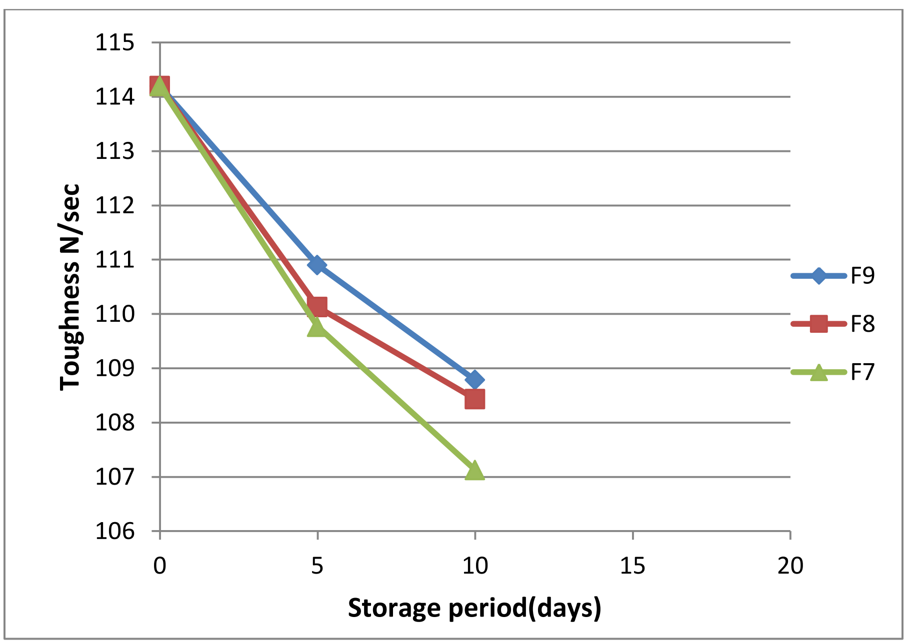


Fig. 4.35 Change in toughness of *Muttechi* variety stored in plywood box

In the present study cassava roots stored in wooden shavings (F9), sawdust (F8) and coconut fibre (F7) filler materials and boxes made of wood, maintained firmness, toughness and freshness of the roots. It may be due to the better air circulation, less bacterial activity and retention of the moisture. Change in firmness and toughness were in accordance with the same results observed by Ubalua and Oti, (2008).

The rapid water removal in the roots may cause the cell wall polysaccharides to shrink permitting greater interactions by means of hydrogen bonding and Vanderwals forces, which might result in increased cell rigidity and softening during storage of tubers (Ezeocha and oti, 2013).

When the results of earlier experiments were verified with these results, it was found that firmness and toughness are closely associated with parameters such as retention of moisture content, retention of nutritional values of the cassava roots. Since these are the qualities favorable from the consumption point of view, the firmness and toughness of the roots could be treated as a broad indicator of the quality of the cassava roots. Though the parameters were measured scientifically in this experiment, it can be evaluated by physical touching and sensing by experience.

4.4.6 Physiological loss in weight

4.4.6.1 Change in physiological loss in weight of *M4* variety

In case of *M4* variety up to 15 days of storage minimum weight loss was observed in cassava roots stored in clay (F3) filler material followed by sponge (F4) and plastic cutting (F6). Between 15 days and 35 days of storage, minimum weight loss was observed in cassava roots stored in wooden shaving (F9) filler material up to 40th day followed by sand (F2) filler (up to 25th day) as shown in the Fig. 4.36. The trend in minimum weight loss in cassava roots stored in wooden shavings (F9) filler material is explained by the equation 4.13.

$$y = 0.059x+1.142(R^2 = 0.708) \qquad \text{…. 4.13}$$

Where x=storage period

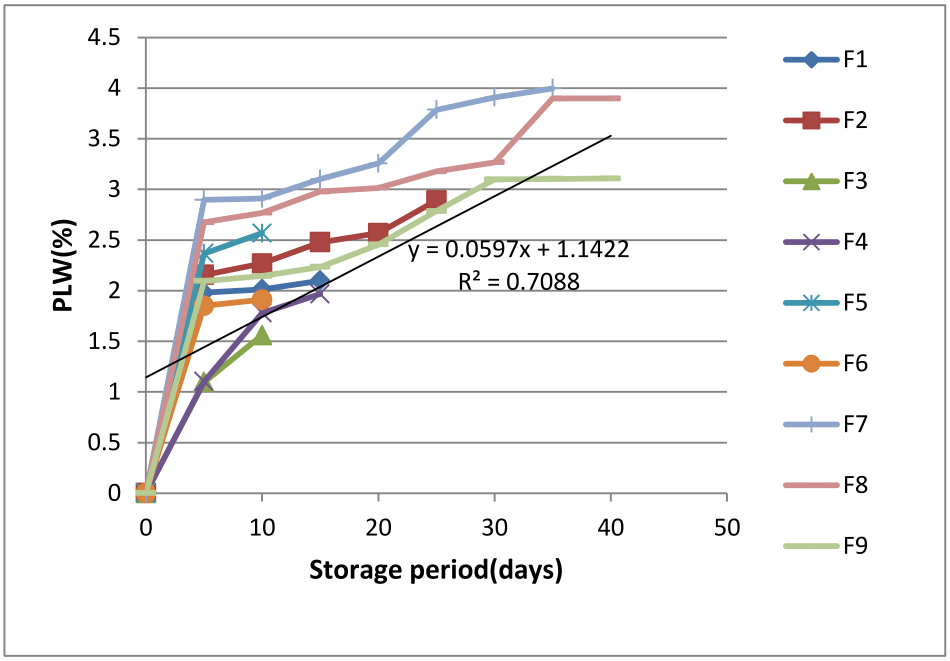


Fig. 4.36 Change in PLW of *M4* variety

4.4.6.2 Change in physiological loss in weight of *Muttechi* variety

In *Muttechi* variety, minimum weight loss up to 17 days was observed in cassava roots stored in coconut fibre (F6) filler material followed by clay (F3) and cassava leaves (F1) filler materials shown in Appendix VII. Between 17 days and 32 days, minimum weight loss was observed in cassava roots stored in wooden shavings (F9) filler material as shown in the Fig. 4.37 here under. The trend of minimum weight loss in cassava roots stored in wooden shaving (F9) filler is shown by the equation 4.14

$$y = 0.072x + 1.494 \ (R^2 = 0.585) \qquad \text{…. 4.14}$$

Where x=storage period

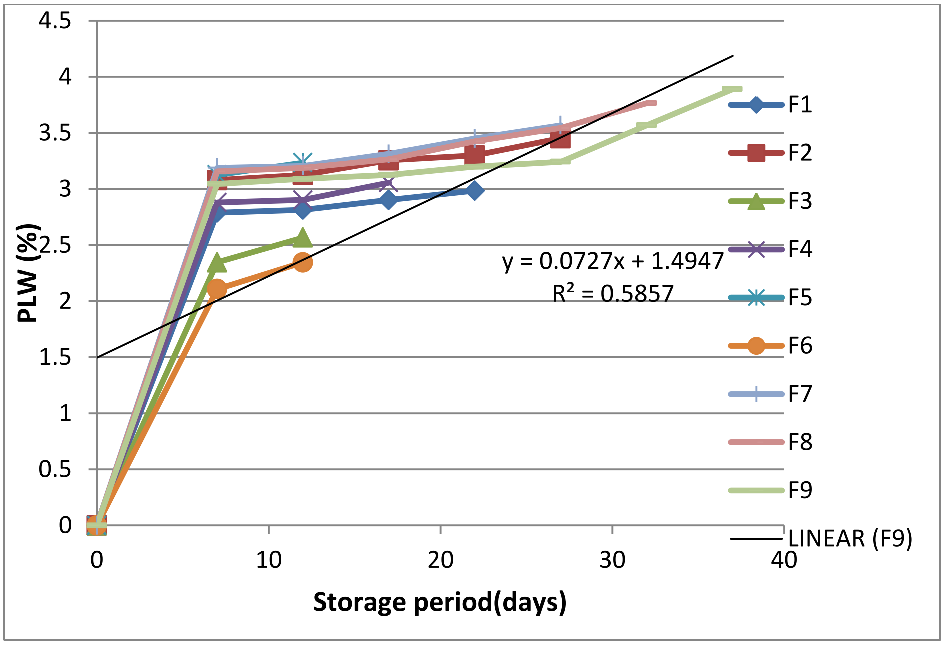


Fig. 4.37 Change in PLW of *Muttechi* variety

4.4.6.3 Change in physiological loss in weight of cassava roots stored in three different filler materials in nine boxes made up of three different materials

There was no significant difference in weight loss of cassava roots in the third Study. Compared to other filler materials cassava roots stored in filler wooden shavings (F9) had minimum decrease followed by sawdust (F8) and coconut fibre (F7) as shown in the Fig. 4.38, 4.39 and 4.40. With regards to the materials, cassava roots stored in material of box made of plastic (M2) had minimum decrease in weight in case of all the filler materials when compared to box made of wood (M1) and plywood (M3) material.

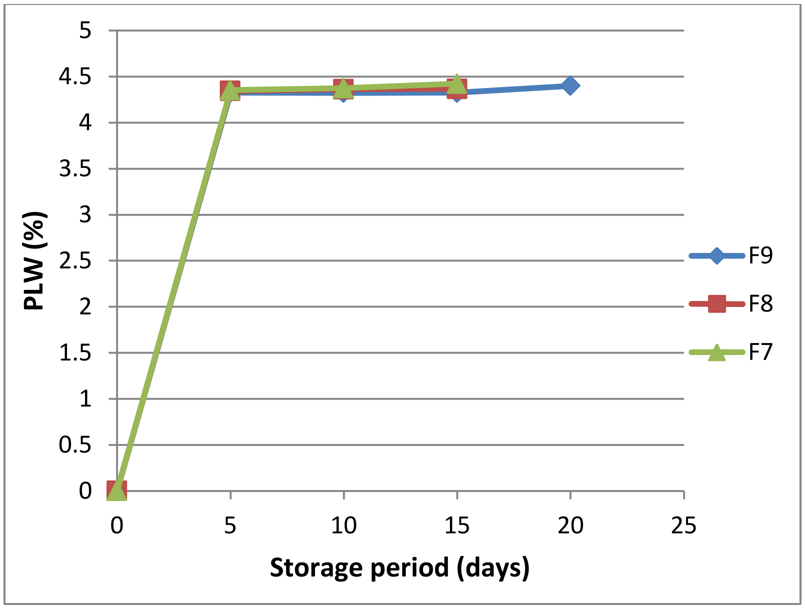


Fig. 4.38 Change in PLW of *Muttechi* variety stored in wooden box

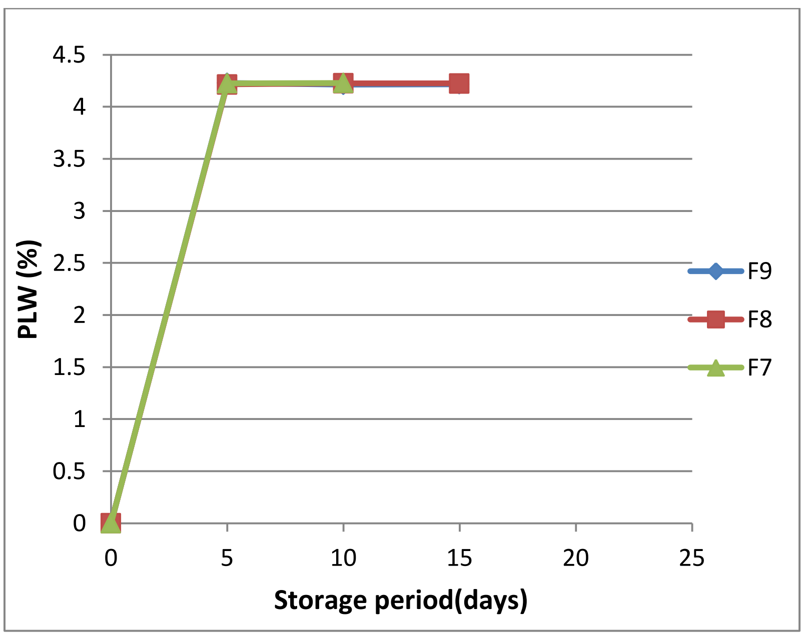


Fig. 4.39 Change in PLW of *Muttechi* variety stored in plastic box

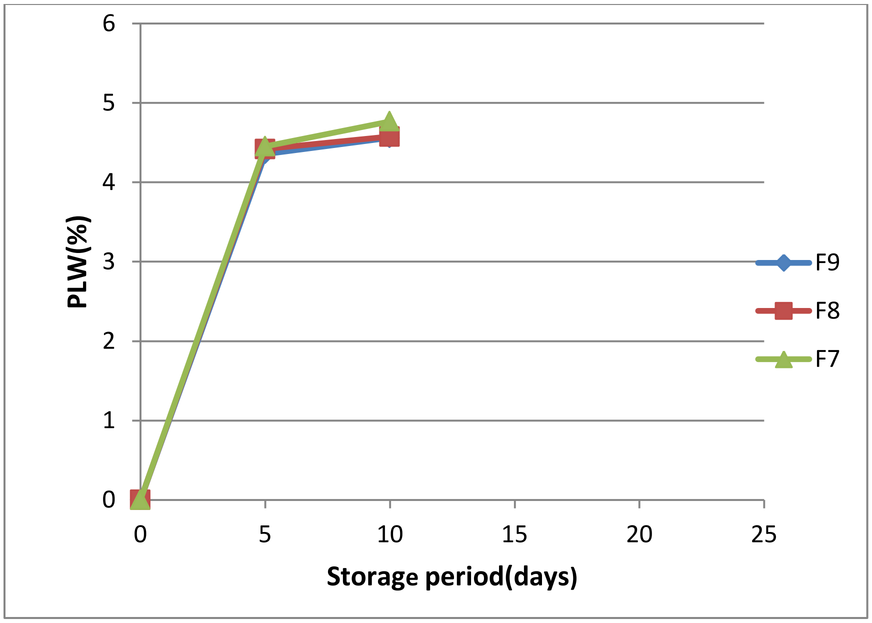


Fig. 4.40 Change in PLW of *Muttechi* variety stored in plywood box

Reduction in weight loss in stored cassava roots depend on storage conditions (Booth, 1977; Booth *et al*., 1976; Taye, 2000) and also it might occur due to the reduction in moisture content and other nutrients. The major problem in cassava tuber storage are sprouting, respiration and transpiration, which cause weight and quality losses. Low temperature and high humidity, slow down these physiological processes in turn reducing weight loss (Ikediobi, 1983). Weight loss may not be a significant factor from the point of cultivator who cultivates cassava for his own consumption use. However it may affect a trader who is selling the cassava roots after storing them for certain number of days.

In the present study it was observed that cassava kept in plastic box had minimum weight loss followed by plywood and wooden box. But the storage duration was only for 15days and hence this parameter for plastic box and plywood cannot be taken into account for quality studies. It is obvious that plastic and plywood retain water than wooden box. Hence this discussion is confined for experiments conducted in wooden boxes. Cassava roots stored in wooden shavings (F9) as a filler material in wooden boxes had minimum decrease in weight loss in first and second experiments. The minimum reduction in weight loss in cassava roots stored in this filler material could be due to the maintenance of low temperature and humidity between the filler materials and the reduction in sprout development and growth in cassava roots stored in this filler material. The decreasing trend in weight was observed with many other studies

(Osunde and Yisa, 2000; Ayodele *et al.*, 2007). Retention of weight also indicate the retention of nutritional values within the roots making it more fit for consumption purposes.

4.4.7 Rotten percentage

Rotting of the cassava roots may be due to the increased bacterial and fungal activity encouraged by excess moisture content.

4.4.7.1 Rotten percentage of cassava roots of *M4* variety

In case of *M4* variety, up to 15days of storage duration maximum rotten percentage of cassava roots were observed in cassava roots stored in filler clay (F3) with 34.102% followed by filler coconut fibre (F6), cassava leaves (F1) and laterite (F5). Filler Sand (F2) had a rotten percentage of 27.9% on 30th day. Minimum rotten percentage of cassava roots were observed in cassava roots stored in filler wooden shavings (F9) with 23.1% followed by cassava roots stored in filler sawdust (F8) up to 40 days of storage as shown in the table 4.4 here below

Table 4.4 Rotten percentage of *M4* variety

Filler	0th d	5th d	10th d	15th d	20th d	25th d	30th d	35th d	40th d	45th d
F1	0	0	0	0	30					
F2	0	0	0	0	0	0	27.93			
F3	0	0	0	34.10						
F4	0	0	0	0	30.01					
F5	0	0	0	29.13						
F6	0	0	0	33.51						
F7	0	0	0	0	0	0	0	0	27.81	
F8	0	0	0	0	0	0	0	0	0	24.06
F9	0	0	0	0	0	0	0	0	0	23.15

4.4.7.2 Rotten percentage of *Muttechi* variety

Table 4.5 reveals that maximum percentage of cassava roots of *Muttechi* variety rotten was observed in cassava roots stored in filler clay (F3) followed by plastic cutting (F6) and laterite (F5) for a storage period of 17 days. Minimum percentage of cassava roots rotten was observed in cassava roots stored in filler wooden shavings (F9) with 23.453% on 42nd day followed by filler sawdust (F8) with 25.324% on 37th day.

Table 4.5 Rotten percentage of *Muttechi* variety

Filler	0th d	7th d	12th d	17th d	22nd d	27th d	32nd d	37th d	42nd d
F1	0	0	0	0	0	29.52			
F2	0	0	0	0	0	0	28.13		
F3	0	0	0	33.15					
F4	0	0	0	0	30.81				
F5	0	0	0	29.09					
F6	0	0	0	32.98					
F7	0	0	0	0	0	0	28.60		
F8	0	0	0	0	0	0	0	25.32	
F9	0	0	0	0	0	0	0	0	23.45

4.4.7.3 Rotten percentage of cassava roots of *Muttechi* variety stored in three different filler materials in nine boxes made up of three different materials

Cassava roots stored in filler wooden shavings (F9) had a minimum percentage of cassava roots rotten followed by filler sawdust (F8) and coconut fibre (F7) in different boxes. With regard to the materials, cassava roots stored in box made of plywood (M3) material in different filler materials had a maximum percentage of cassava roots rotten followed by plastic (M2) and wood (M1).

Table 4.6 Rotten percentages of cassava roots of *Muttechi* variety stored in three different filler materials in nine boxes made up of three different materials

Box	Filler	0^{th} d	5^{th} d	10^{th} d	15^{th} d	20^{th} d	25^{th} d
Wooden box	F9	0	0	0	0	0	22.68
	F8	0	0	0	0	24.16	
	F7	0	0	0	0	27.12	
Plastic box	F9	0	0	0	0	25.12	
	F8	0	0	0	0	27.25	
	F7	0	0	0	27.34		
Plywood box	F9	0	0	0	28.23		
	F8	0	0	0	32.14		
	F7	0	0	0	36.28		

The materials of the boxes play a major role in prolonging the storage life of cassava. Cassava stored in plywood and plastic spoiled completely before 20 days. Hence the discussion is confined to wooden boxes.

From the above mentioned tables it can be noted that the rotten percentage is more with soils and inorganic materials where there is less air circulation, less respiration for the roots and less evaporation of moisture. Maximum rotten was observed in cassava roots stored in clay (F3), plastic cutting (F6) filler material it might be due to characteristic nature of these filler to absorb more moisture and not to evaporate moisture due to less ventilation and aeration nature of these fillers. This shows that cassava roots should be kept moist but not wet. Increase in moisture content also reduces shelf life of roots due to fungal attack. Ventilation reduces incidence of rotting in stored cassava roots. The reduction in rotting of cassava roots stored in wooden shaving (F9) filler could be due to the fact that the better air flow facility in wooden shaving (F9) filler helps to disperse any accumulation of heat on or around the tubers. Filler wooden shaving (F9) absorbs water to become moist and keeps the surroundings at a reduced temperature thereby restricting the fungal and bacterial activities. In fact, more than any other factor rotting of the tuber roots makes them completely unfit for use. Any filler material or method which postpones rotting of the roots is beneficial both for consumers and the retail traders.

4.4.8 Sensory evaluation

A consumer purchases cassava based on the color, flavor, texture and appearance of fresh cassava. Normally people will reject spoiled roots by visual observation. Black spots indicate spoiled root. Black spots may start appearing on the cassava roots from the second day onwards, if not preserved properly.

The samples for sensory evaluation were taken in the interval of 5 to 7 days on a nine hedonic scale by a panel of 12 untrained judges. Judges were given a score card as shown in section 3.6.9. The average score was taken for all the parameters. The first day observation is taken as the control. The mean scores was applied to the all scores obtained for each samples of cassava roots of *M4* variety and are presented in the Table 4.7.

Table 4.7 The mean rank for sensory evaluation of *M4* variety (Raw)

Filler	Appearance	Color	Flavour	Texture	Overall acceptability
F1	6.50	5.00	5.33	5.67	5.50
F2	6.75	6.00	5.87	6.77	6.67
F3	1.50	3.33	3.21	2.67	3.00
F4	4.00	3.45	3.67	3.33	4.33
F5	3.00	3.67	3.45	4.33	3.17
F6	1.50	3.00	2.67	3.00	2.83
F7	5.50	6.21	6.00	5.33	5.83
F8	7.25	7.67	7.67	6.67	7.33
F9	8.30	7.00	6.67	7.33	6.33
Control	8.70	8.40	8.89	8.45	8.80

The mean scores were applied to the all scores obtained for each samples of cassava roots of *Muttechi* variety and are presented in the Table 4.8

Table 4.8 Mean rank for sensory evaluation of *Muttechi* variety (Raw)

Filler	Appearance	Color	Flavour	Texture	Overall acceptability
F1	7.67	6.50	6.00	5.67	6.33
F2	6.00	5.17	5.33	4.67	5.33
F3	2.67	2.67	3.00	2.67	2.67
F4	4.33	4.33	4.00	4.00	3.67
F5	3.67	3.00	4.76	4.33	4.33
F6	2.67	3.33	2.33	2.67	2.67
F7	6.10	6.33	7.67	7.00	6.67
F8	6.45	6.56	6.33	6.83	6.00
F9	6.32	7.33	6.62	7.17	7.33
control	8.56	8.90	8.45	8.56	8.13

The mean scores were obtained for each samples of cassava roots of *Muttechi* variety used in third experiment and are presented in the Table 4.9.

Table 4.9 Mean rank for sensory evaluation of *Muttechi* variety of third experiment (Raw)

Box	Filler	Appearance	Color	Flavor	Texture	Overall acceptability
Wooden box	wooden shavings	7.33	7.10	6.18	7.09	7.10
	sawdust	6.33	6.00	6.17	6.83	6.67
	coir	4.00	3.50	4.33	3.67	4.83
Plastic box	wooden shavings	5.33	6.15	5.33	4.67	5.00
	sawdust	7.21	7.33	7.33	6.67	6.67
	coir	5.33	5.00	5.17	5.83	5.17
Plywood box	wooden shavings	3.50	3.67	2.33	3.00	3.00
	sawdust	2.50	2.33	3.17	4.67	2.67
	coir	3.33	3.83	3.83	2.33	3.33
control		7.81	7.56	7.98	8.10	7.83

4.4.8.1 Appearance

For *M4* variety it was observed that cassava roots stored in filler wooden shavings (F9) received maximum scores followed by sawdust (F8) and sand (F2)**.** In the case of *Muttechi v*ariety cassava roots stored in filler sawdust (F8) followed by wooden shavings (F9) and coconut fibre (F7) received maximum scores and in third experiment cassava roots stored in box made of wooden (M1) with wooden shavings (F9) as filler received maximum scores followed by M2 (F8). Hence it can be safely stated that wooden shavings (F9) is the best filler material giving best appearance for the product.

4.4.8.2 Color

Color is the main identification to detect whether the roots are fresh or spoiled and consumer acceptability mainly depends on color. In *M4* variety sawdust (F8) filler received maximum scores followed by wooden shaving (F9) filler material. In case of *Muttechi* variety cassava roots stored in filler wooden shaving (F9) received maximum scores followed by sawdust (F8) as filler. And in third experiment cassava roots stored in box made of plastic (M2) with sawdust (F8) as filler received maximum scores followed by M1 (F9). Even though sawdust (F8) as the filler material was found to be best in the case of first and third experiment and wooden shavings found to be best in the second. Both sawdust and wooden shavings have almost similar properties.

4.4.8.3 Flavor

Flavor is commonly defined as being the sensation arising from the integration or interplay of signals produced as a consequence of sensing smell, taste and irritating stimuli from a food or a beverage (Shankaracharaya, 2002). In *M4* variety cassava roots stored in filler sawdust (F8) received maximum scores followed by wooden shavings (F9) and coconut fibre (F7). In case of *Muttechi* variety cassava roots stored in filler coconut fibre (F7) received maximum scores followed by wooden shavings (F9) as filler. And in third experiment cassava roots stored in box made of plastic (M2) with sawdust (F9) as filler received maximum scores followed by M1 (F9).

4.4.8.4 Texture

Texture has long been recognized as an important element in the total sensory impression obtained during the consumption of the cassava roots. Results of the tables 4.10 showed that *M4 v*ariety cassava roots stored in filler wooden shavings (F9) had a better texture followed by roots stored in sand (F2) and sawdust (F8). In case of *Muttechi* variety cassava roots stored in filler wooden shavings (F9) received maximum scores followed by coconut fibre (F7) as filler. And in third experiment cassava roots stored in box made of wood (M1) wooden shavings (F9) as filler received maximum scores followed by box made of wood (M1) sawdust (F8) as a filler.

4.4.8.5 Cooking time

The main aim of all experiments is to benefit the ultimate consumer, more particularly the unprivileged weaker sections of the society. Hence the cooking time and the nutrition values are more important factors from this point of view.

It was observed that cooking time was taken more in the case of roots stored up to 10 days in clay (F3) and plastic cuttings (F6) filler materials for both varieties of cassava. *M4* variety took around 27 minutes. *Muttechi* variety in the second experiment took around 31 minutes .Whereas the roots stored in wooden shaving (F9) filler material cooked faster. It was observed that *M4* variety took around 20 minutes, *Muttechi* cooked at 25 minutes in second experiment and 24 minutes in third experiment for these filler materials as shown in Appendix VIII. From this observation we can infer that the roots which deteriorated in quality took more time to cook and roots which retained their firmness, toughness, nutritional values and freshness took less time for cooking.

It was also noted that high moisture content, softness and less firmness are not supporting the quick cooking of the roots. The roots which had increased fiber content stored in clay (F3), laterite soil (F5), plastic cutting (F6) took more time for cooking .Similar trend of increase in cooking time after storage were observed by Balagopalan (2000).

Reduction in cooking time appears to have close link to rotting of the cassava roots. The roots stored in clay (F3), laterite (F5), plastic cutting (F6) filler materials which tend to rot early showed extension of cooking time. Moreover, in the third experiment the roots kept in plywood box (M3) with any of the filler material including wooden shavings (F9) could not survive for more than 10 days. The cooking time in these cases extended up to 31- 35minutes. It can be postulated that cassava roots which are about to deteriorate take longer duration for cooking. Hence it can be concluded that the lesser cooking time of the roots could be treated as a indicator towards the nutritional value and good quality of the roots.

4.4.9 Storage conditions

In the first and second experiment cassava roots were kept in a dark room with an average (Temp 29^0C, R.H 81%), and in third experiment with (Temp of 32^0C.R.H 75%).

4.4. 10 Cost of storage of cassava roots along with wooden shavings as a filler

The computation for cost of storing cassava roots with wooden shavings in wooden boxes is given in Appendix IX. The cost of storing 1kg of cassava roots in wooden boxes with wooden shavings as a filler material including labour charges is Rs. 4.62/-.

Summary and conclusion

CHAPTER 5

SUMMARY AND CONCLUSION

Cassava (*Manihot esculenta*) is one of the major staple food of the economically weaker sections of Africa, Caribbean and some of the under developed Asian countries. In India, Kerala is the major producer of this carbohydrate rich tuber crop and is used mainly for human consumption. In Tamil Nadu and Andra Pradesh. this is used for commercial production of Sago and Starch. It is reported that the Physiological Postharvest deterioration (PPD) of this root starts immediately after harvesting and will become unmarketable after 48 – 72 hours. The main aim of this study was to develop a low cost storage facility to increase the shelf life of this tuber crop which is handy and within the reach of the economically weaker sections of the society.

Method used in the experiments was to pack the roots with locally available different filler materials. The filler materials used for the study are Cassava leaves (F1), Sand (F2), Clay (F3), Sponge (F4), Laterite soil (F5), Plastic cuttings (F6), Coconut fibre (F8), Sawdust (F8), and Wooden shavings (F9). Cassava roots and filler materials were stored in boxes made up of locally available packaging materials (Wood (M1), Plastic (M2), Plywood (M3). Study was carried out in 3 stages. In the first experiment, locally available *M-4* variety of cassava was stored in nine different filler materials in nine wooden boxes and the quality parameters were analyzed. The Second experiment was the repetition of the same experiment with *Muttechi* variety with same nine filler materials in nine wooden boxes. *Muttechi* variety was selected for the third and final stage of study. Out of the nine filler materials, the best three filler materials viz. coconut fibre, Saw dust and wooden shavings were selected and stored in three different boxes made up of three different materials in the third experiment. One centimeter thick wooden box, with inner width of 32 cm, length of 47.5 cm and height of 26.1 cm with ventilation gap of 1cm was developed based on bulk density of cassava roots and was used for the study as a storage system. These

It has been revealed by various studies that the shelf life of the Cassava increases where the filler materials are moist but not wet. Hence, a small amount of water was sprinkled every day with all the different filler materials to keep them moist. This quantity was randomly selected keeping in view of the volume of the box and the quantity of cassava roots of 6 Kg.

During various stages of storage, quality parameters of cassava were that included physical and chemical properties in different stages. These included variations in moisture content, carbohydrate content, cyanide content, fiber content, firmness, toughness, weight loss, rotten percentage and sensory evaluation for fresh cassava roots and the time taken for cooking.

Statistical analysis were carried out for 15 days in case of first experiment with *M4* variety, 17 days in case of second experiment with *Muttechi* variety and 10 days in case of third experiment. The cassava roots stored in filler materials (Cassava leaves (F1), Clay (F3), Sponge (F4), Laterite Soil (F5, Plastic cuttings (F6) in case of first experiment and second experiment were not edible beyond these days. And in third experiment cassava roots stored in all the filler materials in the box made of Plywood (M3) material had the maximum deterioration. It was evident from the results of third experiment that the material of the box stored played an important role in increasing the shelf life of the cassava. Cassava roots kept in plywood box (M3) could not survive even for 15 days and cassava kept in plastic boxes could not remain safe for 20 days even though three best filler materials were used for the study.

Results of first and second experiments were almost identical which revealed that different varieties of cassava roots have similar post harvest deteriorating trend and the results of increased shelf life aided with different filler materials and boxes are almost identical.

In the case of first experiment with *M4* variety, the rotten percentage with filler materials of sponge and plastic cuttings (F4 & F6) varied up to 30.01% and 33.51% between 15 days and 20 days. In the second experiment with *Muttechi* variety, the rotten percentage varied from 30.81% and 32.98% between 17 days and 22 days with the same filler materials. The results also revealed that filler materials and boxes made up of synthetic materials adversely affect the shelf life. Natural materials such as cassava leaves, clay, laterite soil and even sand which are characterized by retaining excess water and have less air circulation, also did not show significant increase in the shelf life. Hence, it may be inferred that filler materials and boxes which allow more respiration and retain moisture but do not remain wet are the best in increasing the shelf life of cassava roots. It may be attributed to the increased germinating and bacterial activity in these wet conditions.

There appears to be close relationship between moisture content and rotten percentage of the cassava roots. Cassava roots stored in filler materials such as clay (F3), sponge (F4), laterite soil (F5) and plastic cuttings (F6) which retained more moisture and remained wet were more prone to deterioration. Moisture content had increased marginally in case of filler materials.

Sand (F2) and cassava leaves (F1) showed good results in the quality parameters up to the initial stages of 15 days and 17 days in case of *M4* and *Muttechi* varieties respectively. However, beyond these days the advantages of these parameters shifted toward coconut fibre (F7), saw dust (F8) and wooden shavings (F9). For shorter duration cassava leaves were found to be a good filler material. Sand (F2) appears to be good in the initial stages as well as for the medium term as evident from the charts attached to this study report. However, they are heavier in weight and transportation of boxes is also difficult when compared to wooden shavings (F9), sawdust (F8) and coconut fibre (F7) filler materials. Moreover, for longer durations of storage wooden shavings (F9), sawdust (F8) and coconut fibre (F7) filler materials in wooden boxes gave better results. Therefore, for the further study in the third experiment sand (F2) was not continued as a filler material.

Change in quality parameters varied with the filler materials and material of the boxes. The minimum increase in fiber content was observed in cassava roots stored with coconut fibre (F7) filler material for both the varieties. *M4* variety increased only 1.40% (15-35 days) and *Muttechi* variety increased 1.8% (17-27 days) closely followed by wooden shavings (F9) and sawdust (F8) fillers. Minimum increase in fiber content may be due to the retention of moisture content to the desired level by these natural materials.

The decrease in carbohydrate content was from to 26.71% to 21.07% with wooden shavings (F9) filler materials on the 40th day of storage for *M4* variety. The decrease was from 22.31 to 16.75% with *Muttechi* variety on 37th day of storage. This was followed by sawdust (F8) filler material. This showed that wooden shavings (F9) filler was more useful in retaining the nutritional values of the roots.

Cyanide content decrease in cassava roots was predominant with coconut fibre (F7) filler material with a mean value of 59.23 mg/Kg with regard to *M4* variety between 15 to 35 days. This was closely followed by wooden shavings (F9) filler. With regard to *Muttechi* variety the decrease was more in cassava roots stored in sawdust (F8) filler material with a mean value of 44.54 mg/Kg between 17 to 32 days period closely followed by wooden shavings (F9) filler material. Cyanide content decrease was seen as a positive trend as the harmful effects of cyanide could be reduced for safe consumption. Hence it can be inferred that consumption of stored cassava roots after 15 days of time was less harmful compared to the freshly harvested roots as the harmful effects of cyanide content would be marginalized after 15 days. It is also observed that cyanide content decrease of different varieties of cassava varies with the filler materials. However, wooden shavings (F9) filler material appears to be better as both the tried varieties show similar trend in decrease of cyanide in coconut fibre (F7) filler material.

Retention of physical parameters of firmness was observed with regard to wooden shavings (F9) filler with a value of 86.17 N in *M4* variety closely followed by coconut fibre (F8) and plastic cuttings (F7) filler materials with the period of study as discussed above. *Muttechi* variety showed more retention in sawdust (F8) filler material with a value of 92.44 N closely followed by wooden shavings (F9) and plastic cuttings (F7) filler materials for the period.

Toughness measured with wooden shavings (F9) filler material with a value of 106.1227N/Sec was more in *M4* variety closely followed by sawdust (F8) and coconut fibre (F7) filler materials for the same period. The retention value was more with sawdust (F8) filler material with a value of 113.762 N/Sec with regard to *Muttechi* variety for the period discussed above followed by wooden shavings (F9) and coconut fibre (F7) filler materials.

Change in PLW (Physiological loss in weight) was minimum in cassava roots stored in wooden shavings (F9) filler material followed by sawdust (F8) and coconut fibre (F7) filler materials in both varieties.

Physical parameters such as firmness, toughness and change in Physiological loss indicate more retention of moisture, nutritional values and less deterioration in the roots and hence have better marketing qualities. This is examined by the results observed for time taken for cooking of both the varieties. Time taken for cooking was minimum with regard to the cassava roots stored in wooden shavings (F9) filler material which is an indication of the freshness of the roots. Wooden shavings (F9) filler materials appeared to best, which showed constant results with regard to both the varieties in these parameters. This is supported by the sensory evaluation of raw cassava roots results which were undertaken by 12 independent untrained judges representing the ultimate consumer of the products.

The third experiment was conducted with *Muttechi* variety harvested during the summer season and with best of the filler materials of the first and second experiments viz. coconut fibre

(F7), sawdust (F8) and wooden shavings (F9). It was found that shelf life of cassava was only up to 20 days during summer season, while the first and second experiments done during rainy and winter seasons extended the shelf life up to 40 days and 37 days respectively with regard to *M4* and *Muttechi* varieties. This indicated that external climatic conditions also play an important role in the shelf life of the roots. Obviously, the humid and cold climate is conducive for the survival of the roots and the hot climatic conditions are not supportive.

Various studies done with accepted values of quality parameters as discussed above showed that wet conditions with excess humidity, synthetic materials and other filler materials/boxes which restrict air circulation, the hot climate of the summer were not conducive to the survival of cassava roots. Sand (F2) and cassava leaves (F1) are good filler materials for short duration, but for the longer durations they could not tally the results of wooden shavings (F9) in the wooden boxes. Moreover, sand with wooden boxes is heavier and is not easily transportable from place to place. The combination of wooden shaving (F9) and wooden box container (M1) with retention of moisture by sprinkling small quantity of water just sufficient to retain the moisture of the filler materials is best suited for extending the shelf life of cassava roots. This may be due to the natural respiration and moist condition naturally provided by the combination of these natural materials. The best results are achieved during the cold, winter season with these combinations probably due to the maintenance of moist condition naturally in this climate and less evaporation of moisture and less bacterial activity when compared to the hot summer season. The economic analysis of the storage system was conducted and it was found for storing 1kg of cassava in the developed storage system with wooden shavings as a filler material including labour charges was Rs. 4.62. Hence it can be safely concluded that a combination of wooden shavings as filler material in wooden box containers and a small quantity of water just sufficient to retain the moisture of the filler materials is best suited for extending the shelf life of cassava roots beyond 20 days in all seasons.

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Appendices

Appendix I

a. Change in moisture content of *M4* variety

Filler	Storage period(days)			Mean (%)
	5	10	15	
F1	57.24^{b}	55.68^{b}	54.26^{b}	55.72
F2	57.23^{b}	55.66^{b}	54.24^{b}	55.71
F4	59.90^{a}	60.09^{a}	61.97^{a}	60.65
F7	56.96^{c}	55.02^{c}	53.41^{c}	55.13
F8	57.24^{b}	55.68^{b}	54.26^{b}	55.73
F9	57.23^{b}	55.67^{b}	54.25^{b}	55.71

b. Change in moisture content of *Muttechi* variety

Filler	Storage period (days)			Mean (%)
	7	12	17	
F1	55.88^{b}	54.32^{b}	52.90^{b}	54.37
F2	55.88^{b}	54.33^{b}	52.91^{b}	54.37
F4	54.50^{e}	51.40^{c}	50.85^{c}	52.25
F7	57.23^{a}	55.67^{a}	54.26	55.72
F8	55.02^{d}	54.31^{b}	52.89^{c}	54.08
F9	55.58^{c}	54.32^{b}	52.89^{c}	54.26

c. Change in moisture content of *Muttechi* variety stored in wooden box

Filler	Storage period (days)		Mean (%)
	5	10	
F9	55.80^{a}	55.15^{a}	55.47
F8	55.64^{b}	54.24^{b}	54.94
F7	54.67^{c}	53.45^{c}	54.06

d. Change in moisture content of *Muttechi* variety stored in plastic box

Filler	Storage period (days)		Mean (%)
	5	10	
F9	56.35[a]	56.21[a]	56.28
F8	56.26[b]	56.05[b]	56.16
F7	56.09[c]	55.76[c]	55.92

e. Change in moisture content of *Muttechi* variety stored in plywood box

Filler	Storage period(days)		Mean (%)
	5	10	
F9	53.94[a]	53.08[a]	53.51
F8	53.21[b]	52.04[b]	52.63
F7	52.782[c]	50.16[c]	51.47

Appendix II

a. Change in fibre content of cassava roots of *M4* variety

Filler	Storage period (days)			Mean (%)
	5	10	15	
F1	1.96^{d}	2.31^{e}	2.74^{d}	2.34
F2	1.38^{b}	1.49^{c}	1.71^{b}	1.52
F4	1.80^{c}	1.81^{d}	1.83^{c}	1.81
F7	1.34^{b}	1.34^{b}	1.36^{a}	1.35
F8	1.17^{a}	1.28^{a}	1.31^{a}	1.25
F9	1.18^{a}	1.30^{b}	1.35^{a}	1.28

b. Change in fibre content of *Muttechi* variety

Filler	Storage period (days)			Mean (%)
	7	12	17	
F1	1.99^{b}	2.29^{d}	2.64^{c}	2.30
F2	1.30^{a}	1.47^{a}	1.70^{a}	1.49
F4	1.91^{b}	1.92^{c}	1.94^{b}	1.92
F7	1.34^{a}	1.53^{b}	1.7^{a}	1.54
F8	1.35^{a}	1.54^{b}	1.77^{a}	1.55
F9	1.34^{a}	1.51^{b}	1.71^{a}	1.52

c. Change in fibre content of *Muttechi* variety stored in wooden box

Filler	Storage period (days)		Mean (%)
	5	10	
F9	1.36^{a}	1.36^{a}	1.364
F8	1.38^{a}	1.38^{a}	1.38
F7	1.40^{b}	1.40^{b}	1.40

d. Change in fibre content of *Muttechi* variety stored in plastic box

Filler	Storage period (days)		Mean (%)
	5	10	
F9	1.39[a]	1.41[a]	1.40
F8	1.42[b]	1.43[a]	1.42
F7	1.45[b]	1.46[a]	1.45

e. Change in fibre content of *Muttechi* variety stored in plywood box

Filler	Storage period (days)		Mean (%)
	5	10	
F9	1.39[a]	1.41[a]	1.40
F8	1.42[b]	1.43[a]	1.42
F7	1.45[b]	1.46[a]	1.45

Appendix III

a. Change in carbohydrate content of *M4* variety

Filler	Storage period (days)			Mean (%)
	5	10	15	
F1	20.52[d]	16.51[f]	16.49[f]	17.84
F2	22.84[b]	22.32[c]	22.08[c]	22.41
F4	20.62[c]	16.63[e]	16.53[e]	17.93
F7	22.67[c]	22.20[d]	21.13[d]	22.00
F8	23.85[b]	23.35[b]	22.13[b]	23.11
F9	23.92[a]	23.58[a]	23.08[a]	23.52

b. Change in carbohydrate of *Muttechi* variety

Filler	Storage period (days)			Mean (%)
	7	12	17	
F1	16.13[f]	12.27[f]	12.13[f]	13.51
F2	18.51[c]	17.94[c]	17.63[c]	18.02
F4	16.23[e]	12.30[e]	12.21[e]	13.58
F7	18.29[d]	17.84[d]	17.48[d]	17.87
F8	19.48[b]	18.97[b]	17.72[b]	18.72
F9	19.57[a]	19.19[a]	18.72[a]	19.16

c. Change in carbohydrate content of *Muttechi* variety stored in wooden box

Filler	Storage period (days)		Mean (%)
	5	10	
F9	18.04[a]	17.48[a]	17.76
F8	18.02[b]	17.43[a]	17.72
F7	17.97[c]	17.36[b]	17.66

d. Change in carbohydrate content of *Muttechi* variety stored in plastic box

Filler	Storage period (days)		Mean (%)
	5	10	
F9	17.56[a]	16.96[a]	17.26
F8	17.55[a]	16.94[a]	17.24
F7	17.52[a]	16.86[b]	17.18

e. Change in carbohydrate content of *Muttechi* variety stored in plywood box

Filler	Storage period (days)		Mean (%)
	5	10	
F9	17.28[a]	16.68[a]	16.98
F8	17.27[a]	16.63[a]	16.95
F7	17.22[a]	16.52[b]	16.87

Appendix IV

a. Change in cyanide content of *M4* variety

Filler	Storage period (days)			Mean (mg/Kg)
	5	10	15	
F1	70.51	69.01	67.69	69.07
F2	70.31	68.71	67.53	68.85
F4	70.73	69.43	68.15	69.43
F7	70.71	69.39	68.09	69.39
F8	70.61	69.23	67.85	69.23
F9	70.56	69.1	67.8	69.15

b. Change in cyanide content of *Muttechi* variety

Filler	Storage period (days)			Mean (mg/kg)
	7	12	17	
F1	50.98[d]	51.42[f]	50.45[f]	50.95
F2	50.95[d]	50.53[e]	50.14[e]	50.54
F4	49.98[b]	49.77[c]	48.86[e]	49.54
F7	50.46[c]	50.31[d]	49.00[d]	49.92
F8	49.45[a]	48.42[a]	46.77[a]	48.21
F9	49.91[b]	49.12[b]	47.87[b]	48.97

c. Change in cyanide content of *Muttechi* variety stored in wooden box

Filler	Storage period (days)		Mean (mg/kg)
	5	10	
F9	51.11[b]	51.09[a]	51.10
F8	51.10[b]	51.07[a]	51.08
F7	51.08[a]	51.00[a]	51.04

d. Change in cyanide content of *Muttechi* variety stored in plastic box

Filler	Storage period (days)		Mean (mg/kg)
	5	10	
F9	51.11[b]	51.09[a]	51.10
F8	51.10[b]	51.07[a]	51.09
F7	51.09[a]	51.08[a]	51.091

e. Change in cyanide content of *Muttechi* variety stored in plywood box

Filler	Storage period (days)		Mean (mg/kg)
	5	10	
F9	51.08[c]	51.05[c]	51.06
F8	49.89[b]	49.45[b]	49.67
F7	48.95[a]	48.50[a]	48.72

Appendix V

a. Change in firmness of *M4* variety

Filler	Storage period (days)			Mean (N)
	5	10	15	
F1	88.89[d]	88.42[d]	87.02[d]	88.11
F2	90.89[c]	90.61[c]	88.66[c]	90.05
F4	88.14[e]	88.01[e]	87.01[d]	87.72
F7	90.91[b]	90.65[c]	88.65[c]	90.07
F8	90.96[b]	90.96[b]	90.86[b]	90.92
F9	92.02[a]	92.00[a]	90.88[a]	91.63

b. Change in firmness of *Muttechi* variety

Filler	Storage period (days)			Mean (N)
	7	12	17	
F1	94.72[d]	94.26[d]	92.73[e]	93.90
F2	96.85[c]	96.55[c]	94.49[d]	95.96
F4	94.12[e]	93.97[e]	92.94[f]	93.68
F7	96.90[b]	96.62[b]	94.57[c]	96.03
F8	96.96[b]	96.64[b]	94.71[b]	96.10
F9	98.01[a]	97.98[a]	95.41[a]	97.14

c. Change in firmness of *Muttechi* variety stored in wooden box

Filler	Storage period (days)		Mean (N)
	5	10	
F9	90.96[a]	90.89[a]	90.93
F8	90.95[a]	90.88[a]	90.91
F7	90.93[a]	90.86[a]	90.90

d. Change in firmness of *Muttechi* variety stored in plastic box

Filler	Storage period (days)		Mean (N)
	5	10	
F9	90.94[a]	90.87[a]	90.91
F8	90.94[a]	90.87[a]	90.90
F7	90.94[a]	90.86[a]	90.90

e. Change in firmness of cassava roots of *Muttechi* variety stored in plywood box

Filler	Storage period (days)		Mean (N)
	5	10	
F9	90.93[a]	90.86[a]	90.89
F8	90.90	90.83[a]	90.87
F7	90.89[b]	90.79[b]	90.84

Appendix VI

a. Change in toughness of cassava roots of *M4* variety

Filler	Storage period (days)			Mean (N/sec)
	5	10	15	
F1	111.54^{c}	109.82^{d}	108.56^{e}	109.97
F2	113.50^{b}	112.11^{c}	111.45^{d}	112.35
F4	111.54^{c}	108.82^{e}	108.23^{f}	109.53
F7	113.51^{b}	112.15^{c}	112.10^{c}	112.58
F8	113.92^{a}	112.86^{b}	112.53^{b}	113.10
F9	113.98^{a}	113.65^{a}	113.92^{a}	113.85

b. Change in toughness of *Muttechi* variety

Filler	Storage period (days)			Mean (N/sec)
	7	12	17	
F1	117.31^{f}	116.22^{f}	113.81^{f}	115.78
F2	120.91^{c}	120.47^{c}	119.39^{c}	120.26
F4	118.94^{e}	116.94^{e}	115.52^{e}	117.13
F7	120.87^{d}	119.52^{d}	118.38^{d}	119.59
F8	121.41^{a}	121.27^{a}	119.51^{a}	120.73
F9	121.31^{b}	121.04^{b}	119.41^{b}	120.59

c. Change in toughness of *Muttechi* variety stored in wooden box

Filler	Storage period (days)		Mean (N/sec)
	5	10	
F9	112.95^{a}	112.80^{a}	112.87
F8	112.93^{a}	112.61^{b}	112.77
F7	112.92^{a}	112.58^{c}	112.75

d. Change in toughness of *Muttechi* variety stored in plastic box

Filler	Storage period(days)		Mean (N/sec)
	5	10	
F9	112.93^{a}	111.60^{a}	112.26
F8	112.92^{a}	110.58^{b}	111.75
F7	112.90^{a}	109.45^{c}	111.18

e. Change in toughness of *Muttechi* variety stored in plywood box

Filler	Storage period(days)		Mean (N/sec)
	5	10	
F9	110.897[a]	108.784[a]	109.8405
F8	110.125[b]	108.432[b]	109.2785
F7	109.765[c]	107.124[c]	108.4445

Appendix VII

a. Change in PLW of *M4* variety

Filler	Storage period (days)									
	0	5	10	15	20	25	30	35	40	Mean (%)
F1	0	1.98	2.01	2.09						2.03
F2	0	2.15	2.26	2.47	2.56	2.89				2.47
F3	0	1.09	1.56							1.32
F4	0	1.10	1.78	1.96						1.61
F5	0	2.36	2.56							2.46
F6	0	1.85	1.91							1.88
F7	0	2.89	2.90	3.10	3.25	3.78	3.90	3.99		3.40
F8	0	2.67	2.76	2.97	3.01	3.17	3.26	3.89	3.89	3.20
F9	0	2.09	2.14	2.23	2.45	2.78	3.09	3.10	3.10	2.62

b. Change in PLW *of Muttechi* variety

Filler	Storage period (days)								Mean (%)
	0	7	12	17	22	27	32	37	
F1	0	2.78	2.81	2.90	2.98				2.87
F2	0	3.07	3.12	3.25	3.29	3.45			3.24
F3	0	2.34	2.56						2.45
F4	0	2.87	2.90	3.05					2.94
F5	0	3.12	3.23						3.17
F6	0	2.10	2.34						2.22
F7	0	3.18	3.20	3.31	3.45	3.56			3.34
F8	0	3.15	3.18	3.26	3.42	3.54	3.76		3.39
F9	0	3.045	3.089	3.12	3.19	3.24	3.56	3.89	3.308

c. Change in PLW of *Muttechi* variety stored in wooden box

Filler	Storage period (days)					Mean (%)
	0	5	10	15	20	
F9	0	4.32	4.32	4.32	4.39	4.34
F8	0	4.34	4.36	4.36		4.35
F7	0	4.35	4.3	4.42		4.38

d. Change in PLW of *Muttechi v*ariety stored in plastic box

Filler	Storage period (days)				Mean (%)
	0	5	10	15	
F9	0	4.23	4.21	4.21	4.21
F8	0	4.216	4.22	4.22	4.21
F7	0	4.226	4.23		2.22

e. Change in PLW of *Muttechi* variety stored in plywood box

Filler	Storage period (days)			Mean (%)
	0	5	10	
F9	0	4.35	4.56	4.45
F8	0	4.42	4.57	4.49
F7	0	4.45	4.76	4.60

Appendix VIII

a. Change in cooking time of *M4* variety

Filler	0^{th} d	5^{th} d	10^{th} d	15^{th} d	20^{th} d	25^{th} d	30^{th} d	35^{th} d	40^{th} d
F1	15min	22min	22min	24min					
F2	15min	20min	24min	24min	28min	29min			
F3	15min	27min	27min						
F4	15min	23min	25min	25min					
F5	15min	22min	22min						
F6	15min	25min	25min						
F7	15min	18min	22min	22 min	22 min	22min	26min	26min	
F8	15min	18min	20min	20 min	20 min	23min	23min	23min	23min
F9	15min	18min	20min	20 min	20min	22min	22min	22min	22min

b. Change in cooking time of *Muttechi* variety

Filler	0^{th} d	7^{th} d	12^{th} d	17^{th} d	22^{nd} d	27^{th} d	32^{nd} d	37^{th} d
F1	18min	27min	29min	29min	29min			
F2	18min	24min	28min	33min	33min	33min		
F3	18min	31min	31min					
F4	18min	27min	29min	29min				
F5	18min	27min	28min					
F6	18min	31min	31min					
F7	18min	23min	28min	28min	28min	32min		
F8	18min	22min	25min	25min	25min	28min	28min	
F9	18min	22min	25min	26min	28min	29min	29min	29min

c. Change in cooking time of *Muttechi* variety in third experiment

Material	filler	0^{th} d	5^{th} d	10^{th} d	15^{th} d	20^{th} d
Wooden box	F9	20min	24min	24min	24min	27min
	F8	20min	25min	26min	28min	
	F7	20min	26min	26min	28min	
Plastic box	F9	20min	27min	29min	29min	
	F8	20min	29min	29min	31min	
	F7	20min	30min	32min		
Plywood box	F9	20min	28min	31min		
	F8	20min	30min	33min		
	F7	20min	32min	35min		

Appendix IX

Cost estimation

Sl. no		Rupees
1.	Cost of 1 Wooden Box (Jungle wood) of 1cm. Thickness (Length of 47.5 cm, Width of 32 cm, Height of 26.1 cm)	Rs. 100/-
2.	Wooden Box is re-usable at least for 15 times. Hence the Fixed cost of Wooden Boxes for ONE use (Rs.100/15)	Rs. 6.7/-
3.	Cost of 1kg of wooden shavings	Rs. 5/-
4.	Total Cost of Storing 6 Kg of Cassava Roots in one Wooden Box with 3kg Wooden shavings as filler materials (for ONE use)	Rs. 21.7/-
5.	Hence the cost of storing 1 Kg of Cassava Root in wooden Box with wooden shavings as filler material (Rs.21.7/6 =Rs.3.62)	Rs. 3.62/-
6.	Labour charges for handling 100 boxes per day (600kg)	Rs. 600/-
7.	Labour incurred for handling 1kg of cassava roots	Rs.1/-
8.	Hence the cost of storing 1 Kg of Cassava Root in wooden Box with wooden shavings as filler material along with labour charges (Rs. 3.62+1)	Rs. 4.62/-

Abstract

DEVELOPMENT AND EVALUATION OF A CASSAVA *(Manihot esculenta)*

STORAGE CUM PACKAGING SYSTEM

By

CHINTHANA.D.T

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ABSTRACT OF THE THESIS

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ABSTRACT

Cassava (*Manihot esculenta*) has its origins in South America. This tuber root crop has become the staple food of the economically weaker sections of these countries as this can be grown in most of the adverse climatic and in fertile soil condition. In India the major production today is still from Kerala followed by Tamil Nadu and Andra Pradesh where it is gaining commercial importance for the production of Sago and Starch. The shelf life of this crop starts deteriorating immediately after harvesting and becomes unmarketable within 2-3 days. Hence, this study was undertaken to develop a more practical and affordable method to increase the shelf life of cassava by keeping in mind the economically weaker sections of society worldwide.

The method chosen was to store the fresh cassava roots in boxes made up of locally available materials such as (wood, plastic, plywood) and filled with easily available cheap filler materials which are within the reach of the common man. To maintain moist condition of the filler materials small quantity of water was sprinkled daily. The filler materials selected ranged from different types of soils like sand , clay and laterite soil, cheap synthetic materials like sponge and plastic cuttings, and easily available organic materials like cassava leaves, coir, saw dust and wooden shavings. For the present study, the size of the box was developed to house around 6 Kgs of the roots along with filler materials. Two locally available popular varieties of Cassava viz. *M4* and *Muttechi* were chosen for the study.

First experiment was carried out with *M4* variety with nine different filler materials as explained above stored in nine wooden boxes. Quality parameters were studied periodically in a range 5 days. It was found that cassava could be stored for 40 days using wooden shavings as filler material followed by sawdust and coconut fibre for 35day. The second experiment was the repetition of the same study with another variety commonly known as *Muttechi* variety in Kerala. Quality parameters were studied periodically in a range 5 – 7 days. It was found that cassava could be stored for 37 days using wooden shavings as filler material followed by sawdust (32days) and coconut fibre 27days. First two experiments revealed that synthetic filler materials like sponge, plastic etc were harmful to their survival. Organic materials like cassava leaves, Sand as a filler material was good in the initial stages but could not support for longer durations.

The above two experiments were conducted using wooden boxes. In order to find the impact of material of construction of box on the storage duration of cassava, a third study was done choosing three materials (wooden box, plastic box and plywood boxes). Nine boxes were used for the study (3 each for the same material). The best three filler materials coconut fibre, saw dust and wooden shavings out of nine filler materials used in first and second experiments were used in the third experiment R.H 75% and temperature was 32ºC. Results of third experiment showed that the storage box played an important role more than that of the filler materials, as the roots stored in plywood box with best of the three filler materials could not survive for more than 15 days

Comparing all the quality parameters it was observed that cassava roots stored in wooden box with wooden shavings as filler materials with routine replenishing of moisture by adding small quantity of water was best suited for extending the shelf life of the cassava roots up to 37 days during winter and the results could be less during summer with the extended shelf life of around 15 days. The economic analysis of the storage system was conducted and it was found for storing 1kg of cassava in the developed storage system with wooden shavings as a filler material including labour charges was Rs. 4.62/-.

Hence, it can be concluded that this simple method of extending the shelf life of cassava roots by storing them in wooden boxes with wooden shavings as filler material with retention of moisture in the boxes by sprinkling small quantity of water daily is very economical, successful and easy for quick transportation.