IMPROVEMENT OF THE STORABILITY AND MAINTENANCE OF POSTHARVEST QUALITY OF CASSAVA USING SURFACE COATING

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IMPROVEMENT OF THE STORABILITY AND MAINTENANCE OF POSTHARVEST QUALITY OF CASSAVA USING SURFACE COATING

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DECLARATION

The work described herein is my original work, and it has not been submitted previously to any university in whole or in part for the award of any degree, fellowship or any other academic titles.

Signature…… Date.....

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

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DEDICATION

First to the Almighty God for His strength to complete my work successfully. I also dedicate this thesis to my parents Walter Oduor and Evalin Oduor and my siblings Fredrick, Liz and Jenipher for their unending support and encouragement.

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LIST OF ABBREVIATIONS AND ACRONYMS

DAAD	German Academic Exchange Service
DAH	Days after Harvest
DMC	Dry matter content
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Databases
FFS	Film Forming Solution
GAE	Gallic acid Equivalent
GRAS	Generally Regarded as Safe
HCN	Hydrocyanic glucoside
JKUAT	Jomo Kenyatta University of Agriculture and Technology
MAP	Months after Planting
PPD	Postharvest Physiological Deterioration
PPM	Parts per million
ROS	Reactive Oxygen Species
USAID	United States Agency for International Development
UV	Ultraviolet

ABSTRACT

Cassava (*Manihot esculenta*) is an important dietary source of carbohydrates for communities in tropical regions. However, the crop is highly susceptible to postharvest physiological deterioration (PPD) which affects its nutritional quality and leads to the unpalatability and unmarketability of the roots in a span of 2-3 days after harvest. Edible surface coatings have been found to be effective in preserving the quality of various food products. However, there are variations in effectiveness among the different coating solutions, hence the need for optimization of the concentrations. This study was undertaken with the objective of determining the most effective mode of coating application between the dipping and spraying method and investigating the effect of surface coatings on the postharvest shelf life and quality of a selected cassava variety (KME 1). The cassava (variety KME 1) was harvested from the JKUAT farm at physiological maturity and immediately transported to the postharvest laboratory in plastic crates where they were cleaned, sorted and then divided into homogenous batches for various treatments. There was significant difference ($P \leq 0.05$) between the two modes of application based on the cassava property being assessed. The colour, cyanide content, phenolic content and ethylene content were not affected by the different modes of application. The dipping method was adopted for subsequent coating as it was simpler to perform hence easily adaptable by the small scale farmers. The treatments used to determine the effect of coating on physical, physiological and chemical properties of cassava included 1%, 1.5% and 2% guar gum, 1.5%, 2% and 2.5% xanthan gum and 1%, 1.5% and 2.5% xanthan/guar gum w/v. There was an initial increase in the flesh firmness which later declined in all the treatments, though this was profound in the control samples. The final flesh firmness of the treated roots ranged from 8.4N±0.28 for the control roots to 42.6N±0.47 for the 1% xanthan/guar gum coated root. There was progressive loss in weight of the roots ranging from 17.5%±0.20 in the 2% xanthan/guar gum coated root to 31.4%±0.13 in the control roots. The total cyanide and total phenolic content also decreased with the best combination being 1% and 1.5% xanthan/guar gum coated root respectively. The ethylene and respiration rates were retarded by the coating process accompanied with the delayed onset of PPD. The browning of the flesh which accompanied PPD development led to a decrease in the L* values ranging from 73.1±1.54 in the control roots to 88.5±0.66 for the 2% xanthan coated roots which was the best. Based on the sensory evaluation results, the 1.5% xanthan/guar gum coated roots was most preferred as it was more acceptable by the panelists as compared to the other treated roots with an overall acceptability value of 6.73. The coating process significantly ($P \leq 0.05$) delayed the changes in the quality parameters measured. The results revealed that the use of 1.5 xanthan/guar gum combination as an edible coating can extend the cassava shelf life by up to 20 days when stored at ambient temperature as it maintained the quality of the root with regards to the properties measured in this study. The use of edible surface coatings can therefore be considered as a novel technology in a bid to increase the cassava root shelf life while preserving its quality. This technology can be easily taken by the producers and traders as a preservation technique which will in the long run be of economic benefit to all key players in the cassava value chain.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The total cassava production in Africa increased by 18.9% from 132,200,764 tonnes to 157,271,697 tonnes between the period of the year 2010 to 2016 (Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), 2018a). Postharvest physiological deterioration (PPD) is associated with mechanical damage that occurs during root harvesting process as the root is separated from the plant creating a wound (Raju *et al*., 2015). Since this wounding is unavoidable various techniques may be employed to delay PPD occurrence. Edible coatings have long been used to retain the shelf life of various commodities while still retaining their quality by formation of a thin edible film (Baraiya *et al*., 2016). Edible films are thin layers formed on a food product that has been coated. These products have been used for a long time to prevent loss of moisture from the product, reduce ethylene and respiration rates and lead to an eventual extension in the shelf life of the product (Swathi *et al*., 2017). The edible films can be consumed with the product as they are generally regarded as safe (GRAS) and they do not impart any extraneous flavours on the product (Embuscado & Huber, 2009). They have also been found to have anti-browning effects for instance in cucumbers (Pascual, 2013).

Food insecurity can be defined as the lack of economic and social access to adequate and nutritious foods at all times that satisfies dietary and personal preferences for a healthy body (Coleman-Jensen *et al*., 2016). It encompasses the accessibility of food products in their right form to consumers. The attainment of food security globally is hindered by many factors including the increase in arid and semi-arid areas due to climate change. However, little has been done on the improvement and commercialization of traditional food crops such as cassava which have been deemed crucial in the attainment of food security due to their ability to thrive in adverse climatic conditions (Mulu-Mutuku *et al*., 2013). Cassava is an important staple food crop of marginal and semi-arid areas of

Kenya with the potential to serve as a food security crop owing to its drought tolerant nature (Mwango'mbe *et al*., 2013). It has great potential to become a solution to improving food security in this time of global warming and climate changes.

Cassava (*Manihot esculenta*) is a major tropical root crop grown in Africa, Latin America, Oceania and Asia. Majority of the cassava cultivation occurs in Africa. The crop needs very little water for growth, can survive in nutrition deprived soils and has flexibility in harvesting time as it can remain in the soil without harvest for extended periods of time (Oluoko-Odingo, 2017). This can secure local food source for years especially in the marginal and food insecure areas (Burns *et al*., 2010).

Cassava is an important dietary carbohydrate source for approximately 800 million people in the tropics (Clement *et al*., 2010) and 250 million people in Africa (Sayre *et al*., 2011). The root, which is the major edible portion of the plant, is an important source of dietary carbohydrate producing approximately 61.8g/100g portion on dry basis (Adelekan, 2010). It comprises more than 80% starch, and is also rich in vitamin C, carotenoids, calcium, and potassium (Montagnac *et al*., 2009).

Africa is the main producer of cassava worldwide followed by Asia and Latin America, with a total production of around 200 million (Omojola , 2013). Nigeria is the world's largest producer of cassava producing about 54 million metric tonnes per annum, while Thailand is the largest exporter of dried cassava in form of crisps and flour although it produces half of what is produced in Nigeria (Onyenwoke & Simonyan, 2014). In Africa, cassava is mostly grown by subsistence farmers for food and the remainder is used as a source of income.

In East Africa, Tanzania and Uganda produce higher outputs of cassava as compared to Kenya (FAO, 2009a). In 2016, Kenya produced 571,848 tonnes of cassava as compared to Uganda's 2,885,446 tonnes and Tanzania's 5,575,304 tonnes (Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), 2018b). Cassava in Kenya is grown on approximately 77,502 hectares majorly for food and income. It is mostly grown at the Coast, Western and Nyanza regions with smaller amounts being grown in

Eastern, Central and Rift valley regions (USAID, 2010). There has not been a rise in the production of cassava in the country over the years in spite of the addition of new varieties of cassava in the country and its promotion by the government and other interested organizations such as IITA and FAO (Mulu-Mutuku *et al*., 2013). This has been attributed to various reasons including the highly perishable nature of the cassava roots. Almost all cassava that is produced in Kenya is consumed locally and a small amount is made into starch for commercial purposes (USAID, 2010). Most of the varieties grown in Kenya include Tereka and Serere in Western region, Katsunga and Kibandameno in the Coastal region and Mucericeri, Ndolo and KME in Central region (USAID, 2010).

Cassava is a highly perishable crop due to its high moisture content which varies with genotype and other factors including diseases and mechanical damage during harvest (Iyer *et al*., 2010). Deterioration is a major challenge limiting commercial production of cassava (Bull, 2011) with approximately 29% losses occurring in Africa (Anderson, 2015). The postharvest physiological deterioration is characterized by blue-back streaking of the vascular tissues of the xylem (Salcedo & Siritunga, 2011) accompanied by an unpleasant odor and flavor. Production of reactive oxygen species (ROS) is another early sign leading to the onset of PPD (Zidenga *et al*., 2012). This process is an unavoidable situation caused by aerobic respiration, damage during harvest, stress or when attacked by pathogens (Salcedo & Siritunga, 2011).

In recent years, research has been directed towards the delay of PPD of the cassava roots and given priority by FAO and the Cassava Biotechnology Network (Raju *et al*., 2016). Options currently used include processing into more stable industrial products especially useful at small scale level, coating with paraffin wax and storing in controlled atmosphere (Venturini *et al*., 2015). There is need for the development of adequate postharvest treatments for cassava roots as their optimum use are of great necessity and economic importance. Adequate postharvest treatments are needed to reduce losses and preserve the roots to meet consumer demands for constant availability and good quality throughout the year.

Various treatments and techniques can be employed in order to control metabolic changes, prevent spoilage and preserve quality in perishable food crops. One of the interventions that can reduce PPD is the use of surface coatings. Edible films and coatings are useful materials mainly produced from edible biopolymers and food-grade additives (Generally Recognized as Safe- GRAS). Coatings are a type of films directly applied on the food product surface. The application of edible coatings can improve the physical features of food products and improve visual features on the product surface (Baraiya *et al*., 2015). For maximum activity of the surface coatings, it is necessary to optimize their application and the drying step conditions in order to reach optimal effectiveness. Moisture barrier properties of edible coatings can be useful in preventing dehydration which leads to loss in quality (Janjarasskul & Krochta, 2010).

To enhance the commercialization of cassava in Kenya, there is need to develop measures of extending its shelf life and ensuring that the produce reaches its target market at its peak quality. This study investigated the most effective surface coating that can practically be used with ease by the small scale farmers and the commercial cassava industry in Kenya to delay the onset of PPD in cassava. The different surface coating solutions studied included guar gum, xanthan gum, shrink wrap and liquid seal.

1.2 Statement of the problem and justification

1.2.1 Statement of the problem

Cassava is considered a drought resistant crop that is an important source of energy, but is extremely affected postharvest physiological deterioration (PPD) which greatly affects its postharvest shelf-life (Sowmyapriya *et al*., 2017). The PPD of freshly harvested cassava is a problem not known in any other crop (Tumuhimbise *et al*., 2015). PPD is characterized by blue-black streaking of the vascular tissues of the xylem, accompanied by an unpleasant odor and flavor. Cassava roots showing visible symptoms of PPD are considered to be of poor quality. The physical deterioration due to water loss which affects nutritional quality (Zidenga *et al*., 2012). The amount of water lost during the

storage period of cassava roots greatly affects its nutritional quality (Sánchez *et al*., 2013a). The market value and consumer acceptance of the product is also greatly reduced due to the physiological deterioration (Zainuddin *et al.*, 2017).

PPD has restricted the trade of the product, profoundly impacting processing as well as leading to financial constraints to the cassava processors, traders, farmers and the ultimate consumer.

1.2.2 Justification

Surface coatings are a postharvest technology with potential of extending shelf life of cassava as it has been proven to be effective in various fruits and vegetables (Raghav *et al*., 2016). Coatings can help reduce the postharvest losses eventually leading to lowering of prices and thereby boosting domestic consumption and exportation. This will enable marketing of the cassava roots to distant markets without the need for more costly preservation techniques. The use of these biodegradable polymers has also proved effective in the reduction of non-biodegradable packaging materials since they are environmentally friendly. The coating formed on the product act as a water barrier leading to eventual shelf life extension due to various mechanisms (Swathi *et al*., 2017). Their effectiveness on cassava is yet to be reported.

The use of hydrocolloids such as xanthan gum and guar gum as edible coating materials is easily accessible to the small scale farmers since they are sourced from underused marine and agricultural products (Swathi *et al*., 2017). Xanthan gum has successfully been used in the coating of *Carica papaya* and grapes while guar gum has been used to extend the shelf life of guava by 9 days (Lin & Zhao, 2007; Wijewardane, 2013). To enhance the commercialization of cassava in Kenya, there is need to extend their shelf life and ensure that they reach the target market at their peak quality in order to fetch optimum prices. Extended postharvest life will ensure that fresh roots are available for consumption, industrial use and for export purposes. It will leads to reduction in postharvest losses eventually improving food security. The knowledge gained could also

be used by policy makers to create an enabling environment for the commercialization of the cassava.

1.3 Objectives

1.3.1 Main Objective

To investigate the effect of surface coatings on postharvest shelf life and quality of cassava.

1.3.2 Specific Objectives

i. To compare the efficacy levels of different application methods (dipping and spraying) on the shelf life prolongation of cassava roots.

ii. To determine the effects of different surface coatings on the physical, physiological, chemical and organoleptic qualities of cassava roots.

1.3.3 Null hypothesis

i. The different application methods have no significant differences in their shelf life prolongation of cassava.

ii. The surface coatings have no significant effect on the physical, physiological, chemical and organoleptic quality of the cassava root.

CHAPTER TWO

LITERATURE REVIEW

2.0 Cassava

2.1 History of cassava

Cassava (*Manihot esculenta*) originated from Brazil and Paraguay, but has spread throughout tropical areas of South and Central America (O'connor, 2013). Wild cassava subspecies were cultivated and domesticated in the West- Central Brazil about 10,000 BC. Due to its ability to grow in nutrient poor soils and hot climates, it became a staple food of the native South American people hence was referred to as a drought resistant crop.

The Portuguese arrived in Brazil in 1500 where they found cassava as a staple food being used to process bread and this technique is still used today (Iwuagwu, 2012). When Portuguese imported slaves from Africa about 1550, they used cassava as a staple food for the slaves and began cultivating it along the Coast of West Africa. The Portuguese introduced the crop to all of West Africa, East Africa, Madagascar and Indonesia (Ceballos *et al*., 2010). It was then introduced in Asia by the Spanish and distributed throughout tropical Asia by the 19th century.

2.2 Botany and Taxonomy of cassava

The genus *Manihot* belongs to the dicotyledonous family, Euphorbiaceae. It belongs to the genus *Manihot,* species *esculenta* and order of *malpighiales. Manihot* genus range in habit from herbs to shrubs, small trees and even climbing vines (Nassar & Ortiz, 2007). Their skin can range from smooth to rough and peeling. Their lenticels and central vascular strands are clearly visible. Stems are variable and can reach 30cm in diameter and 5metres in length. The stem skin color varies from light grey, brown, yellowish or reddish. Internal tissues are always tender unless in cases of water loss.

Cassava is propagated by stem cuttings. The roots in the cassava plant develop into root tubers through a secondary thickening process. There is formation of approximately 5-

10 tubers per plant (Ademosun *et al*., 2012). It has both the distal and proximal end where it is joined to the mother plant. It is a drought resistant root hence its low cost of cultivation with flexibility in harvesting (Salcedo *et al*., 2010). It is a woody shrub of the spurge family, Euphorbiaceae. It tolerates a wide range of soil acidity levels of pH 4 to pH 8. In a period of 7-9 months after planting, the root is ready for consumption (Nassar & Ortiz, 2007). However, studies have shown that the optimum harvesting period for the cassava is dependent on the genotype and environmental conditions as some are harvested as early as 6 months after planting (MAP) while some are harvested as late as 12MAP (Mtunguja *et al*., 2016).

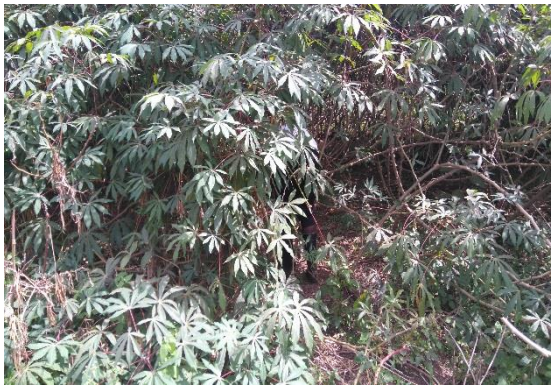


Figure 2-1: Cassava shrub

Figure 2-2: Cassava roots

2.3 Ecological requirements of cassava

Cassava is adaptive in tropical regions with annual rainfall of 600mm, high temperature and solar radiation for optimal leaf development and photosynthetic potential (Burns *et al*., 2010). It requires warm climate but can also grow well in high altitudes, in the tropics and at low altitudes in the sub- tropics. Maximum cassava growth requires temperatures of 25 °C-29 °C but it can tolerate 16 °C-38 °C. It's best cultivated between latitude 30 °North and 30 °South. The ideal soil for cassava is a light, sandy loam soil of medium fertility and with good drainage (Mtunguja *et al*., 2016).

2.4 Types of cassava

There are two main types of cassava namely sweet and bitter. Both types contain the poisonous Hydrocyanic glucoside (HCN), a cyanide producing sugar derivative.

a) Sweet type: HCN is present in only in the peel of the root at very low levels. They can be eaten raw after peeling. They have a soft white flesh and tend to deteriorate fast if not harvested immediately after maturity as compared to the bitter varieties.

b) Bitter type: HCN is present throughout the root, which must be cut up and boiled, then squeezed out and then re-boiled in clean water. Its tubers have a firm yellow flesh and have higher levels of cyanide content than the sweet type on dry weight basis (Mühlen *et al*., 2013).

2.5 Global Production of cassava

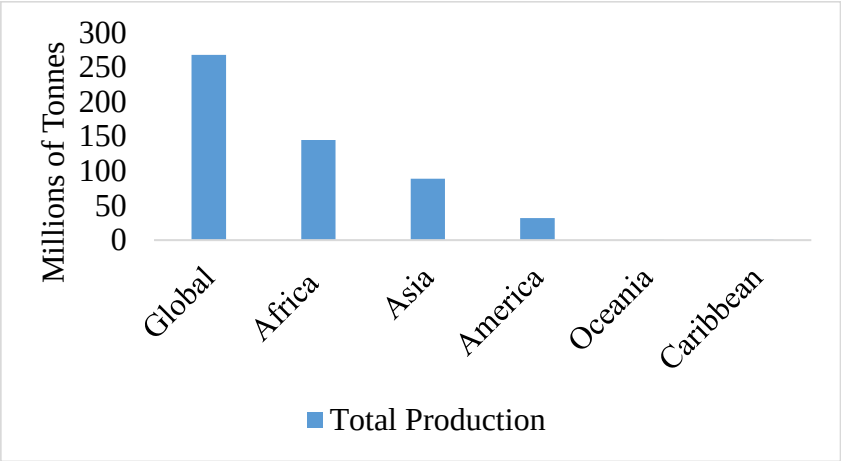


Figure 2-3: Cassava production in 2014 for major cassava-growing regions

Source: (FAOSTAT, 2014)

2.6 Cassava production in Kenya.

Cassava is the second most important food crop after maize in the western and coastal regions of Kenya (Mulu-Mutuku *et al*., 2013). At the Kenyan coast, cassava is cultivated on small farms in mixed cropping systems together with cereal crops such as maize or grain legumes such as cowpea, beans or green-grams. The semi-arid agro-ecological zones of Kenya constitute 80% of the country's land mass and support 95% of the poor population. It is an important source of food and the surplus is used for income generation(Mulu-Mutuku *et al*., 2013).

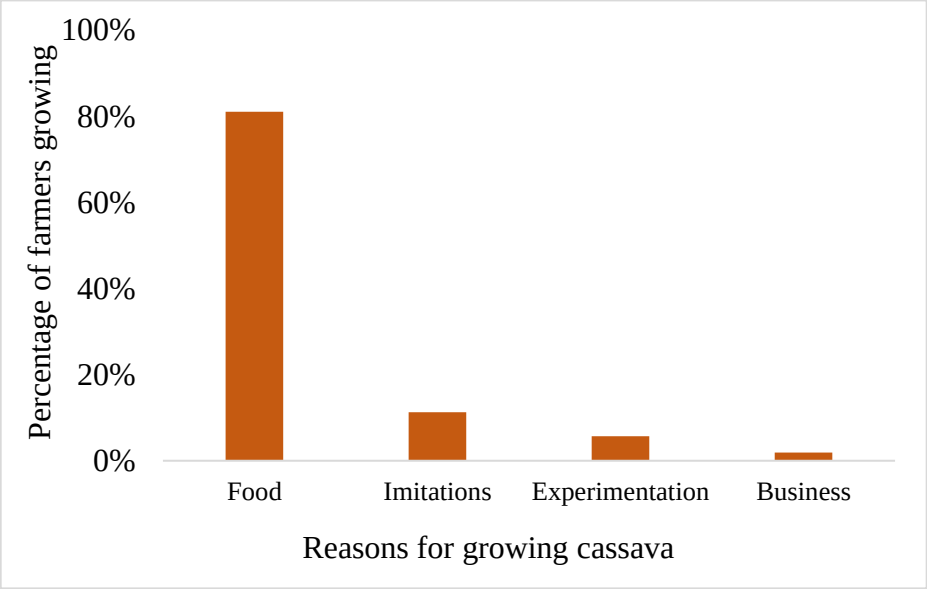


Figure 2-4: Reasons for cassava growing in Kenya

Source: Mulu-Mutuku *et al*., (2013)

Cassava productivity in Kenya is 11 tonnes per hectare which is below the potential yield of 90 tonnes per hectare. This low productivity may be due to the low yield potential of popular varieties, susceptibility to pests and diseases, PPD menace and poor crop management practices among other constraints (Mware *et al*., 2009; Mulu-Mutuku *et al*., 2013). This has led to inconsistent availability and quality of the crop hence processing tends to be affected. As a result of this, cassava trade in Kenya hasn't really picked unlike other African countries including Nigeria, Congo and Ghana (Adelekan, 2010).

2.7 Cassava varieties in Kenya

In Kenya, there are both improved and local varieties. Farmers are being advised to plant the new improved varieties which are supplied by KALRO. Most of the cassava I Kenya is grown in the former Coastal and Western regions which a little production occurring in the Central/Eastern region. In the coastal region there is growth of Kaleso, Guso and 5543/156 which are all improved varieties. The local varieties grown here include kibandameno and katsunga. In western there is growth of tereka serere, adhiambo tera, BAO and CK1 which are

all improved varieties while in central/eastern region there is growth of mucericeri, Ndolo and KME1 (USAID, 2010). KME is Kenya's top yielding cassava variety (Evelyn Otieno, 2012). It is the sweet type of cassava and therefore has very little quantities of cyanide. There are various type of this variety including KME-01 (karibuni), KME-02 (tajirika) and KME-03 (shibe).

2.8 Nutritional composition of cassava roots

The cassava root is rich in starch which makes it a very important source of dietary energy (FAO, 2009b). However, cassava is a root crop with low protein concentration and other major nutrients. The starchy root of the cassava contains cyanogenic potential (the ability to produce hydrogen cyanide). The nutritional composition of cassava varies with cultivator, age of plant, environmental conditions, processing and the cooking methods applied (Tewe, & Lutaladio, 2004; Apea-Bah *et al*., 2011). However, it's rich in carbohydrates ranging from 32-35% hence it's a very good energy source (Montagnac *et al*., 2009). The cassava root contains minimal amounts of minerals but the calcium content is relatively high compared to maize (Montagnac *et al*., 2009). The cassava root also contains anti-nutrients and toxic substances that deter digestibility and bio availability of major nutrients. HCN is an example of toxic compound found in higher levels in the bitter type of cassava.

2.9 Post-harvest changes in cassava

Physiological/Chemical changes

Cassava deteriorates 2-3 days after harvest and this leads to a phenomenon known as postharvest physiological deterioration (Quevedo *et al*., 2014). This is triggered by the harvesting process. The physiological changes occur due to the production of reactive oxygen species (ROS) which are induced by injuring of the root (Anderson, 2015). The reactive oxygen species are produced through the process of cyanogenesis. The ROS act on the phenolic content of the cassava root leading to its oxidation and formation of coumarin which lead to the blue/black coloration on the cassava flesh. This leads to a decrease in phenolic content of the root with time (Uarrota *et al*., 2014). The endogenous enzymes are also triggered leading to a change in the firmness hence leading to weight loss (Ampe & Brauman, 1995). There's a gradual cyanide loss due to the depletion of linamarin and linamarase enzyme with increased storage duration. It is estimated

that approximately 29% of all cassava produced in Africa is lost due to these changes (Anderson, 2015).

Microbial changes

These are induced by the development of PPD. It often leads to rotting of the cassava root and fermentation. It occurs 5-7 days after harvest (Morante *et al*., 2010). Microorganisms that lead to the development of this type of deterioration include the *Aspergillus* spp. *Rhizopus* spp. and *Bacillus* spp. (Uchechukwu-Agua *et al*., 2015).

Mechanical/physical changes

This mainly occur due to the carless handling of the roots during harvest, storage and transportation. Mechanical damage to the root is the major contributor to the development of PPD. Damages that occur due to injury caused by farm tools or during removal of the root from the ground lead to this form of deterioration. Friction between the roots during transportation can also lead to bruising hence injury to the roots. It is estimated that in Nigeria there is an approximate loss of 12% on-farm and 6% due to transportation, trading and careless handling (Naziri *et al*., 2014).

2.10 Factors influencing pre and post-harvest deterioration of cassava

Pre-harvest cassava losses occur even before the cassava root is harvested while the post-harvest losses occur at harvest, transportation, storage and processing stages. Losses that occur during the retail and consumption stages are called food wastages. Pre-harvest losses are mainly due to bacterial diseases/viruses. Underground storage of the cassava root may also lead to infestation by both rodents and insects leading to losses. Post-harvest losses are due to various factors including:

i. Careless handling during harvesting which leads to broken and injured roots which cannot be sold.
ii. Damage during transportation and trading. Delays during the two processes also leads to spoilage due to the roots short shelf life.

iii. Injury during transport both loading and off-loading leading to damaged roots.
iv. Pest and disease infestation which renders the root unsafe for consumption.
v. Postharvest deterioration which occurs 2-3 days after harvest.

2.11 Postharvest physiological deterioration of the cassava root

Cassava roots are far more perishable as compared to other staple food crops (Bandna, 2012). Cassava roots suffer various physiological changes that affect their shelf life after harvest. Preparation processes such as sorting and washing may promote cell tissue disruption which further accelerates this deterioration process. Commercial production of cassava is hindered by its proneness to deterioration after harvest (Okigbo *et al*., 2009). Approximately 29% of all cassava produced in Africa is lost due to PPD (Anderson, 2015). The process of PPD starts within 24-72 hours after the cassava is harvested depending on the cultivar, environmental conditions and genotype (Cortés *et al*., 2002). This affects the cassava both qualitatively and quantitatively. The PPD process starts approximately 15 minutes after root harvesting and the process is only visible after 2-3 days (Owiti *et al*., 2011). The discoloration first appears around the wound and then it spreads to the other parts of the cassava root (Liu, 2016). The process is followed by fermentation which leads to an eventual rotting of the root. Microbial deterioration starts as early as four to five days after harvest (Venturini *et al*., 2015). PPD affects the appearance and the taste of the root (Liu, 2016).

Cassava roots continue to respire even after harvest hence they are prone to deterioration and have a limited shelf-life. The physiological changes that occur after harvest are associated with water loss, synthesis of ethylene, increase in enzyme activities, attack by pests and root respiration (Salcedo & Siritunga, 2011). The postharvest deterioration which generally causes spoilage of the root can be classified into three different factors, namely physiological, microbial and mechanical. These changes cause a great challenge to optimal storage of the freshly harvested roots. PPD is a major constraint to the exploitation and commercialization of the cassava root due to wastage and other additional production costs.

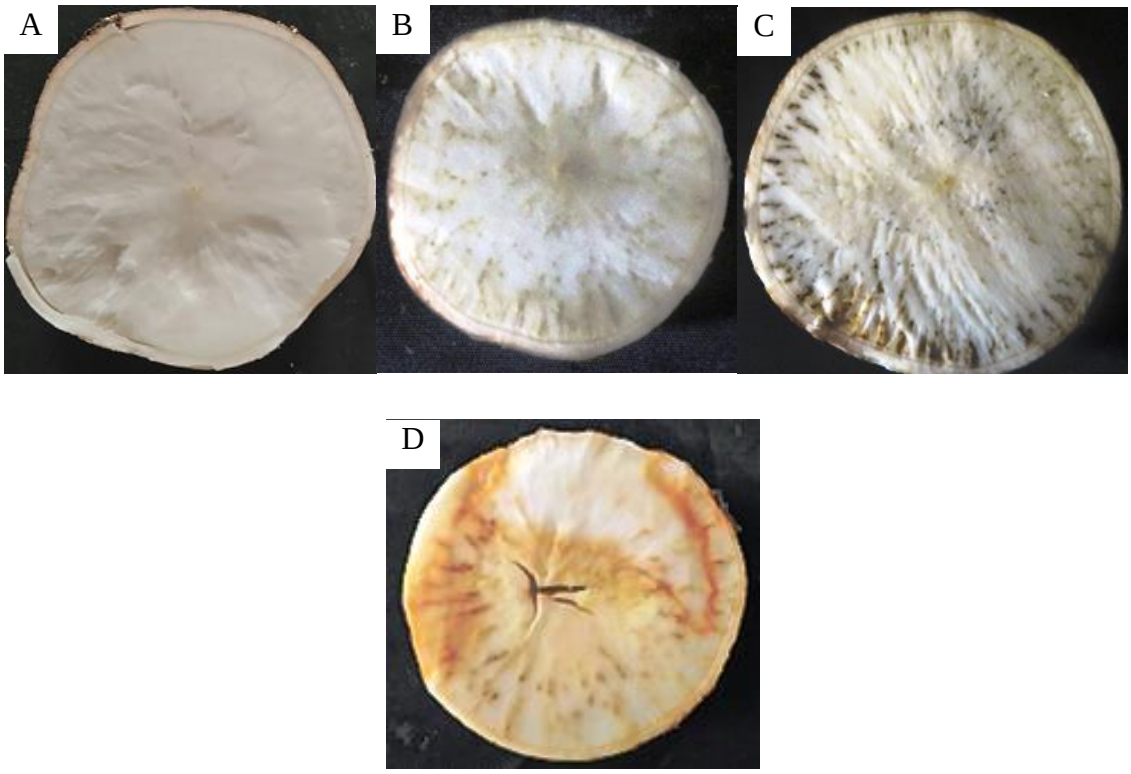


Figure 2-5: PPD in cassava root cross section. A) Fresh root no PPD, B) Cassava root at day 2 PPD, C) Cassava root at day 3 PPD and D) Cassava root at day 4 PPD when stored at room temperature. From day 2 onwards, there's colour change on the cassava flesh due to formation of the blue/black streaks. This is triggered by the damages that occur during harvesting

Storage of cassava is a vital aspect in postharvest handling of the product. Cassava roots have been reported to store best at temperatures below 3°C with very minimal weight loss (Uchechukwu-Agua *et al*., 2015). Cassava roots stored above this temperature exhibit internal browning disorder and the rate of deterioration is faster once removed from low temperatures to room temperature (Lebot *et al*., 2009). The quality, sustainability and safety of the cassava root lies majorly on the postharvest management strategies especially due to its rapid deterioration rate (Iyer *et al*., 2010).

2.12 Use of edible coatings and films on perishable produce

Coating of perishable products has proved to be an effective way in which the products shelf life can be slightly elongated. The main film-forming materials are bio-polymers such as proteins and polysaccharides (Campos *et al*., 2011). Polysaccharide derived coatings are majorly extracted from marine animals and agricultural products. The coat used acts as a preventive cover that reduces water loss from the product and gaseous exchange between the product and its environment which leads to eventual shelf life extension due to various mechanisms (Dhall, 2013). The coat also acts as a barrier that deters the growth of microorganisms on the surface of the product.

Edible films are defined as a thin layer of edible materials formed on a food as a coating or placed in between food components (Dhall, 2013). If the film forming solution (FFS) is applied as a thin layer on a flat surface and is allowed to dry, it is referred to as an edible film, the physical and mechanical properties of which can be studied separately from the coated material. Films or coatings can also be used as wraps. The FFS is applied to the surface of a food product, it provides a barrier against migration of moisture, oxygen, carbon dioxide, aromas, lipids and other solutes (Janjarasskul & Krochta, 2010). This application is a technology for not only extending shelf life and reducing the risk of pathogen growth on food surfaces, but also providing a functional product with health benefits to the consumer. The thickness of the coating solution is crucial to the activity of the coat hence it should be well adjusted to suit its purpose. A very thick film may lead to anaerobic respiration hence the production of CO_2, and off-flavors. The thickness of the coating directly correlates to the concentration, draining time and viscosity of the coating solution (Lin & Zhao, 2007). The methods used for film formation are solvent casting (wet process) and extrusion (dry process) (Bull *et al*., 2011).

Solvent casting is the most common technique used to form hydrocolloid edible films. Hydrocolloids are films that consist of proteins or polysaccharides. They are partially or fully soluble in water and act as the gelling agent (Raghav *et al*., 2016). The extrusion

process uses thermoplastic biopolymers associated with plasticizers and low levels of moisture. Extrusion processes are related to high temperatures, which could be affecting some sensible active compounds on films. When comparing extrusion with solvent casting process, there can be observed an increase in its elongation, although film solubility does not change significantly between the different processes such as injection, compression or extrusion (Andreuccetti *et al*., 2012). Films prepared by solvent casting are more homogenous and transparent, with lower opacity and water vapor permeability values, compared to films prepared by other techniques (Fakhouri *et al*., 2013). The structural matrix of edible coatings and films is developed from proteins, polysaccharides, and lipids or blends of them, called composite films. Edible films and coatings must be uniform and without defects to optimize functionalities (Skurtys *et al*., 2001).

The use of edible coatings is considered a form of active packaging (Suppakul *et al*., 2003). This is a system in which a product, the package and the environment work together to maintain the quality of the product. The edible coatings can be safely consumed with the food product as they conforms to food safety (Teja *et al*., 2016). Edible films are usually made from polymers that are able to provide mechanical strength as a stand-alone thin structure. The formation of edible films combines the use of at least one component which is able to form a matrix, having cohesion and continuity to form a good coat. Edible coatings are directly applied to the surface of the materials. They can protect food products from moisture migration, microbial growth on the surface and oxidation of nutrients. They can also act as barriers against oils, gases or vapors and carriers of active substances (Campos *et al*., 2011).

The application of a film-coating material in its liquid form can be performed by spraying and dipping the produce into the coating solution (Lin & Zhao, 2007; Henriques *et al*., 2016). The dipping method of application tends to lead to formation of a uniform coat hence ensuring complete coverage. Films applied by spraying tends to be thinner than those applied by dipping (Lerdthanangkul & Krochta, 1996). For spray-

coating, the drying time required is short due to insignificantly minimal coating solution. Spray coating is the most commonly used mode of coating application commercially according to Debeaufort and Voilley (2009). Edible films and coatings enhance the quality of food products, protecting them from physical, chemical, and biological deterioration, which results in extended shelf-life and improved safety. These coatings also reduce the risk of pathogen growth on the sample due to formation of the film. They can be used on fruits and vegetable produce. Edible coatings can help retain or improve food product quality (Fan *et al*., 2009; Rojas-grau *et al*.,2009; Baraiya *et al*., 2015) by forming an efficient barrier to prevent moisture loss or by delaying ripening process in vegetables, through selective permeability to gases that affect postharvest metabolism, extending the storage life, reducing lipoxygenase enzyme action in frying process, adding vitamins or other functional ingredients to enhance quality and by incorporating active additives such as antimicrobial agents and antioxidants.

Xanthan gum

Xanthan gum is a polysaccharide derived from *Xanthomonas campestris* through microbial fermentation systems which is a biotechnological process (Campos *et al*., 2011). It is a hydrocolloid and is fully soluble in water and can be used as a thickener or gelling agent. It forms films with improved adhesion and wettability (Lin & Zhao, 2007). At high concentrations it shows weak gel-like properties and at low concentrations it gives a highly viscous solution. The optimum temperature for its preparation is 40 °C. It thickens when dissolved in water due to the formation of strong hydrogen bonds. with water and intermolecular friction during application of shear (Nieto, 2009). It has been used to form edible coatings in pawpaws (Adetunji *et al*., 2014) and grapes (Baraiya *et al*., 2016).

Guar gum

Guar gum is a galactomannan that is extracted from guar seed *Cyamopsis tetragonolobus* (Raghav *et al*., 2016). It is soluble in both hot and cold water with

formation of very highly viscous solutions at very low concentrations due to its high molecular weight. To ensure optimum dispersion, the gum is heated at 80 °C for two hours. When heated at high temperatures, the dissolution rate is increased while viscosity is highly reduced due to thermal degradation of the molecules. It has a pseudoplastic behavior. Its high solubility is due to the presence of high galactose and multiple side chains. It is considered as a very economical thickener mostly used for juices and can also be used for film-forming solutions (Nieto, 2009).Guar gum has been used to extend the shelf life of guava for 9 days (Wijewardane, 2013).

Xanthan and guar gum have been found to have synergistic effects (Xue & Sethi 2012). Their mixture exhibited an increase in viscosity as compared to the different gums separately. The galactomannan and the polysaccharide interact to form solutions having high viscosity at very low concentrations. This effect is usually magnified at low temperatures when the xanthan structure is in an orderly conformation. The most viscos solution is formed at temperatures of 60 °C.

2.13 Functionality of edible coatings

The ultimate functionality of edible films is related to their bioactivity, and their mechanical and physical properties. In addition, they can preserve or enhance the sensorial properties and may have the ability to modify the internal atmosphere of the foods. Plant-based bioactive agents are being incorporated in food as prominent alternatives to chemical preservatives and additives. Research has shown that films and coatings improve the active properties such as antioxidants, antimicrobial and antibrownings (Siripatrawan & Noipha, 2012). Bioactive properties include antioxidant, antimicrobial activities. Physical properties include barrier to oxygen, UV-vis light, carbon dioxide and water vapor permeability (Jiménez *et al*., 2012).

Mechanical properties

Tensile strength and elongation at break are parameters related to the film's mechanical properties and chemical structure (Swathi *et al*., 2017). Changes in mechanical

properties of a biopolymer based film are affected when natural extracts are added. Some extracts increase while others decrease these properties. E.g. Vitamin E addition to the films modifies the mechanical properties over time (Dhall, 2013). It decreases the film tensile strength and the elongation of gelatin-based films (Jiménez *et al*., 2012a).

Water vapor and gas barrier properties

Due to the hydrophilic nature of the films, its barrier properties are dependent on the relative humidity of the surroundings (López-de-Dicastillo *et al*., 2012). Differences in oxygen barrier properties depend on chemical composition, molecular structures of the polymers (Mokwena & Tang, 2012) and water content. To prevent the dehydration of foods, films used as coatings must control the transfer of humidity from the product to the environment; hence the water vapor permeability of these films must be as low as possible (Ma *et al*., 2009). Films providing a semi-permeable barrier to oxygen or carbon dioxide could prevent the leaching of vitamins during washing of the products.

Light barrier properties and appearance

Transparent packages facilitate oxidation and degradation of most nutritional compounds as they act as a catalyst for these processes. The light barrier properties of the films are related to the color and opacity of the edible films. Plant extracts are mostly used to provide color and opacity to polymers hence providing adequate barrier to light, which is also important for preventing the loss of ascorbic acid and subsequent browning when used to prevent light sensitive properties of a product (Hui, 2007). The types of extract added to the films determine the efficacy of the edible films depending on the end results required (Campos *et al*., 2011).

CHAPTER THREE

COMPARISON OF DIPPING AND SPRAYING COATING APPLICATION METHODS ON THE POSTHARVEST QUALITY OF CASSAVA

Abstract

There are various modes of application of the edible coatings including dipping and spraying. These methods have not been tested on the cassava root cop. Due to their variation in the coat dispersion and film formation, there is need to determine the most effective mode of application for cassava. Cassava roots of variety KME 1 were harvested at physiological maturity (9 months after planting), cleaned to remove extraneous debris and divided into seven equal cassava portions. The various portions were coated with 1.5% xanthan gum combination, 1.5% xanthan/guar gum combination and 2% xanthan/guar gum combination by both dipping and spraying method. Depending on the parameter being measured, there were significant differences on the effect of the two different coating methods on the cassava quality. The colour of the 2% xanthan/guar gum and 1.5% xanthan/guar gum treated roots showed significant ($P \leq 0.05$) differences of 67.9 and 83.2 and 77.1 and 60.2 for the dipped and sprayed samples, respectively at 20 days after harvest (DAH). The 1.5% xanthan/guar dipped and sprayed samples differed significantly on their effect on flesh firmness with final values of 35.4N and 46.1N respectively at 20 days after harvest. The 1.5% xanthan and 2% xanthan/guar gum treated roots showed no significant difference in their effect on both dry matter content and ethylene production rate. The 1.5 xanthan treated roots had a final dry matter content of 72.5% for the sprayed samples and 76.0% for the dipped sample while the 2% xanthan/guar gum treated roots had a final dry matter content of 64.6% and 74.1% for the dipped and sprayed root samples respectively. This study suggested that based on the coating solution and the parameters being observed on the cassava root, there generally were significant ($P \leq 0.05$) effects of dipping and spraying methods of coating application. Hence, the choice of the efficient mode of application to use would

depend on other factors such as the availability of equipments especially for the spraying method, ease of application, viscosity of the coating solution and the drying time.

3.1 Introduction

Coating of food products can be done by either dipping, spraying, brushing, extrusion, panning or solvent casting (Raghav *et al*., 2016). The mostly used modes of application are dipping and spraying due to their high convenience (Skurtys *et al*., 2001). Dipping is one of the oldest used coating technique from as early as the 12th century. It has a very simplified mode of application in which the product is dipped into the coating solution for a specified amount of time, drained and left to dry before storage (Skurtys *et al*., 2001). It can lead to formation of thick layers on the solid foods which may cause problems during storage due to anaerobic respiration (Andrade *et al*., 2012). This mode of application may lead to dilution of the coating solution leading to unwanted residue on the product (Lin & Zhao, 2007). It's also difficult to get good adhesion of the coating solution on the product due to the draining effect of the solution hence multiple dipping may be necessary to ensure full coverage on the product (Embuscado & Huber, 2009). It is best used for irregularly shaped products.

The spraying technology is mostly used in food industries due to its convenience (Skurtys *et al*., 2001). This technique uses a spray machine in which the coating solution is forced out of the nozzle onto the surface of the produce (Embuscado & Huber, 2009). It is mostly preferred when using less viscous solutions as the highly viscous solutions are not easily sprayed and they also block the nozzles. The spraying efficiency depends on the nozzle size, coating fluidity and the amount of pressure put to release the fluid through the nozzles (Andrade *et al*., 2012). This mode of application leads to formation of an even coat due to the similarity in the drop size distribution and similar overlap effect (Bartolozzo *et al*., 2016). It is mostly used on products with a large surface area (Embuscado & Huber, 2009).

The effectiveness of the two modes of application differ based on the food products being coated. There is also contradicting information on the most efficient between the

two methods. This study was carried out with the objective of determining the best technique for coating (dipping versus spraying) cassava roots that could lead to optimal shelf life extension with minimal or no effects on its nutritional quality.

3.2 Materials and methods

3.2.1 Acquisition of raw materials

In the preliminary study, xanthan and guar gum were sourced from Sigma-Aldrich. Fresh cassava root crops of variety KME 1 at physiological maturity (9 months after planting) were obtained from the JKUAT farm. KME 1 was chosen since it's a sweet variety and it is the top yielding cassava variety in Kenya. The variety obtained from the JKUAT farm is disease-free. The cassava roots were transported to the JKUAT postharvest laboratory in plastic crates and sorted according to size (50-60 cm long) and the amount of injuries. Injured roots were discarded. They were then cleaned using a soft brush to avoid bruising them and stored in clean plastic crates at room temperature ready for coating.

3.2.2 Study design

The study design was experimental using the completely randomized design. The treatments were applied to the experimental units randomly selected assumed to be homogenous. The treatments included 3 different concentrations of 1.5% xanthan gum, 1.5% xanthan/guar gum and 2% xanthan/guar gum giving a total of 7 treatments inclusive of the control samples. The experimental units were 420 cassava roots. This had previously been determined during the preliminary studies (appendix 5) and it was based mainly on the rate of colour degradation of the coated root which was based on the viscosity of the coating solution formed. Higher concentrations of the coating solutions led to shriveling on the cassava root skin and enhanced deterioration. This experimental design was performed in two replicates. The different treatments were applied by both dipping and spraying method. The data was recorded at the fresh stage and at 2 day intervals for a storage duration of twenty days.

3.2.3 Preparation and application of coating formulation

Two different coating application methods were tested to determine the most effective mode of application to be used on the cassava roots. Coating was performed on the same day that the cassava roots were harvested. The differently treated roots were then subjected to physical, physiological and chemical analysis for the entire storage duration at two-day intervals. Xanthan gum (Batch number 1170908039, MFG. 10-09-2015, Expiry 09-09-2018) and guar gum (Batch number 1089120215, MFG 02-08-2015, Expiry 01-08-2018) were used.

The coating formulations used were 1.5% xanthan gum, 1.5% xanthan/guar gum and 2% xanthan/guar gum. The 1.5% xanthan gum was prepared by dispensing 1.5 g of xanthan gum into 100 ml of distilled water. This was heated at 40 °C on a magnetic stirrer for one hour. The 1.5% xanthan/guar gum solution was prepared by dispensing 0.75 grams of xanthan gum and 0.75 grams of guar gum into 100 ml of distilled water while the 2% xanthan guar gum solution was prepared by dispensing 1 gram of both xanthan gum and guar gum into 100 ml of distilled water. This was then heated at 60 °C on a magnetic stirrer for one hour. Coating was done on the same day that the roots were harvested. The roots were then placed in clean crates for air drying and stored at 25 ˚C. Cassava roots under the different treatments were then tested for the twenty days storage duration at two-day intervals to determine the effect of the coatings on the physical, physiological and chemical properties of the cassava roots.

For the dipping method of application, the already cleaned roots were immersed into a bucket containing the coating solution. The roots were le to stay in the solution for three minutes after which they were removed and excess solution left to drip off the cassava. The roots were then placed in clean plastic crates and left to dry after which they were stored for the twenty day storage duration. For the spraying technique, the solution was put in a hand held sprayer and this was then dispersed onto the cleaned roots. The excess solution was let to drain before drying and storage.

3.2.4 Determination of flesh firmness

A hand held penetrometer (N/g model ver 0.2, CRD-100D, Sun Scientific Co., Ltd, Japan) fitted with a probe was used to determine the firmness of flesh of the roots to a depth of 10 mm and the corresponding force required to penetrate this depth was determined according to Famiani *et al* (2012). A cylindrical cork borer was used to get even samples of 2 cm length. The test was carried out at a probe speed of 6mm/s. The firmness of each cassava was measured at three points along the equatorial region of the cassava. Firmness was taken to be the resistance of the flesh to the penetration of the plunger expressed as mean force in newtons.

3.2.5 Determination of colour change

The colour of the cassava samples (3 replicates per treatment) was determined using a hunter lab colour difference meter (Minolta, Tokyo, Japan) according to Hernández-Muñoz *et al* (2008). The instrument was standardized each time with a white a black ceramic plate. The colour was measured at four different regions along the mid-section spaced 90^0C apart. Results were recorded as L* values used to determine the rate of color changes of the flesh with time. Only the L* values were used as they indicate the rate of darkening of the root from white (100) to black (0).

3.2.6 Determination of weight loss

Cassava samples (3 replicates per treatment) were weighed while fresh and at an interval of two days for twenty days. The difference between initial and final root weight was determined for that storage period and expressed as a percentage on a fresh weight basis (Paniagua *et al*., 2013).

$$\%\, weight\ loss = \frac{Initial\ weight\ of\ sample - current\ weight\ of\ sample}{Initial\ weight\ of\ sample} * 100$$

3.2.7 Determination of dry matter content

This was determined according to Ebah-Djedji *et al* (2012). 20 g of the chopped and ground roots were oven-dried at 105 ˚C for 24 hours. Dry matter was then expressed as a percentage of the dry weight relative to the fresh weight.

$$\%\ dry\ matter\ content = 100 - \left(\frac{Dish\ and\ Sample\ wight - Dish\ weight}{Sample\ weight}\right) * 100$$

3.2.8 Determination of total phenolic content

The amount of total phenolic contents was determined by the Folin-Ciocalteu method as described by Ainsworth and Gillespie (2007) with modifications. Two grams (2 g) of the cassava root was ground in an ice-cold mortar and pestle using 20 ml of ice-cold 95% methanol. The samples were then vortexed and incubated at 25 ˚C for 72 hours in the dark. The puree was then filtered to remove debris and the residue centrifuged at 13,000 g for 10 minutes at room temperature and the supernatant collected. The sample was then passed through a 0.45µl membrane filter. To 1 ml of the sample extract and the standard, 2 ml of 10% (vol/vol) Folin-Ciocalteu was added and vortexed and 4 ml of saturated Na_2CO_3 solution was then added. The mixture was then allowed to stand at 25 ˚C for 2 hours and the absorbance measured at 765 nm using UV-vis spectrophotometer. A standard curve was generated using the absorbances of gallic acid as standards in ppm (Appendix 1). The amount of total phenols was expressed as gallic acid equivalents per 100 g of the sample.

3.2.9 Determination of cyanide content

Total HCN was analyzed using the alkaline titration method according to Famurewa & Emuekele (2014). Approximately 4g of the cassava was ground and passed through a sieve. This was then soaked in a mixture of distilled water (40ml) and orthophosphoric acid. The samples were then thoroughly mixed and left to stand at room temperature overnight for 24 hours. This was done to set free the hydrocyanic acid. The remaining sample was then transferred into a distillation flask and a drop of paraffin added to the broken chips to act as an antifoaming agent. The sample was then distilled and about

45ml of the distillate collected in the receiving flask containing 4ml distilled water and 0.1g of sodium hydroxide pellets. The distillate was then transferred to a 50ml volumetric flask and made up to the mark using distilled water. 1.6ml of 5% potassium iodide was then added and titrated against 0.01M Ag(NO_3). The endpoint was indicated by a faint but permanent turbidity. The total HCN content in mg/kg was calculated as total

$$\text{HCN content} = \frac{13.5 * \text{TV}}{\text{M}}$$

Where:

TV=titre value

M=mass of sample

3.2.10 Determination of respiration rate

Air tight containers of specific known volume fitted with self-sealing rubber septums were used. The weight of each cassava root was measured. The samples were then incubated in the air-tight plastic containers for one hour. After one hour, 1 ml of the headspace gas was drawn from each container using an air-tight syringe and injected into a gas chromatography (Shimadzu Corp., Kyoto, Japan, model GC-8A) fitted with a thermal conductivity detector and a Propak N column. Standard curves were generated by injecting pure gas samples of known concentrations (Appendix 3) .The respiration rate was measured as mg CO2 per Kg per hour.

3.2.11 Determination of ethylene production rate

This was done according to Fugate *et al* (2010) with a few modifications. Air tight containers of specific known volume fitted with self-sealing rubber septums were used. The weight of each cassava root to be used was taken. The samples were then incubated in the air-tight plastic containers. After one hour, 1ml of the headspace gas was drawn from each container using an air-tight syringe and injected into a gas chromatography model GC-9A, Shimadzu Corp., Kyoto, Japan. The detector used was the flame

ionization detector fitted with activated alumina. Standard curves were generated by injecting pure gas samples of known concentrations (Appendix 2). The rate of ethylene production was then calculated in nl C_2H_4/g/h.

3.2.12 Statistical analysis

Comparisons among the various treatments and storage duration effects was determined by analysis of variance (ANOVA) while mean variations were performed using Tukey multiple comparison test at α=0.05 significance level. Two way ANOVA was used since there were two independent variables (factors). Data analysis was carried out using Genstat statistical package 12th edition, 2009 (VSN International, UK).

3.3 Results and discussion

3.3.1 Flesh Firmness

The flesh firmness of the treated samples was determined and recorded from the first day after harvest to 20DAH (Table 3-1).

The 1.5% xanthan treated samples were both dipped and sprayed with the coating solution. The dipped sample attained a flesh firmness peak of 91.4N at 12DAH while the sprayed sample attained its firmness peak of 95.6N on the same day. From 12DAH onwards, the two samples declined in their flesh firmness newtons as they approached 20DAH. At this point, the dipped sample had 21.2N while the sprayed sample had a slightly higher flesh firmness of 29.1N with no significant ($P>0.05$) differences.

In the 1.5% xanthan/guar treated cassava root, the dipped sample attained its peak of 95.8N at 8DAH while the sprayed samples attained its peak of 95.0N at 10DAH. Thereafter, there was a general decline in the flesh firmness of the treated samples as they approached 20DAH. By 20DAH, the sprayed sample had a higher flesh firmness of 46.1N while the dipped sample had 35.4N. At 20DAH, the dipped and sprayed sample showed a significant ($P\leq0.05$) difference on the flesh firmness of the treated samples.

Table 3-1: Changes in flesh firmness (Newtons) of cassava roots dipped and/or sprayed with different edible coating solution from first day to 20 days after harvest

Period of storage (Days)	TREATMENTS								
	Control	**1.5% xanthan Dipping**	**1.5% xanthan Spraying**	**1.5% xanthan/guar Dipping**	**1.5% xanthan/guar Spraying**	**2% xanthan/guar Dipping**	**2% xanthan/guar Spraying**	**LSD (5% LEVEL)**	**F**
DAY 1	61.8±0.9^{a}	61.8±0.9^{a}	61.8±0.9^{a}	61.8±0.9^{a}	61.8±0.9^{a}	61.8±0.9^{a}	61.8±0.9^{a}	2.7	1.000
DAY 2	71.4±4.6^{a}	65.7±3.5^{a}	62.2±8.2^{a}	66.5±4.4^{a}	73.1±8.0^{a}	63.8±0.9^{a}	69.4±10.0^{a}	19.4	0.871
DAY 4	76.8±9.5^{a}	70.2±6.0^{a}	64.8±1.0^{a}	68.1±2.4^{a}	76.2±11.8^{a}	69.9±5.0^{a}	81.5±7.1^{a}	21.4	0.667
DAY 6	80.5±1.2^{ab}	78.2±1.2^{ab}	69.5±1.5^{a}	76.9±7.5^{ab}	88.8±6.8^{b}	75.5±0.5^{ab}	84.0±6.7^{ab}	14.1	0.176
DAY 8	90.1±4.5^{cd}	79.4±2.5^{b}	71.2±2.2^{a}	95.8±0.4^{d}	89.2±3.6^{cd}	84.1±1.5^{bc}	88.0±2.3^{bcd}	8.2	<0.001
DAY 10	81.2±9.3^{bc}	92.5±2.9^{bc}	77.3±3.4^{b}	55.5±1.1^{a}	95.0±1.4^{c}	97.2±1.9^{c}	86.1±8.8^{bc}	14.1	0.176
DAY 12	54.8±11.2^{a}	91.4±3.8^{b}	95.6±3.3^{b}	50.8±5.6^{a}	96.0±2.3^{b}	66.3±3.5^{a}	61.7±6.8^{a}	18.0	<0.001
DAY 14	22.7±0.9^{a}	58.3±4.0^{c}	62.4±2.5^{c}	39.6±9.5^{b}	87.5±3.3^{d}	53.1±1.5^{bc}	51.4±6.2^{bc}	14.7	<0.001
DAY 16	15.9±4.1^{a}	46.7±4.0^{b}	49.3±0.9^{b}	49.5±4.4^{b}	78.2±8.6^{c}	52.4±0.2^{b}	42.6±1.5^{b}	13.0	<0.001
DAY 18	9.1±0.6^{a}	22.5±5.4^{ab}	36.0±2.3^{bc}	44.4±6.1^{cd}	54.2±4.2^{d}	48.7±3.5^{cd}	31.8±10.3^{bc}	16.5	<0.001
DAY 20	4.0±0.7^{a}	21.2±3.3^{b}	29.1±2.6^{bcde}	35.4±2.2^{ce}	46.1±0.8^{f}	24.5±4.3^{bcde}	24.3±6.3^{bcd}	10.3	<0.001

Values are means ± SE. Means with different superscript letters in a row are significantly (P≤0.05) different, n=3

The 2% xanthan/guar treated roots attained firmness peak of 88.0N for sprayed samples at 8DAH while the dipped sample attained the peak of 97.2N at 10DAH. This was followed by a decline in the flesh firmness of the treated roots. The dipped sample had a final firmness of 24.5N while the sprayed sample had a firmness of 24.3N at 20DAH. Upon coating, the treated samples generally showed an increase in the flesh firmness to 10DAH followed by a decrease till 20DAH as shown in Table 3-1. This was also observed by Ampe & Brauman (1995) on cassava roots from harvesting period to the stage at which the roots rotted.

At 20DAH, the control sample had a flesh firmness of 4.0N which was significantly ($P>0.05$) different from all the treated cassava root samples. There was generally no significant differences of the two application methods on the flesh firmness**.**

The change in flesh firmness of the cassava root samples is affected by the occurrence and development of the PPD. After harvesting of the cassava root crop, there is an increase in the flesh firmness of the cassava and then a later decline in the firmness as was observed between 20DAH and 14DAH. The permeabilizing of the cell membrane enhances the loss of the water and this may have led to the increase in flesh firmness (Akely *et al*., 2016). With the progress of the PPD, there's softening of the root and eventual decay (Uchechukwu-Agua *et al*., 2015). This may have led to the decline of the flesh firmness of the root. The decline in flesh firmness has also been reported to be due the activity of endogenous enzymes that are naturally present in the root but are triggered by a decrease in the pH of the cassava (Ampe & Brauman, 1995).The endogenous enzymes include pectin methyl estearase, pectin estearase and polygalacturonase. There is an initial decrease in the activity of these enzymes which peaks as the tissue softened a leading to a decline with increased storage duration. The coating process reduced the rate at which the flesh firmness changed. As the root storage progressed towards 20DAH, the control roots started decaying leading to a final flesh firmness of 4.0N. This may have been due to the effects of the PPD that lead to microbial decay.

3.3.2 Colour

The cassava root crop suffers cell disruption during the harvesting process and other subsequent postharvest activities such as transportation, sorting and washing. This cell disruption leads to PPD development. With the onset of PPD, there's formation of blue/black streaks on the vascular bundles of the cassava. The L* values recorded during colour evaluation of the cassava root crop range from black (0) to white (100).A reduction in the L* values from the day of harvest means that there's darkening of the cassava flesh (Canto *et al*., 2013). 1.5% xanthan treated samples showed a decline in the L* value from the first day after coating. At 20 DAH, the dipped sample had no significant ($P>0.05$) difference from the sprayed sample though it had a higher L* value of 79.5 while the sprayed sample had 65.9.

There also was a decline in the L* value of the 1.5 xanthan/guar treated samples. Upon coating, the L* value was 92.4 and this decreased for both the dipped and sprayed samples. At 20DAH, the dipped sample had a higher L* value of 77.1 hence a whiter flesh than the sprayed sample that had 60.2. This was significantly ($P\leq0.05$) different for the two samples.

The 2% xanthan/guar gum treated root samples had a similar declining trend in the L* value of the flesh colour. However, the sprayed samples showed a better value as compared to the dipped samples at 20DAH. At 20DAH, the sprayed sample had an L* value of 83.2 while the dipped sample had 67.90 which was significantly ($P\leq0.05$) difference from all the treated samples at this day (Table. 3-2).

There were generally no significant ($P>0.05$) differences among the treatments that were dipped and those that were sprayed with the coating solutions. This suggested that the two different coating applications had the same activity in terms of maintenance of the cassava root flesh colour.

Table 3-2: Changes in colour (L* values) of cassava roots dipped and/or sprayed with different edible coating solution from the first day to 20 days after harvest

Period of storage (Days)	TREATMENTS								
	Control	**1.5% xanthan Dipping**	**1.5% xanthan Spraying**	**1.5% xanthan/guar Dipping**	**1.5% xanthan/guar Spraying**	**2% xanthan/guar Dipping**	**2% xanthan/guar Spraying**	**LSD (5% LEVEL)**	**F**
DAY 1	92.4±0.3^{a}	92.4±0.3^{a}	92.4±0.3^{a}	92.4±0.3^{a}	92.4±0.3^{a}	92.4±0.3^{a}	92.4±0.3^{a}	0.8	1.000
DAY 2	90.4±1.1^{b}	90.5±0.7^{b}	89.6±1.2^{ab}	90.5±0.7^{b}	87.6±0.1^{a}	91.0±0.2^{b}	90.9±0.4^{b}	2.2	0.054
DAY 4	86.5±0.9^{a}	89.8±0.3^{b}	89.3±0.7^{b}	90.5±0.3^{b}	90.6±0.3^{b}	89.9±0.4^{b}	90.2±0.3^{b}	1.5	<0.001
DAY 6	86.6±1.1^{a}	89.9±0.2^{b}	88.7±0.1^{b}	89.9±0.2^{b}	89.8±0.5^{b}	89.6±0.2^{b}	90.1±0.4^{b}	1.4	0.002
DAY 8	87.0±1.1^{a}	88.9±0.8^{ab}	88.4±0.6^{ab}	88.4±0.3^{ab}	89.7±0.3^{b}	89.2±0.8^{b}	89.7±0.2^{b}	1.9	0.122
DAY 10	82.2±2.2^{a}	89.0±0.4^{b}	87.9±0.4^{b}	86.7±0.4^{b}	89.6±0.3^{b}	88.0±0.7^{b}	88.0±1.1^{b}	1.4	0.002
DAY 12	79.3±4.2^{a}	88.3±0.4^{ab}	83.4±4.0^{ab}	86.8±1.8^{ab}	89.5±0.3^{b}	84.9±3.4^{ab}	88.0±1.0^{ab}	8.1	0.187
DAY 14	77.9±1.6^{a}	87.1±0.1^{b}	80.8±5.7^{ab}	84.9±0.7^{ab}	88.7±0.3^{b}	81.1±1.6^{ab}	85.7±0.1^{b}	7.1	0.054
DAY 16	77.3±1.6^{a}	86.0±1.2^{cd}	70.5±5.1^{a}	83.3±0.3^{bcd}	88.4±0.2^{d}	76.2±5.1^{ab}	85.6±1.7^{bcd}	8.8	0.006
DAY 18	73.6±4.9^{ab}	84.3±1.0^{ab}	70.3±4.2^{a}	82.4±1.2^{ab}	77.9±8.0^{ab}	75.5±2.5^{ab}	85.8±2.0^{b}	12.4	0.131
DAY 20	49.9±7.0^{a}	79.5±3.3^{cd}	65.9±5.8^{bc}	77.1±0.9^{cd}	60.2±3.4^{ab}	67.9±4.5^{bc}	83.2±3.0^{d}	13.3	0.001

Values are means ± SE. Means with different superscript letters in a row are significantly (P≤0.05) different, n=3

After harvest of the cassava root crops, there's development of PPD that affected the colour of the flesh as was recorded by Liu (2016). The colour of a fresh sweet variety cassava root was white as recorded by Ademosun *et al* (2012) but with the development of PPD, it developed blue black streaks. This initial L* value of the fresh sample was recorded as 92.43 and with its deterioration, the value decreased towards zero. This change in colour was manifested by blue/black streaking of the xylem bundles (Uchechukwu-Agua *et al*., 2015). The control sample had a drastic change in colour as compared to the coated samples and this may have been due to the different efficacy levels of the coating solutions.

3.3.3 Weight loss

The weight loss of the treated root samples was determined and recorded from the first day to 20DAH. There was an increase in the percentage weight loss of the various samples till 20DAH

The 1.5% xanthan treated root samples showed an increase in weight loss to 30.0% for the dipped sample and 43.8% for the sprayed sample at 20DAH. These two samples had a significant ($P \leq 0.05$) difference on their effect on weight loss at this day (Table 3-2).

The dipped 1.5% xanthan/guar treated roots had a percentage weight loss of 38.6% while the sprayed root had 45.6% at 20DAH. There were significant ($P \leq 0.05$) differences between the two samples at this day.

The 2% xanthan guar treated roots had no significant ($P > 0.05$) difference at 20DAH. The dipped sample had a percentage weight loss of 37.0% while the sprayed sample and 37.7%.

At 20DAH, the control root had a 50.2% weight loss and this was the highest as compared to the lowest recorded weight loss of 30.0% which was observed in the sample treated with 1.5% xanthan gum by dipping (Table. 3-3). Generally, the treated cassava samples had a significant ($P > 0.05$) difference on the weight lost during the entire storage duration.

Once the cassava roots have been harvested, their weight gradually reduces due to the loss of moisture from the root due to respiratory activities (Atanda *et al*., 2011). This may have been the cause of the weight loss recorded in all the cassava root samples. The control cassava roots showed a higher weight loss as compared to the coated samples. This may have been due to the activity of the coating film which reduced the respiration rate hence reduced water released from the roots. The weight lost increased with the storage duration as was recorded by Chen & Weil (2010).

Table 3-3: Changes in weight (percentage) of cassava roots dipped and/or sprayed with different edible coating solution from the first day to 20 days after harvest

Period of storage (Days)	TREATMENTS								
	CONTROL	1.5% xanthan Dipping	1.5% xanthan Spraying	1.5% xanthan/guar Dipping	1.5% xanthan/guar Spraying	2% xanthan/guar Dipping	2% xanthan/guar Spraying	LSD (5% LEVEL)	F
FRESH	0	0	0	0	0	0	0	-	-
DAY 2	10.0 ± 0.4^{cd}	6.0 ± 0.5^{a}	11.3 ± 1.5^{d}	9.3 ± 0.2^{bcd}	9.3 ± 0.2^{bcd}	7.3 ± 0.6^{ab}	8.3 ± 0.2^{bc}	2.0	0.001
DAY 4	15.9 ± 0.3^{c}	13.1 ± 0.3^{b}	16.6 ± 0.8^{c}	13.7 ± 0.2^{b}	12.8 ± 0.5^{b}	10.3 ± 0.3^{a}	11.2 ± 0.1^{a}	1.2	<0.001
DAY 6	20.2 ± 0.2^{d}	11.9 ± 0.2^{a}	21.2 ± 0.8^{d}	17.1 ± 0.1^{c}	16.6 ± 0.2^{c}	13.3 ± 0.2^{b}	13.8 ± 0.4^{b}	1.2	<0.001
DAY 8	25.4 ± 0.6^{e}	15.1 ± 0.2^{b}	29.2 ± 0.3^{f}	20.9 ± 0.4^{d}	21.2 ± 0.4^{d}	17.1 ± 0.5^{c}	13.1 ± 0.4^{a}	1.3	<0.001
DAY 10	28.2 ± 0.2^{d}	17.0 ± 0.5^{a}	32.8 ± 1.4^{e}	23.6 ± 0.4^{bc}	24.5 ± 0.5^{c}	24.4 ± 0.6^{c}	21.7 ± 0.8^{b}	1.2	<0.001
DAY 12	32.6 ± 0.5^{e}	20.1 ± 0.2^{a}	37.6 ± 1.0^{f}	27.1 ± 0.5^{c}	28.9 ± 0.5^{d}	29.9 ± 0.4^{d}	24.2 ± 0.2^{b}	1.6	<0.001
DAY 14	35.9 ± 0.2^{d}	23.0 ± 0.5^{a}	39.6 ± 0.5^{e}	31.0 ± 0.4^{c}	35.0 ± 1.0^{d}	31.2 ± 0.4^{c}	29.0 ± 0.5^{b}	1.6	<0.001
DAY 16	39.0 ± 0.5^{c}	25.7 ± 0.6^{a}	41.2 ± 0.7^{d}	33.9 ± 0.4^{b}	41.1 ± 0.1^{d}	32.8 ± 1.2^{b}	32.9 ± 0.3^{b}	1.9	<0.001
DAY 18	44.6 ± 1.4^{c}	27.6 ± 0.8^{a}	42.1 ± 1.2^{c}	35.7 ± 0.9^{b}	43.4 ± 1.3^{c}	35.7 ± 1.9^{b}	34.5 ± 0.8^{b}	3.8	<0.001
DAY 20	50.0 ± 0.1^{d}	30.0 ± 1.7^{a}	43.8 ± 1.4^{c}	38.6 ± 1.7^{b}	45.6 ± 0.9^{cd}	37.0 ± 2.2^{b}	37.7 ± 1.9^{b}	4.7	<0.001

Values are means ± SE. Means with different superscript letters in a row are significantly ($P \leq 0.05$) different, n=3

3.3.4 Dry matter content

The dry matter of the treated roots was determined and recorded for a period of twenty days on a two-day interval. There was an increase in the dry matter content of the treated roots as they approached 20DAH.

The dipped 1.5% xanthan treated root attained a dry matter content of 76.0% while the sprayed root sample had 72.5% at 20DAH which was significantly ($P \leq 0.05$) different. The samples treated with 1.5% xanthan/guar using dipping method had a content of 72.4% while the sprayed root had 71.7%. In addition, the 2% xanthan/guar dipped root had 64.6% while the sprayed root had 74.1% at 20DAH (Table. 3-4).

All the treated roots had a significant ($P \leq 0.05$) difference at 20DAH as compared to the control root that had the highest dry matter content of 77.8%. Generally, there were significant ($P \leq 0.05$) differences between the differently treated roots.

Table 3-4: Changes in dry matter content (percentage) of cassava roots dipped and/or sprayed with different edible coating solution from the first day to 20 days after harvest

Period of storage (Days)	TREATMENTS								
	CONTROL	1.5% xanthan Dipping	1.5% xanthan Spraying	1.5% xanthan/guar Dipping	1.5% xanthan/guar Spraying	2% xanthan/guar Dipping	2% xanthan/guar Spraying	LSD (5% LEVEL)	F
FRESH	56.1±0.2^{a}	56.1±0.2^{a}	56.1±0.2^{a}	56.1±0.2^{a}	56.1±0.2^{a}	56.1±0.2^{a}	56.1±0.2^{a}	0.6	1.000
DAY 2	62.9±0.9^{b}	57.4±0.3^{a}	55.9±2.5^{a}	57.7±0.6^{a}	54.6±1.9^{a}	53.1±1.3^{a}	56.2±1.1^{a}	4.3	0.006
DAY 4	64.6±8.2^{a}	60.2±1.5^{a}	57.9±0.4^{a}	58.9±0.5^{a}	55.0±0.4^{a}	55.9±1.2^{a}	60.5±9.2^{a}	14.3	0.821
DAY 6	67.9±0.9^{b}	62.7±3.9^{ab}	59.1±0.6^{ab}	61.3±2.8^{ab}	56.4±0.4^{ab}	55.9±1.2^{a}	61.6±0.4^{ab}	5.8	0.095
DAY 8	69.5±1.0^{b}	64.5±1.6^{ab}	59.7±4.0^{a}	61.5±4.3^{a}	57.7±1.2^{a}	56.6±1.6^{a}	61.9±0.7^{ab}	7.5	0.036
DAY 10	71.5±2.4^{d}	66.0±1.6^{c}	62.0±0.6^{bc}	62.1±0.9^{bc}	56.6±0.5^{a}	58.2±1.3^{ab}	63.0±2.1^{bc}	5.8	0.095
DAY 12	73.4±2.0^{c}	67.9±5.2^{abc}	62.8±1.0^{ab}	65.0±1.4^{abc}	58.3±0.8^{a}	62.2±0.5^{ab}	68.8±0.7^{bc}	9.3	0.047
DAY 14	73.4±1.5^{b}	67.4±2.2^{bc}	64.1±0.9^{abc}	67.9±3.1^{bcd}	58.8±0.1^{a}	62.6±0.3^{ab}	69.7±2.9^{cd}	5.6	0.001
DAY 16	73.4±0.3^{d}	73.8±3.3^{c}	70.5±0.9^{bc}	71.0±1.5^{bc}	67.2±0.9^{ab}	63.8±1.3^{a}	70.9±0.6^{bc}	5.2	0.012
DAY 18	74.3±4.8^{c}	74.8±0.4^{b}	71.6±0.4^{b}	71.3±3.7^{b}	71.1±0.7^{b}	63.9±1.1^{a}	72.3±0.4^{b}	4.9	0.008
DAY 20	77.8±0.8^{c}	76.0±0.7^{bc}	72.5±2.8^{b}	72.4±0.7^{b}	71.7±0.9^{b}	64.6±1.5^{a}	74.1±0.6^{bc}	4.1	<0.001

Values are means ± SE. Means with different superscript letters in a row are significantly (P≤0.05) different, n=3

The initial dry mater content of the fresh cassava root was recorded as 56.1% similar to the range of 10%-57% reported by Ebah-Djedji *et al* (2012). They also stated that the dry matter content of cassava differs based on the genotype and age at harvest. The increase in dry matter content of the cassava root is caused by the loss of moisture from the root surface due to various biochemical activities. This increases with the storage duration of the root (Quevedo *et al*., 2014). In the present study, there was a general increase in the dry matter content of all the root samples as reported by (Tumuhimbise *et al*., 2015). However, the control sample exhibited a higher dry matter content throughout the storage duration as compared to the coated root samples. This may be an indication of the effectiveness of the coating film formed in reducing the amount of moisture lost from the root samples. Depending on the storage conditions (Sánchez et al., 2013b) the cassava root crops remain of acceptable eating quality even with increased dry matter content (Booth *et al*., 1976).

3.3.5 Total phenolic content

The total phenolic content was recorded on the first day until 20DAH. There was no significant ($P>0.05$) differences amongst the various treatments (Table 3-5).

The 1.5% xanthan dipped root sample had a decrease in its phenolic content to 8.4 mg/100g GAE while the spayed root sample had 9.1 mg/100g GAE at 20DAH. The 1.5% xanthan/guar treated root sample had 6.0 mg/100g GAE and 9.1 mg/100g GAE for the dipped and sprayed root sample respectively while the 2% xanthan/guar treated samples had 8.2 mg/100g GAE and 6.0 mg/100g GAE for the dipped and sprayed root samples respectively. At 20DAH, the treated root samples had no significant ($P>0.05$) difference as compared to the control that had a total phenolic content of 7.7 mg/100g GAE. On coating using the various methods, there was a general gradual decline in the total phenolic content as it approached 20DAH. (Table. 3-5).

Table 3-5: Changes in total phenolic content (mg/100g GAE) of cassava roots dipped and/or sprayed with different edible coating solution from the first day to 20 days after harvest

Period of storage (Days)	TREATMENTS								
	CONTROL	**1.5% xanthan Dipping**	**1.5% xanthan Spraying**	**1.5% xanthan/guar Dipping**	**1.5% xanthan/guar Spraying**	**2% xanthan/guar Dipping**	**2% xanthan/guar Spraying**	**LSD (5% LEVEL)**	**F**
FRESH	29.2±2.1^{a}	29.2±2.1^{a}	29.2±2.1^{a}	29.2±2.1^{a}	29.2±2.1^{a}	29.2±2.1^{a}	29.2±2.1^{a}	6.3	1.000
DAY 2	24.3±1.9^{ab}	17.9±3.5^{a}	27.7±2.6^{b}	18.5±3.0^{a}	27.7±2.6^{b}	23.4±2.0^{ab}	21.5±2.1^{ab}	7.9	0.091
DAY 4	19.9±4.6^{a}	16.7±0.8^{a}	22.5±1.2^{a}	21.6±0.9^{a}	22.5±1.2^{a}	20.2±3.9^{a}	19.6±1.2^{a}	7.4	0.668
DAY 6	17.0±3.3^{a}	14.5±1.3^{a}	18.1±2.3^{a}	16.2±0.6^{a}	18.1±2.3^{a}	17.8±0.7^{a}	14.5±1.8^{a}	6.0	0.693
DAY 8	15.2±1.3^{a}	13.6±12^{a}	15.1±1.3^{a}	15.2±1.1^{a}	15.1±1.3^{a}	14.5±1.1^{a}	13.1±2.3^{a}	4.3	0.89
DAY 10	14.5±1.0^{b}	12.6±0.5^{ab}	14.8±1.0^{b}	11.5±0.3^{a}	14.8±1.0^{b}	14.0±1.0^{ab}	13.1±0.8^{ab}	6.0	0.693
DAY 12	14.4±2.2^{a}	12.5±0.2^{a}	14.5±1.4^{a}	11.0±1.1^{a}	14.5±1.4^{a}	12.6±0.7^{a}	12.6±0.3^{a}	3.8	0.359
DAY 14	12.8±0.9^{a}	11.5±0.6^{a}	12.8±0.2^{a}	10.6±2.2^{a}	12.8±0.2^{a}	12.1±0.8^{a}	12.4±1.1^{a}	3.2	0.712
DAY 16	12.0±0.9^{a}	9.5±3.8^{a}	12.1±1.0^{a}	10.5±1.2^{a}	12.1±1.0^{a}	11.3±1.5^{a}	12.4±1.7^{a}	5.6	0.896
DAY 18	8.0±1.0^{a}	9.2±0.9^{ab}	9.4±0.3^{ab}	10.7±0.5^{b}	9.4±0.3^{ab}	9.5±0.5^{ab}	10.3±1.4^{ab}	2.4	0.365
DAY 20	7.7±2.5^{a}	8.4±0.3^{a}	9.1±0.5^{a}	6.0±1.3^{a}	9.1±0.5^{a}	8.2±0.3^{a}	6.0±1.2^{a}	3.6	0.361

Values are means ± SE. Means with different superscript letters in a row are significantly (P≤0.05) different, n=3

There was a decrease in the total phenolic content of the cassava root samples as was reported by Freire *et al* (2015). This decrease continued with the increased storage duration. This may have been due to the increase in polyphenol oxidase with time hence the increased oxidation of the phenols and the eventual darkening of the flesh. The dark insoluble pigments that are formed during PPD are usually as a result of the oxidation of phenolic compounds in the cassava (Tomás-Barberán & Espín, 2001). Enzymatic browning is directly correlated to the type and amount of the phenolic substrate. With PPD development, there's accumulation of phenolic secondary metabolites including scopoletin (Zainuddin *et al*., 2017). These are the major phenolic compound that may have led to the darkening of the cassava root flesh (Saravanan, 2015) with the storage duration. The coating process may have led to a delay in the oxidation of the phenols. There was a delay in the browning of the coated cassava as compared to the control. This may have been due to the inhibition of oxygen penetration to the cassava hence no formation of secondary metabolites.

3.3.6 Total cyanide content

The total cyanide content was analyzed and recoded at an interval of 2 days for the 20 day storage duration. There was a decline of the total cyanide content from the first day to 20 DAH. The dipped 1.5% xanthan treated root had a final cyanide content of 0.7ppm while the sprayed sample had 1.2ppm at 20 DAH which was 80.6% and 66.7% respectively. The 1.5% xanthan/guar treated roots had no significant difference on their effect on cyanide content at 20 DAH. The dipped root had a percentage decline of 50% while the sprayed sample had a decline of 77.8% at 20 DAH. The dipped 2% xanthan/guar treated cassava root had a final cyanide content of 0.9ppm which was 75.0% while the sprayed root had 1.4ppm, a decline of 61.1% at 20 DAH (Table. 3-6). Generally, there was a decline in the total cyanide content of the cassava roots from the first day to 20 DAH.

Table 3-6: Changes in total cyanide content (ppm/ HCN equivalent mg/kg) of cassava roots dipped and/or sprayed with different edible coating solution from the first day to 20 days after harvest

Period of storage (Days)	TREATMENTS								
	CONTROL	**1.5% xanthan Dipping**	**1.5% xanthan Spraying**	**1.5% xanthan/guar Dipping**	**1.5% xanthan/guar Spraying**	**2% xanthan/guar Dipping**	**2% xanthan/guar Spraying**	**LSD (5% LEVEL)**	**F**
FRESH	3.6± 0.4[a]	3.6± 0.4[a]	3.6± 0.4[a]	3.6± 0.4[a]	3.6± 0.4[a]	3.6± 0.4[a]	3.6± 0.4[a]	1.2	1.000
DAY 2	3.4±0.6[a]	3.1±0.3[a]	2.8±0.3[a]	2.7±0.1[a]	3.2±0.2[a]	2.7±0.2[a]	2.8±7.1[a]	0.9	0.500
DAY 4	3.0± 0.5[a]	3.0±0.2[a]	2.5±3.2[a]	2.1±0.5[a]	3.1±0.5[a]	2.7±0.6[a]	2.5±4.3[a]	1.3	0.608
DAY 6	3.0±0.3[a]	2.5±0.3[a]	2.5±4.4[a]	2.3±0.2[a]	2.6±0.3[a]	2.6±0.2[a]	2.4±7.4[a]	0.9	0.801
DAY 8	2.8± 0.4[a]	2.3±0.3[a]	2.2±3.1[a]	1.9±0.2[a]	2.4±0.1[a]	2.5±0.6[a]	2.2±4.1[a]	1.0	0.650
DAY 10	3.0± 0.3[a]	2.1±0.1[a]	2.1±2.2[a]	1.8±0.4[a]	2.2±0.1[a]	2.3±0.4[a]	2.1±0.2[a]	0.8	0.105
DAY 12	2.7±0.1[a]	2.2±0.3[a]	2.2±4.2[a]	1.7±0.2[a]	2.2±0.5[a]	2.2±0.1[a]	2.1±0.1[a]	0.8	0.335
DAY 14	2.6±0.2[a]	1.4±0.5[a]	1.7±0.2[a]	1.4±0.1[a]	1.9±1.0[a]	2.0±0.4[a]	1.7±0.1[a]	1.4	0.629
DAY 16	2.3± 0.1[a]	1.4±0.1[a]	1.4±0.3[a]	1.4±0.1[a]	1.5±0.1[a]	1.7±0.3[a]	1.5±0.1[a]	0.6	0.070
DAY 18	2.0±0.5[a]	1.4±0.4[a]	1.2±0.2[a]	1.5±0.2[a]	1.5±0.1[a]	1.9±0.1[a]	1.4±0.1[a]	0.9	0.511
DAY 20	2.0±0.2[a]	0.7±0.1[a]	1.2±0.3[a]	1.8±0.1[a]	0.8±0.1[a]	0.9±0.3[a]	1.4±0.1 [a]	0.6	0.001

Values are means ± SE. Means with different superscript letters in a row are significantly (P≤0.05) different, n=3

One of the major reasons why the cassava root crop is processed is to reduce the cyanide levels. Injuring of the cassava root crop during harvest triggers the contact of linamarin and linamarase enzyme which leads to an eventual production of hydrogen cyanide (Sowmyapriya *et al*., 2017). This process requires the presence of oxygen (Venturini *et al*., 2015). The coating process prevents oxygen access to the root tissues hence it may have prevented the production of reactive oxygen species (ROS) that accelerate production of cyanide (Liu, 2016). From the data obtained, the coated cassava root crops had an eventual low quantity of cyanide as compared to the control roots that were not coated and hence might have had a higher production of ROS which led to an increased cyanide content. Immediately after harvest, there was production of a high content of cyanide as was observed by Sowmyapriya *et al* (2017) and this reduced towards 20DAH. This may have been due to hydrolysis which may have broken down the cyanide (Bandna, 2012).

3.3.7 Respiration rate

The respiration rate of both the dip and spray treated sample for the first 20DAH is shown in Table 3-7. Upon coating, the treated samples obtained two different peaks. The first peak occurred at the 2DAH while the second peak occurred at different days based on the treatment. The 1.5% xanthan treated root showed its first peak of 2.5 mg CO_2/kg/h and 3.2 mg CO_2/kg/h for the dipped and sprayed samples respectively. The second peak was observed at 14DAH for the dipped sample and 12DAH for the sprayed sample at a respiration rate of 6.6 mg CO_2/kg/h and 7.7 mg CO_2/kg/h respectively. The two samples had significant ($P \leq 0.05$) differences at 20DAH.

Table 3-7: Changes in total respiration rate (mg CO_2/kg/h) of cassava roots dipped and/or sprayed with different edible coating solution from the first day to 20 days after harvest

Period of storage (Days)	TREATMENTS								
	CONTROL	**1.5% xanthan Dipping**	**1.5% xanthan Spraying**	**1.5% xanthan/guar Dipping**	**1.5% xanthan/guar Spraying**	**2% xanthan/guar Dipping**	**2% xanthan/guar Spraying**	**LSD (5% LEVEL)**	**F**
FRESH	1.1 ± 0.1^{cd}	0.7 ± 0.0^{a}	1.1 ± 0.0^{cd}	1.1 ± 0.0^{d}	1.0 ± 0.0^{c}	0.9 ± 0.0^{b}	1.1 ± 0.1^{cd}	0.1	<0.001
DAY 2	5.7 ± 0.0^{ab}	2.5 ± 0.0^{a}	3.2 ± 0.1^{c}	2.5 ± 0.1^{a}	3.5 ± 0.2^{d}	3.1 ± 0.0^{c}	2.8 ± 0.1^{b}	0.2	<0.001
DAY 4	2.6 ± 0.0^{ab}	3.9 ± 0.2^{bc}	5.2 ± 1.6^{c}	3.6 ± 0.1^{bc}	1.1 ± 0.1^{a}	2.9 ± 0.0^{bc}	2.1 ± 0.0^{ab}	1.8	0.006
DAY 6	3.4 ± 0.1^{bcd}	1.3 ± 1.1^{ab}	3.5 ± 0.3^{e}	2.3 ± 0.1^{cde}	1.9 ± 0.1^{a}	3.2 ± 0.3^{de}	2.9 ± 0.0^{abc}	1.4	<0.001
DAY 8	6.2 ± 0.1^{a}	3.09 ± 0.06^{b}	5.38 ± 0.04^{d}	4.47 ± 0.08^{bc}	2.57 ± 0.23^{c}	3.43 ± 0.22^{c}	4.43 ± 0.03^{a}	0.40	<0.001
DAY 10	3.04 ± 0.10^{a}	4.6 ± 0.2^{ab}	6.7 ± 0.2^{c}	5.9 ± 0.0^{bc}	3.6 ± 1.1^{a}	4.3 ± 1.1^{a}	4.2 ± 0.1^{a}	1.4	<0.001
DAY 12	3.1 ± 0.1^{a}	5.1 ± 0.0^{a}	7.7 ± 0.2^{ab}	6.1 ± 0.1^{a}	5.7 ± 0.3^{a}	6.5 ± 0.1^{ab}	12.7 ± 5.3^{b}	6.1	0.1
DAY 14	3.5 ± 0.1^{a}	6.6 ± 0.1^{bc}	7.1 ± 0.2^{bc}	7.5 ± 0.1^{c}	4.0 ± 1.2^{a}	5.7 ± 0.2^{b}	6.1 ± 0.2^{bc}	1.5	<0.001
DAY 16	3.5 ± 0.1^{a}	5.5 ± 0.0^{bc}	7.3 ± 0.0^{de}	8.0 ± 0.1^{e}	3.1 ± 1.2^{ab}	5.0 ± 0.0^{bc}	5.4 ± 0.2^{cd}	1.4	<0.001
DAY 18	4.0 ± 0.3^{ab}	3.8 ± 1.5^{a}	6.0 ± 0.6^{bc}	6.5 ± 0.1^{c}	4.9 ± 0.3^{abc}	4.6 ± 0.2^{abc}	4.5 ± 0.9^{d}	2.1	0.002
DAY 20	3.7 ± 0.1^{b}	0.5 ± 0.1^{a}	3.8 ± 0.5^{b}	3.6 ± 0.4^{b}	3.2 ± 0.2^{b}	3.7 ± 0.3^{b}	3.4 ± 0.2^{b}	0.9	<0.001

Values are means ± SE. Means with different superscript letters in a row are significantly ($P\leq0.05$) different, n=3

The 1.5 xanthan/guar treated sample had their first peaks of 3.6 mg CO_2/kg/h for the dipped sample while the sprayed sample had a respiration rate of 3.5 mg CO_2/kg/h at 4DAH and 2DAH respectively. The second peak was observed at 12DAH for sprayed sample while the dipped sample had its peak at 16DAH. The respiration rate for the samples was 5.7 mg CO_2/kg/h for the sprayed sample while the dipped sample had 8.0 mg CO_2/kg/h. The two samples had no significant ($P>0.05$) differences at 20DAH.

The 2% xanthan/guar treated roots attained their first peak at 2DAH for both the dipped and sprayed roots. The dipped root had a respiration rate of 3.1 mg CO_2/kg/h while the sprayed sample had a rate of 2.8 ml CO_2/kg/h at the same day. The second peak of 6.5 mg CO_2/kg/h was attained at the 12DAH for both the dipped and sprayed roots. The second peak was followed by a decline in the respiration rate towards zero as it approached 20DAH (Table. 3-7). The control sample attained its second peak of 6.2 mg CO_2/kg/h at 8DAH which was earlier than the other treated root samples. Generally, there was no significant difference between the two differently coated cassava roots.

The two peaks formed during the respiration process of the cassava root crop could be due to wounding and biochemical changes for the 1stand 2nd peak respectively (HiRose *et al*., 1984). Increase in cellular respiration of cassava roots has been found to be a major contributor to PPD (Saravanan, 2015). This was observed in the present study as the control roots showed an increase in the respiration process as compared to the coated roots. As a result of the increased respiration rate, the PPD occurrence was higher in the control roots as compared to the coated roots. The increased respiration rate may lead to increased production of the reactive oxygen species which may have led to the enzymatic browning of the cassava root flesh (Freire *et al*., 2015).

3.3.8 Ethylene production rate

Ethylene production rate was determined from the first day to 20DAH and there were no significant differences between the differently coated roots (Table 3-8). Upon coating, there was formation of one peak which was dependent on the activity of the coating solutions, which was followed by a decline.

The dipped 1.5% xanthan treated root attained a peak of 2.2 nl C_2H_4/g/h on 12DAH while the sprayed sample had a peak of 4.9 nl C_2H_4/g/h at 14DAH. The 1.5% xanthan/guar dipped sample had a peak of 2.2 nl C_2H_4/g/h at 14DAH while the sprayed sample had 2.8 nl C_2H_4/g/h on the same day. The sprayed 2% xanthan/guar treated root had its peak of 6.1 nl C_2H_4/g/h at 16DAH while the dipped sample didn't attain a peak during the 20 day storage duration. At 20DAH, there were significant differences in the various treated roots as the ethylene production rate range was very small-0.2 to 0.6 nl C_2H_4/g/h (Table. 3-8). In general, there was no significant difference between the effects of the differently coated cassava root samples on the ethylene production rate.

Ethylene is one of the gases that affect various biochemical processes in various products. From the time of harvest, there was a slight increase in ethylene production leading to formation of a peak and this might be attributed to the ethylene produced due to wounding (Bowles, 1998; Raju *et al*., 2016). This peak formation varied with the different efficacy levels of the coating solutions. The early stages of PPD have been attributed to an increase in ethylene production which accelerates activity of various enzymes (Liu, 2016).This includes the peroxidase enzyme that has been found to oxidize phenols leading to production of secondary metabolites that lead to an eventual enzymatic browning on the cassava flesh. Ethylene production is induced by the production of Aminocyclopropane-1-carboxylic acid (ACC) synthase and ACC oxidase enzymes which have been found to partly increase the activity of other enzymes which lead to the development of PPD. According to Saravanan (2015), ethylene production has an intense effect on the development of PPD. This is contrary to the report by Liu (2016) which stated the specific role that ethylene plays in PPD development is still unclear. The second peak formed for the various treatments was found to have no effect on PPD as was reported by HiRose (1984).

Table 3-8: Changes in total ethylene production rate (nl C_2H_4/g/h) of cassava roots dipped and/or sprayed with different edible coating solution from the first day to 20 days after harvest

Period of storage (Days)	TREATMENTS								
	CONTROL	**1.5% xanthan Dipping**	**1.5% xanthan Spraying**	**1.5% xanthan/guar Dipping**	**1.5% xanthan/guar Spraying**	**2% xanthan/guar Dipping**	**2% xanthan/guar Spraying**	**LSD (5% LEVEL)**	**F**
FRESH	0.5±0.0^{a}	0.04±0.0^{a}	0.1±0.0^{a}	0.1±0.1^{a}	0.1±0.0^{a}	0.2±0.2^{a}	0.02±0.0^{a}	0.2	0.605
DAY 2	2.1±0.0^{a}	0.3±0.0^{a}	0.3±0.0^{a}	0.4±0.1^{a}	0.6±0.1^{a}	1.2±1.2^{a}	0.3±0.0^{a}	0.2	0.019
DAY 4	0.3±0.0^{c}	0.01±0.0^{a}	0.4±0.0^{d}	0.6±0.0^{e}	0.03±0.0^{a}	0.1±0.0^{b}	0.02±0.0^{a}	0.04	<0.001
DAY 6	0.1±0.1^{c}	0.1±0.0^{a}	0.3±0.0^{b}	0.02±0.0^{a}	0.3±0.0^{b}	0.1±0.1^{a}	0.1±0.0^{a}	0.1	<0.001
DAY 8	0.01±0.0^{a}	0.03±0.0^{a}	1.0±0.1^{c}	0.4±0.3^{ab}	1.5±0.1^{d}	1.6±0.1^{d}	0.7±0.1^{bc}	0.4	<0.001
DAY 10	0.4±0.0^{a}	0.9±0.3^{ab}	1.9±0.9^{b}	1.0±0.3^{ab}	1.2±0.7^{ab}	0.1±0.0^{ab}	1.0±0.8^{ab}	1.6	0.287
DAY 12	0.02±0.1^{a}	2.2±0.1^{b}	0.3±0.0^{a}	0.9±0.5^{a}	0.7±0.1^{a}	0.6±0.0^{a}	1.1±0.5^{a}	0.8	0.004
DAY 14	0.2±0.0^{a}	0.9±0.2^{bc}	2.9±0.5^{e}	2.2±0.2^{d}	2.8±0.2^{e}	0.5±0.1^{ab}	1.3±0.0^{c}	0.6	<0.001
DAY 16	12.4±4.0^{c}	0.8±0.2^{a}	4.9±1.1^{ab}	1.6±0.3^{ab}	0.7±0.1^{a}	0.7±0.1^{a}	6.1±0.8^{b}	4.9	0.001
DAY 18	0.2±0.1^{b}	0.3±0.0^{b}	0.1±0.0^{a}	0.1±0.0^{ab}	0.1±0.0^{a}	0.2±0.0^{ab}	0.6±0.1^{c}	0.1	<0.001
DAY 20	0.6±0.0^{ab}	0.3±0.0^{a}	1.0±0.0^{bc}	0.2±0.1^{a}	0.8±0.4^{ab}	0.3±0.0^{a}	1.5±0.2^{c}	0.6	0.003

Values are means ± SE. Means with different superscript letters in a row are significantly (P≤0.05) different, n=3

3.4 Conclusion

Generally, there was a significant ($P \leq 0.05$) difference recorded between the two different coating applications of dipping and spraying on the cassava root samples. No difference was noted on the colour changes, total cyanide content, total phenolic content and firmness for all the treatments. However, the 1.5% differently coated xanthan roots had a significant difference on respiration rate and weight loss, while the 1.5% xanthan/guar gum coated roots had different effects on the ethylene production rate. The dipped and sprayed 2% xanthan/guar gum treated roots showed a significant difference in their effect on the dry matter content. In comparison to the control root sample, the coated cassava roots tended to store longer with better postharvest qualities.

CHAPTER FOUR

EFFECT OF GUAR AND XANTHAN GUM COATINGS ON THE POSTHARVEST QUALITY OF CASSAVA ROOTS

Abstract

Cassava (*Manihot esculenta*) is grown as an important dietary source of carbohydrates for communities in a number of African countries. However, cassava is susceptible to postharvest physiological deterioration which affects its quality and leads to the unpalatability and unmarketability of roots after harvest. Edible surface coatings have been found to be effective in preserving the quality of various perishable food products. This study was undertaken with the objective of determining the best combinations and concentrations of both xanthan gum and guar gum capable as a technology for extending the shelf life of harvested cassava roots. Cassava variety KME 1 was harvested at physiological maturity (12months after planting). The variety and location were preferred as the cassava roots were disease-free. The coating formulations used were: 1%, 1.5%, 2% guar gum, 1.5%, 2%, 2.5% xanthan gum, and 1%, 1.5%, and 2.5% xanthan guar/gum combination in the ratio of 1:1 with some roots left as control. Data on the physical, physiological, chemical and sensory attributes was collected. Sampling was done at 2-day intervals for 20 days. The coated cassava showed lower respiration and ethylene production rates than the control samples while change in quality parameters; phenols, colour, flesh firmness, weight loss and dry matter content was significantly ($P \leq 0.05$) delayed in the coated samples. Based on the sensory evaluation results, the 1.5% xanthan/guar gum coated roots were more acceptable by the panelists as compared to the other treated roots. The results suggested that using 1.5% xanthan guar/gum as an edible coating, cassava shelf life can be extended by upto 20 days at 25 $^{\circ}$C. Hence, both small-scale and commercial farmers can adapt the use of coating solutions to improve on the shelf life of cassava root crops both for subsistence and export purposes.

4.1 Introduction

Despite the fact that cassava is considered a drought resistant crop, the root is susceptible to physiological stress response after harvest commonly referred to as the postharvest physiological deterioration (PPD) (Zidenga, 2012). The PPD leads to loss of market value and acceptance and greatly reduces the postharvest shelf life to between 2-3 days after harvest depending on the cultivar, age and environmental conditions (Iyer *et al*., 2010). The crop undergoes PPD primarily due to the wounding which occurs during harvesting and subsequent microbial deterioration which occurs 5-7 days after harvest (Venturini *et al*., 2015). The PPD is accompanied by unpleasant odor and flavor and occurs as blue-black streaks on the vascular tissues of the xylem (Salcedo & Siritunga, 2011). It is estimated that the postharvest losses due to PPD in cassava can be as high as 25%. Therefore developing technologies to extend the shelf life of cassava can save upto $2.9 billion over a 20 year period in Nigeria alone (Rudi *et al*., 2010).

In other parts of the world PPD is delayed by heating food grade (paraffin) wax to a temperature between 140°C - 160°C and then dipping tuber for 1-2 seconds (Zidenga *et al*., 2012). However, adoption of paraffin wax coating for cassava is a challenge to small holder farmers in areas such as Kenya since the temperature of the wax and the timing has to be precise otherwise it leads to charring of the root. In addition, concerns about non-biodegradable or inorganic chemical based waxes has recently become a major issue of concern, and focus is more on usage of waxes from renewable and biodegradable polymer of agricultural origin. Edible films and coatings are useful materials mainly produced from edible biopolymers and food-grade additives. Coatings are a type of films directly applied on the food product surface. The application of edible coatings can improve the physical features of food products, reduce clustering of food particles and improve visual features on the product surface (Baraiya *et al*., 2015). Many factors determine the success of edible coatings in improving quality and extending shelf-life of foods. These include chemical composition, structure, method used to form coatings and storage conditions of the food product. Moisture loss is the most critical quality degradation factor in fresh produce (Tumuhimbise *et al*., 2015) including cassava

as it leads to increased dry matter content and weight loss which are directly correlated t the PPD development. PPD development also leads to loss in the integrity of the cassava structure leading to loss of firmness. Oxidation of the phenolic content of the cassava root and cyanide production have also been associated with the decreased shelf life of the cassava due to their various activities. Phenol oxidation has been found to lead to the production of highly reactive quinones that form the blue/black colored complexes on the vascular bundles of the cassava root (Salcedo & Siritunga, 2011). The wounding that occurs during harvesting of the cassava roots leads to production of hydrogen cyanide. This production leads to an accelerated production of reactive oxygen species that have been found to induce the PPD onset (Zidenga, 2012). Moisture barrier and oxygen barrier properties of edible films can be useful in preventing dehydration which leads to loss in quality (Janjarasskul & Krochta, 2010).

Xanthan gum is a polysaccharide derived from *Xanthomonas campestris* through microbial fermentation systems which is a biotechnological process. At high concentrations it shows weak gel-like properties and at low concentrations it gives a highly viscous solution. Guar gum is a galactomannan that is extracted from guar seed *Cyamopsis tetragonolobus* (Raghav *et al*., 2016). It is soluble in both hot and cold water with formation of very highly viscous solutions at very low concentrations due to its high molecular weight. It is considered as a very economical thickener mostly used for juices and can also be used for film-forming solutions (Nieto, 2009). Xanthan and guar gum have been found to have synergistic effects (Xue & Sethi, 2012). Their mixture exhibits an increase in viscosity as compared to the different gums separately. The galactomannan and the polysaccharide interact to form solutions having high viscosity at very low concentrations.

There is increasing demand for cassava in specific markets due to the increasing utilization as food, feed and industrial crop. However, since most of the cassava producers tend to be located in areas further from the target markets, the PPD disorder is

a major limitation to the cassava value chain negatively impacting the farmers, traders, processors and consumers.

This study was undertaken with the objective of determining the best combinations and concentrations of both xanthan gum and guar gum capable of extending the shelf life of harvested cassava roots.

4.2 Materials and methods

4.2.1 Acquisition of raw materials

In the preliminary study, xanthan and guar gum were sourced from Sigma-Aldrich. The gums were sourced from the food ingredient supplier. Fresh cassava root crops of variety KME 1 at physiological maturity (12 months after planting) were obtained from the Jomo Kenyatta University of Agriculture and Technology (JKUAT) farm since they are disease-free. KME 1 was chosen since it is the variety with the highest yields in Kenya. The cassava roots were transported to the JKUAT postharvest laboratory in plastic crates and sorted according to size (50-60 cm long) and the amount of injuries. The injured roots were discarded. They were then cleaned using a soft brush to avoid bruising.

4.2.2 Preparation and application of coating formulation

Xanthan gum was prepared by dispensing 1.5 g, 2.0 g, and 2.5 g powder into 100 ml of water to make 1.5%, 2% and 2.5% w/v, respectively. These concentrations had been predetermined during the preliminary study (appendix 5). Higher concentrations of the coating solutions led to shriveling on the cassava root skin and enhanced spoilage. The solutions were heated at 40 °C for one hour with stirring then filtered to remove any undissolved impurities. Guar gum was prepared by dispensing 1.5 g and 2.0 g in 100 ml of distilled water to make 1.5% and 2% w/v and stirred at 80 °C for one hour using a magnetic stirrer to enable complete dispersion. The xanthan guar gum combination was prepared in concentrations of 1%, 1.5% and 2% w/v by dissolving the gums in ratios of 1:1 and heated at 60 °C on a magnetic stirrer for one hour.

There were 9 different treatments in this experiment. This included the 1.5% and 2% guar gum; 1.5%, 2%, and 2.5% xanthan gum; 1%, 1.5% and 2% xanthan/guar gum and the control. The coating solutions were then applied to the unpeeled roots by dipping for three minutes into the coating solution. They were then placed in clean crates for air drying and stored at 25 $^{\circ}$C. Cassava roots under the different treatments were then tested to determine the effect of the coatings on the physical, physiological and chemical properties of the cassava roots for the entire storage duration at two-day intervals. Each day, 27 whole roots were analyzed (three roots for each of the 9 treatments including the control root sample). For each analytical experiment, three replicates were used from the three roots from each treatment cut at the proximal, mid and distal end.

Coating was performed on the same day that the cassava roots were harvested.

4.2.3 Determination of flesh firmness

A hand held penetrometer (CRD-100D, Sun Scientific Co., Ltd, Japan) fitted with a probe was allowed to penetrate the root flesh to a depth of 10 mm and the corresponding force required to penetrate this depth was determined according to Famiani *et al* (2012). A cylindrical cork borer was used to get even samples of 2 cm length.

4.2.4 Determination of colour change

The colour of the cassava samples (3 replicates per treatment) was determined using a hunter lab colour difference meter (Minolta, Tokyo, Japan) according to Hernández-Muñoz *et al* (2008). The hunter lab colour difference meter gives colour values denoted as L*a*b*. The colour meter was put on the cassava flesh and the L* values recorded since they indicate the lightness of a sample to darkness. The a* values and b* values were not recorded since they are used to translate green to red colour and blue to yellow colour respectively. The colour was measured at four regions along the mid-section spaced 90^0c apart. A white plate was used for calibration after each reading. Results were tabulated and the L* values used to determine the color changes of the flesh with time.

4.2.5 Determination of weight loss

Cassava samples (3 replicates per treatment) were weighed while fresh and at an interval of two days for twenty days. The difference between initial and final root weight was determined for that storage period and expressed as a percentage on a fresh weight basis according to Paniagua *et al* (2013). This was calculated as shown:

$$\%\, weight\ loss = \frac{Initial\ weight\ of\ sample - current\ weight\ of\ sample}{Initial\ weight\ of\ sample} * 100$$

(1)

4.2.6 Determination of dry matter content

This was determined according to Ebah-Djedji *et al* (2012) with slight modifications. 20 g of the chopped and ground roots were oven-dried at 105 ˚C for 24 hours. Dry matter was then expressed as a percentage of the dry weight relative to the fresh weight using the equation below:

$$\%\, dry\ matter\ content = 100 - \left(\frac{Dish\ and\ Sample\ weight - Dish\ weight}{Sample\ weight}\right) * 100$$

(2)

4.2.7 Determination of ethylene production rate

This was done according to Fugate *et al* (2010) with a few modifications. Air tight containers of specific known volume with silicon spectrum were used. Standard curves ethylene were generated by injecting pure gas samples of known concentrations. The weight of each cassava was taken. The samples were then incubated in air-tight plastic containers of known volume. After one hour, 1ml of the headspace was taken from each container using a syringe and injected into a gas chromatograph (Shimadzu Corp., Kyoto, Japan, model GC-9A) fitted with a flame ionization detector. The peak area was recorded and this was used to calculate the amount of ethylene produced using the ethylene standard curve (Appendix 2). Ethylene was reported as nl C_2H_4/g/hr.

4.2.8 Determination of respiration rate

Air tight containers of specific known volume fitted with self-sealing rubber septums were used. The weight of each cassava to be used was recorded. The weights varied with each root. The samples were then incubated in the air-tight plastic containers for one hour. After one hour, 1 ml of the headspace gas was drawn from each container using an air-tight syringe and injected into a gas chromatography (Shimadzu Corp., Kyoto, Japan, model GC-8A). The detector used were thermal conductivity detector fitted with Propak N column for respiration. The peak area was recorded. The rate of carbon dioxide production was reported as mg CO_2/kg/hour and this was calculated using the CO_2 standard curve (Appendix 3).

4.2.9 Determination of total phenolic content

The amount of total phenolic contents was determined by the Folin-Ciocalteu method as described by Ainsworth and Gillespie (2007) with modifications. Two grams (2 g) of the cassava root was ground in an ice-cold mortar and pestle using 20 ml of ice-cold 95% (vol/vol) methanol. The samples were then vortexed and incubated at 25 $^{\circ}$C for 72 hours in the dark. The puree was then filtered to remove debris and the residue centrifuged at 11,500 g for 10 minutes at room temperature and the supernatant collected. The sample was then passed through a 0.45 µl membrane filter. To 1 ml of the sample extract and the standard, 2 ml of 10% (vol/vol) Folin-Ciocalteu reagent was added and vortexed and 4 ml of saturated Na_2CO_3 solution was then added. The mixture was then allowed to stand at 25 $^{\circ}$C for 2 hours and the absorbance measured at 765 nm using UV-vis spectrophotometer. A standard curve was generated using the absorbances of the gallic acid standards in ppm (Appendix 1). The amount of total phenols was expressed as gallic acid equivalents per 100 g of the sample.

4.2.10 Determination of cyanide content

Total HCN was analyzed using the alkaline titration method according to Famurewa & Emuekele (2014).

4.2.11 Sensory evaluation

This was carried out twenty days after the coating application. Dipping method of coating application was used. The samples were anonymously presented to a 30-member untrained panel against a fresh control sample. The panelists were selected based on their interests and availability for the test. The panelists were first informed of the product and what was required of them and only the interested ones at the time of study went ahead to perform the sensory evaluation test. Sensory evaluation of the cassava roots consisted of attributes ranging from colour, taste, aroma, texture and flavor. A 9-point hedonic scale (9-like extremely, 1-dislike extremely) was used. Panelists were requested to fill the evaluation form (Appendix 4). A 6-point score was considered a base limit for acceptability of the product.

Sensory evaluation was performed due to the fact that coating solutions may affect the sensory properties of a food product (Dhall, 2013).

4.2.12 Data Analysis

Comparisons among the various treatments and storage duration effects was determined by ANOVA using Genstat Discovery 12th Edition, so as to determine the effect of the different treatments and storage duration on the cassava shelf life and quality parameters. Mean variations were performed using Tukey multiple comparison test. Correlation analysis was also performed to determine the degree of association between the variables.

4.3 Results and Discussion

4.3.1 Firmness

The flesh firmness between the various treatments was significantly ($P \leq 0.05$) affected by the storage duration. The flesh firmness of the cassava roots increased regardless of the treatments and then gradually declined during the storage duration. The 1.5% guar treated sample had a flesh firmness of 96.6N at 8DAH while the 2% guar treated sample had a firmness of 96.6N at 12 Days after harvest (DAH) after which there was general a decline as it approached 20DAH. The 2% guar treated root sample had a flesh firmness

of 21.1N while the 1.5% guar treated root sample had a firmness of 8.9N which was not significantly different from control which had 8.9N as shown in Figure 4-1.

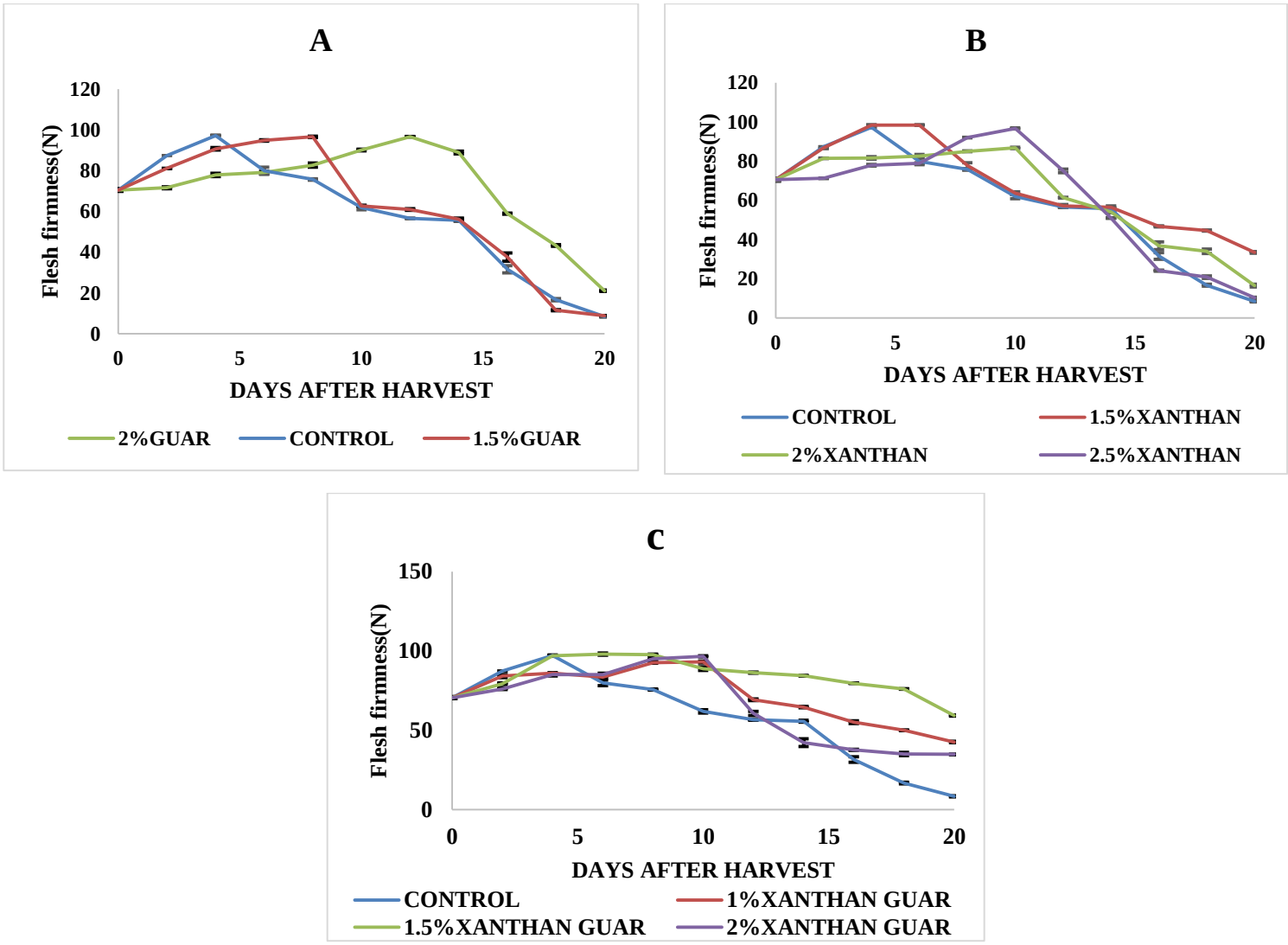


Figure 4-1. Changes of flesh firmness of cassava during storage when coated by guar gum(A), xanthan gum(B) and xanthan guar gum combination (C). *Each value is the mean for 3 replicates. The vertical bars indicates the standard error.

The root samples coated using the 1.5% xanthan attained a firmness peak of 98.4N at 8DAH while the 2% and 2.5% xanthan treated root samples reached their peaks of 86.7N and 96.7N at 10DAH (Fig 4-1). This was followed by a general decline in the

firmness towards 20DAH. At this point, the 2%xanthan treated sample had a firmness of 16.5N while the 1.5% and 2.5% xanthan treated samples had firmness of 33.4N and 10.3N, respectively as compared to the control that reached 8.4N at 20DAH.

Cassava roots coated with 1.5% xanthan/guar gum attained a flesh firmness peak of 98.0N at 6DAH while the 1% and 2% xanthan/guar gum treated samples attained their peaks of 93.1N and 96.6N, respectively at 10DAH. There was a decrease in firmness as the storage time approached 20DAH. The 1.5% xanthan/guar gum treated and the control root samples had flesh firmness of 59.3N and 8.4N respectively whereas the 1% and 2% xanthan/guar gum treated root samples had a firmness of 42.6N and 34.8N, respectively.

Coating using the 1.5% xanthan/guar gum produced roots with the highest flesh firmness as exhibited by a force of 59.3N at 20DAH while the 1.5% guar treated root had a force of 8.9N the lowest flesh firmness as compared to the control root that had firmness of 8.4N on the same day.

The initial increase in the firmness of the cassava samples may be due to water loss which is as a result of various processes. Starch hydrolysis which permeabilizes the cellular membrane might have enabled water to exit from the cell wall hence hardening the flesh of the cassava (Akely *et al*., 2016). Dark respiration processes which lead to water loss from the cassava might have also lead to hardening of the flesh. With increased storage duration, there's an increase in polysaccharide production which lignifies the cell wall hence increasing the firmness (Akely *et al*., 2016). The later decline in the firmness may have been due to the action of pectin enzymes which cause a dramatic loss of firmness.

4.3.2 Colour

The L* value declined over time with the storage duration as shown in Figure 4-2. The hunter L*a*b* colour scale is a visually uniform mode of evaluating the colour of substances including the cassava flesh. The L* value is mostly preferred in reporting cassava flesh and starch colour as it indicates the values from white (100) and this

reduces as the flesh colour darkens (Pérez Elevina and Pérez Liz , 2009; Acedo & Acedo Jr., 2013).

Cassava flesh colour were significantly ($P \leq 0.05$) different between the control roots and the treated samples throughout the storage duration. The 1.5% guar treated roots had a value of 79.2 while the 2% had 70.9 at 20 days after harvest (DAH). This was a decline of 15.1% and 23.9%, respectively. The 1.5% xanthan treated root had a decline of 33.7% while 2% and 2.5% had 21.6% and 20.3%, respectively. At this day, the 2.5% xanthan was significantly ($P \leq 0.05$) different from 1.5% xanthan and 2% xanthan treated roots. The 1% xanthan/guar treated root had a decline of 20.0% while the 1.5% and 2% had a decline of 12.9% and 11.4% decline, respectively by 20DAH. The 1% xanthan/guar gum treated root was significantly ($P \leq 0.05$) different from the 1.5% and 2% xanthan/guar gum treated roots. The lowest L* value was 62.1 detected in the untreated root, while the highest L* value of 82.6 was in the samples treated with 2% xanthan/guar gum at 20DAH. The decline of the L* values seemed to be accompanied by the PPD development of the cassava roots. The coated root samples were significantly ($P \leq 0.05$) different from the control roots.

These results correlate to those reported by Acedo & Acedo Jr (2013) who determined the effects of hot water dipping to elongate the cassava root shelf life. The treated cassava roots showed a delayed colour change as compared to the control samples. The change in colour is due to the onset of PPD as there's formation of blue/black streaks along the roots cross sectional area as reported by Tumuhimbise *et al* (2015) and Salcedo *et al* (2010). The vascular discoloration is accompanied by a decline in the L* values which denotes the onset of root deterioration.

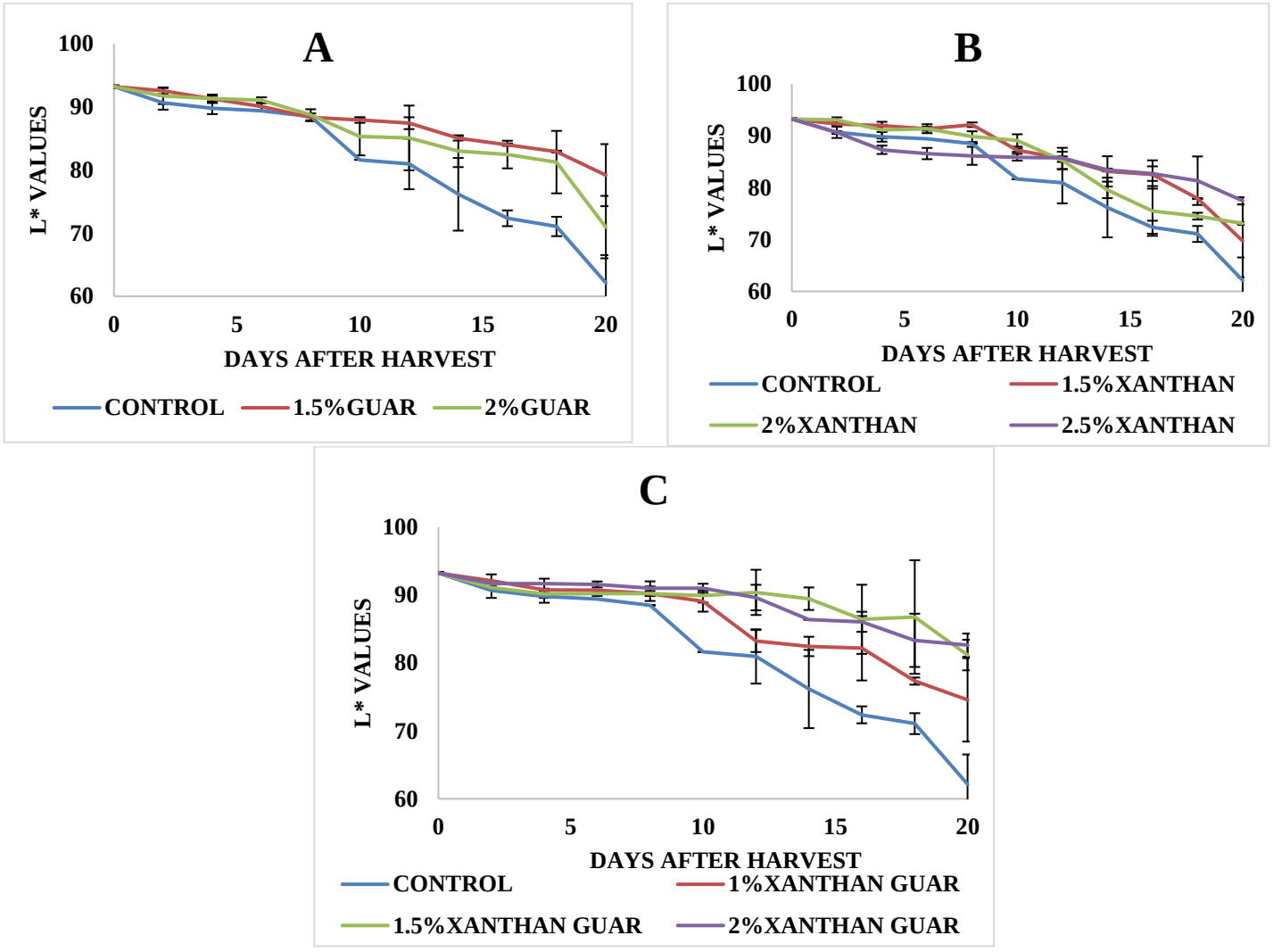


Figure 4-2.Changes in flesh colour of cassava during storage as affected by guar gum(A), xanthan gum(B) and xanthan guar gum combination (C). *Each value is the mean for 3 replicates. The vertical bars indicates the standard error.

4.3.3 Weight loss

There was an increase in the rate of weight loss of cassava roots as it approached 20DAH as shown in Figure 4-3. The rate of weight loss was affected by the treatment induced and the storage time. The 1.5% guar treated roots had a weight loss of 23.56%

while the 2% guar treated root had a weight loss of 21.2% at 20DAH. The 1.5% xanthan treated roots had a percentage weight loss of 23.1% while the 2% and 2.5% xanthan treated roots had 25.4% and 24.5%, respectively at 20DAH. The 1% xanthan/guar gum treated root had 24.6% weight loss while the 1.5% and 2% xanthan/guar gum treated roots had 24.7% and 17.5%, respectively at 20DAH. The highest percentage weight loss at day 20 was recorded in the control sample at 33.4% while the lowest weight loss recorded was 17.5%, 21.2% and 23.1% in 2% xanthan guar/ gum combination, 2% guar and 1.5% xanthan, respectively. There were significant ($P \leq 0.05$) differences between the treatments at 20DAH.

These finding were similar to those reported by Sánchez *et al* (2013) as the treated samples of cassava had a significant ($P \leq 0.05$) delay in the rate of weight loss as compared to the control samples at 20DAH. However, the various treatments had differing rates of weight loss. An increase in the concentration of the coating solution led to an increase in the efficiency of the coating against weight loss during the storage period. The loss in weight is usually due to respiration and transpiration which are normal metabolic processes of the cassava root crop (Abbasi *et al*., 2009). This is caused by diffusion of water vapor due to a pressure gradient between the inside and the outside of the cassava root. The coating solutions may have acted as barriers for water loss with a thicker film reducing the water loss even further by acting as a semi-permeable membrane around the surface of the cassava (Wijewardane, 2013).

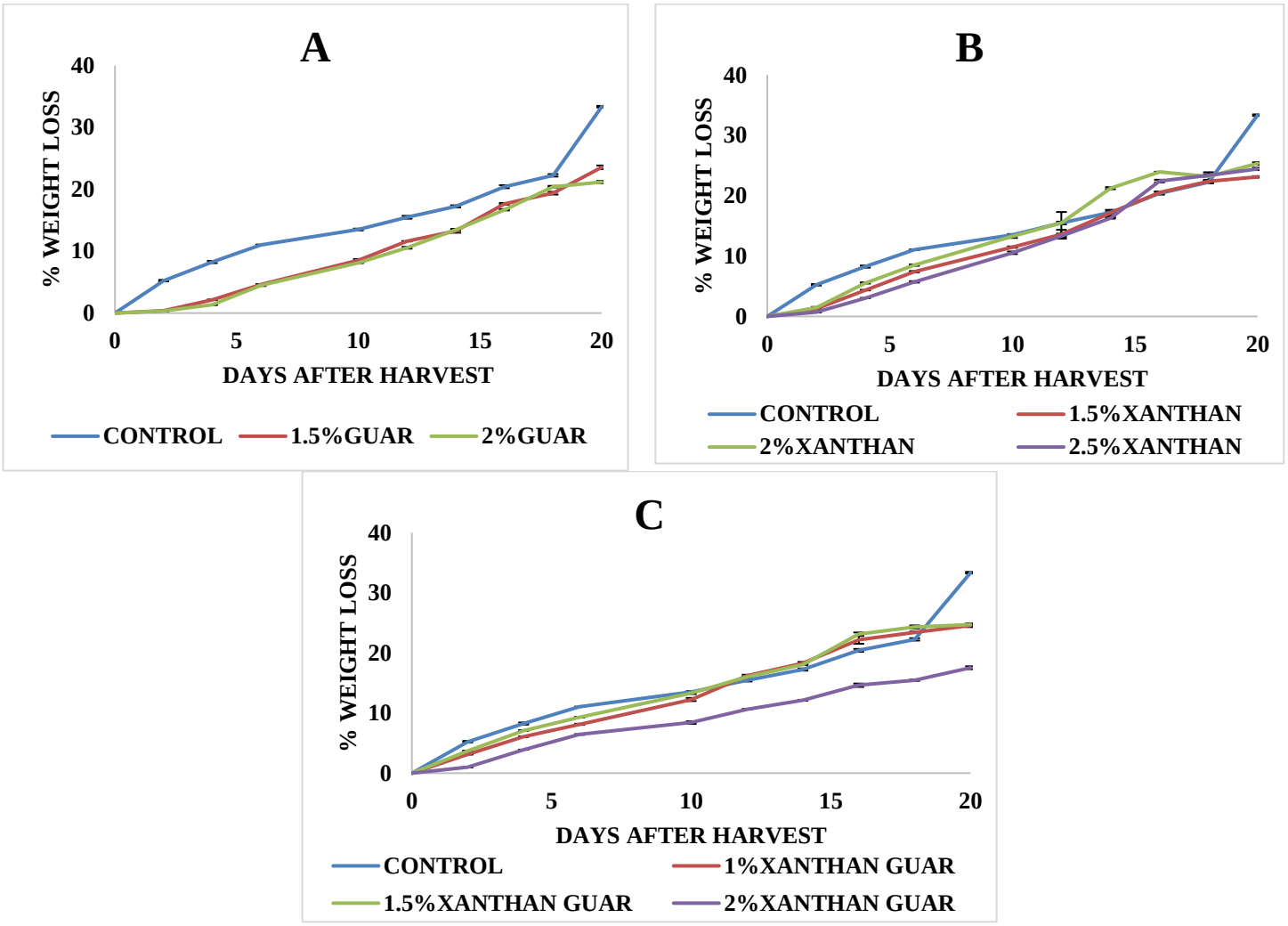


Figure 4-3.Changes in percentage weight loss of cassava during storage when coated by guar gum(A), xanthan gum(B) and xanthan guar gum combination (C). *Each value is the mean for 3 replicates. The vertical bars indicates the standard error.

4.3.4 Dry matter content

Upon coating, there was an increase in the dry matter content of the root samples until 20DAH as shown in Figure 4-4.

The 1.5% guar gum treated root had a percentage increase of 10.9% while the 2% guar gum treated root had 24.2% at 20DAH, whereas 1.5% xanthan treated root an percentage increase of 12.0% while 2% and 2.5% xanthan treated root had 11.6% and 16.6% increase, respectively.

The 1% xanthan/guar gum treated root had a 10.9% increase while the 1.5% and 2% xanthan/guar gum treated roots had 9.5% and 6.9%, respectively at 20DAH.

Generally, there were significant ($P \leq 0.05$) differences among the various treatments during the storage duration. The control samples attained a much higher dry matter content of 72.8% at 20DAH which was a 26.9% increase as compared to the treated samples. Sánchez *et al* (2013) suggested that cassava varieties that have a high dry matter content are more liable to PPD occurrence as compared with the ones with low dry matter content. The rate at which the control roots formed dry matter directly correlates to the high rate of PPD onset.

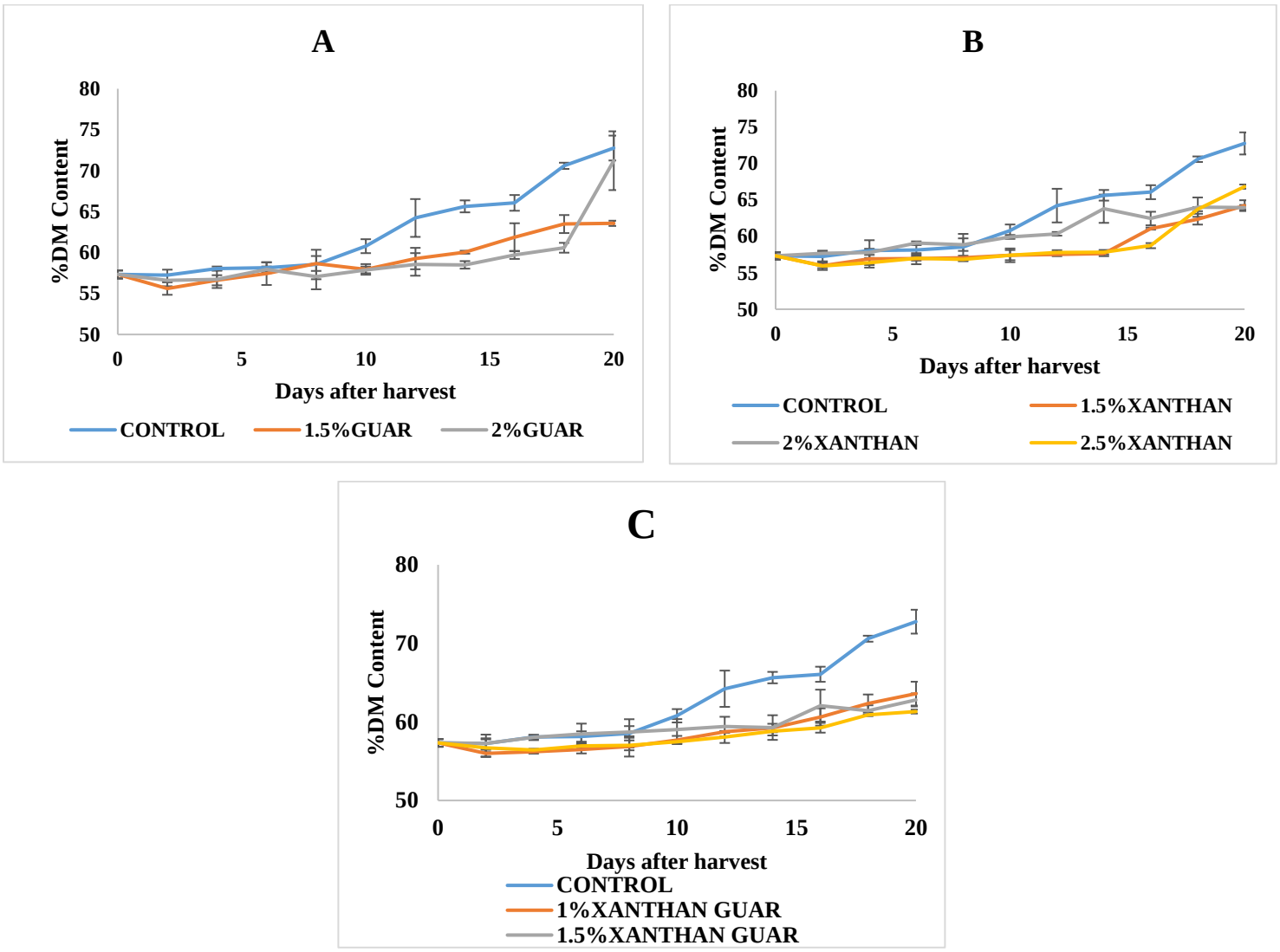
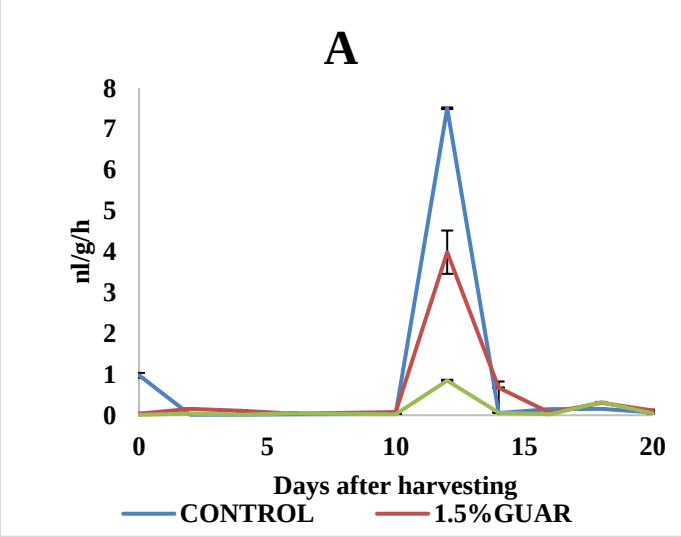


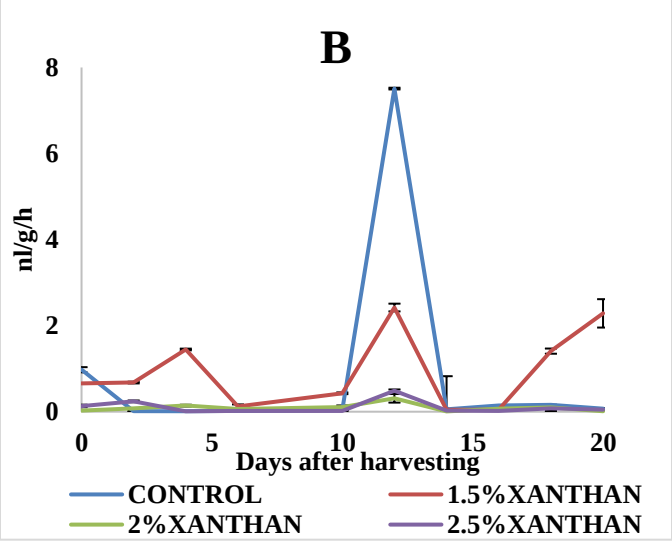
Figure 4-4.Changes in percentage dry matter (DM) content of cassava during storage when coated by guar gum (A), xanthan gum (B) and xanthan guar gum combination (C). *Each value is the mean for 3 replicates. The vertical bars indicates the standard error.

It has been reported that increase in the dry matter is caused by the reduction of water content on the cassava root during the storage period. Water loss is a normal phenomenon that occurs gradually from the harvest period (Quevedo *et al*., 2014). The decrease in the water content of the cassava root may have led to the increased dry matter content hence the increased PPD development. The increased dry matter content has also been associated with a shorter shelf life.

4.3.5 Ethylene production rate

The coating process reduced the ethylene production rate of the cassava roots as shown in Figure 4-5. The 1.5% guar gum treated roots formed the second peak of 4.0 nl/g/h while the 2% guar gum coated root had a peak of 0.9 nl/g/h at 12DAH. The 1.5%, 2% and 2.5% xanthan treated roots had peaks of 2.4 nl/g/h, 0.3 nl/g/h and 0.5 nl/g/h respectively while the 1%, 1.5% and 2% xanthan/guar gum treated roots formed peaks of 2.0 nl/g/h, 0.5 nl/g/h and 1.6 nl/g/h at 12DAH. The 1.5% xanthan treated root and 1.5% xanthan/guar gum treated root were significantly ($P \leq 0.05$) different from other treated roots and the control at the 20th day after harvest.





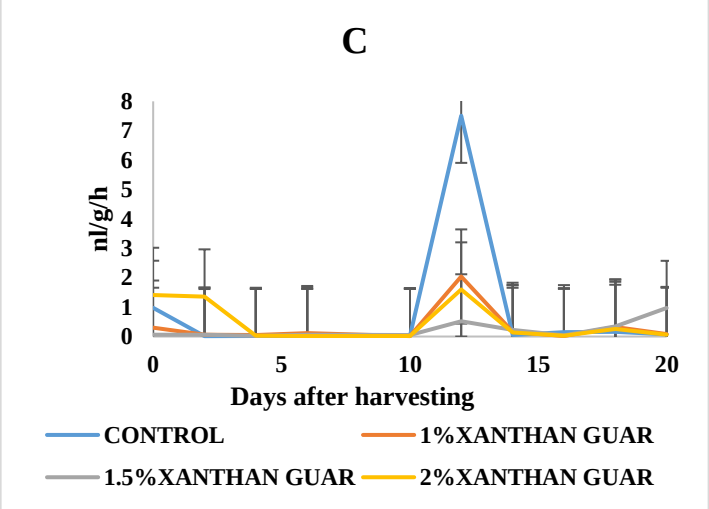


Figure 4-5. Changes in ethylene production rate of cassava during storage when coated by guar gum(A), xanthan gum(B) and xanthan guar gum combination (C). *Each value is the mean for 3 replicates. The vertical bars indicates the standard error.

4.3.6 Respiration rate

Two peaks were observed during cassava respiration as reported by Salcedo & Siritunga (2011). In this study, these two peaks occurred generally at the second day after coating while the second peak varied between treatments depending on the efficiency of the coating solution (Figure 4-6). No significant difference was observed between the different treatments.

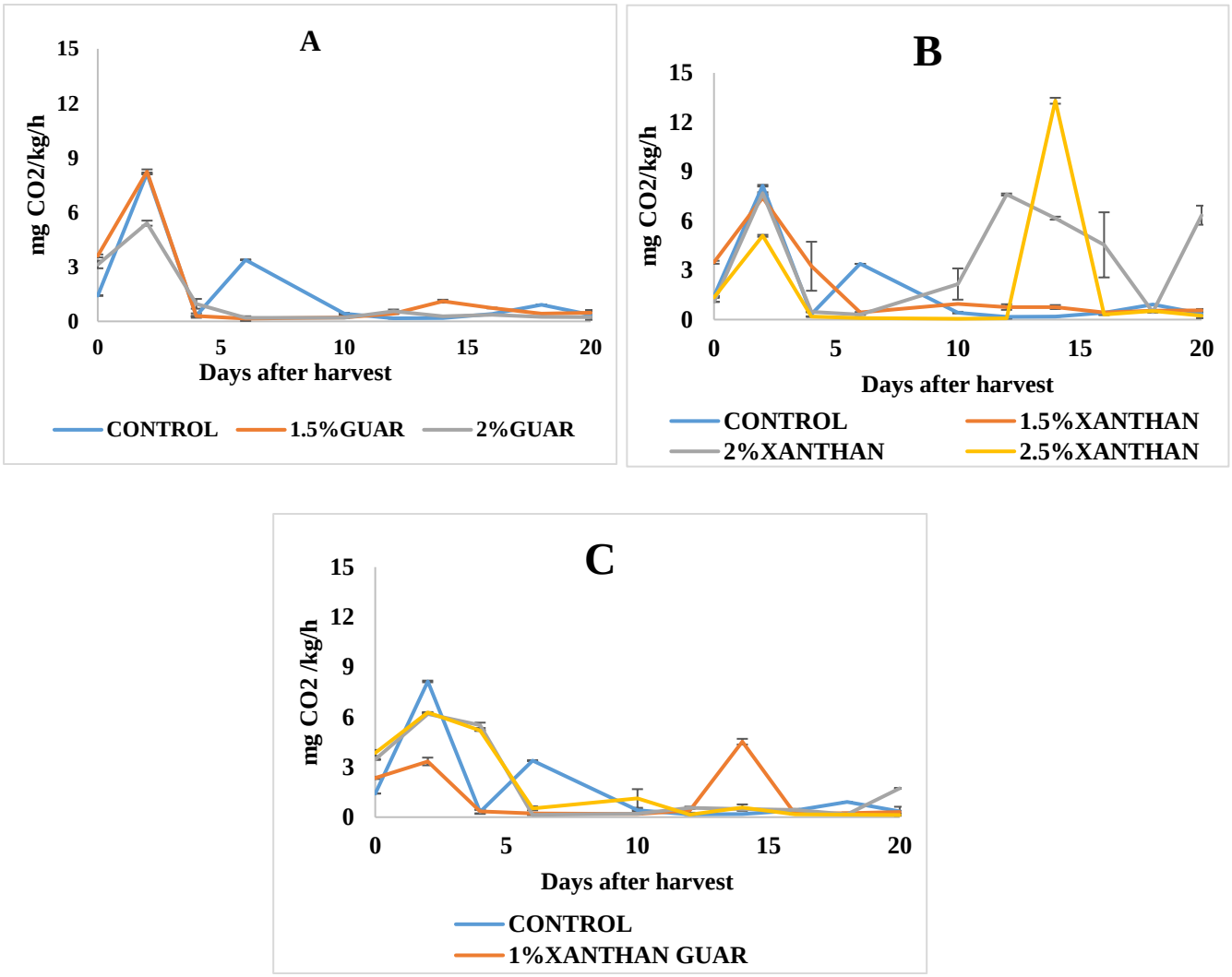


Figure 4-6. Changes in respiration rate of cassava during storage when coated by guar gum(A), xanthan gum(B) and xanthan guar gum combination (C). *Each value is the mean for 3 replicates. The vertical bars indicates the standard error.

The cassava roots coated with 1.5% guar gum reached their second peak of 1.1 mg CO_2/kg/h on 14 days after harvest (DAH) while 2% guar gum coated roots reached their second peak of 0.6 mg CO_2/kg/h on the 12th day after coating. The 1.5% xanthan treated roots reached the second peak of 0.9 mg CO_2/kg/h at 10DAH while 2% and 2.5% xanthan treated roots reached peaks of 7.6 and 13.3 mg CO_2/kg/h at 12DAH and 14DAH, respectively. The 1%, 1.5% and 2% xanthan guar treated samples reached their second peaks of 4.5, 1.7 and 1.1 mg CO_2/kg/h at 14DAH, 20DAH and 10DAH,

respectively. This was compared to the control that reached its second peak of 3.4 mg CO_2/kg/h at 6DAH. From the point where there's formation of a second peak, there's decline of the respiration rate towards zero as it approached 20DAH. 2% xanthan/guar gum treated root had the least respiration rate as exhibited by 0.1 mg CO_2/kg/h while the highest respiration rate at 20DAH was 6.4 mg CO_2/kg/h by 2% xanthan treated root in comparison to the control sample that had 0.4 mg CO_2/kg/h.

The first peak was described to be due to the wounding and it occurs within the first 24 to 48 hours after harvest to suggest the onset of PPD. The second peak is due to biochemical changes induced by the development of the PPD (Iyer *et al*., 2010). In the current study, all the samples had their first peak 2DAH though the intensity was reduced for the coated cassava samples unlike the control samples. The second peak formation varied between the different treatments based on their functionality. The two coating solutions may have formed a thin film on the cassava surface and this may have reduced the gaseous exchange and respiration rate as was reported by Dhall (2013). The different concentrations of the coating solutions led to the significant difference ($P \leq 0.05$) in their slowed respiration rate. Respiration rate of cassava continues after harvest and this brings about biochemical changes that lead to the eventual deterioration of the root. This process may have been delayed by the use of coating solutions.

4.3.7 Total phenolic content

The total phenolic content of the cassava root samples declined with storage duration and treatment as shown in Figure 4-7. There was a percentage decline in the total phenolic content by 91.9% for the 1.5% guar gum treated root to 2.85 mg/100g GAE and by 77.7% for the 2% guar gum treated root to 7.82 mg/100g GAE at 20 days after harvest (DAH). The percentage decline in total phenols was also recorded by Canto, Júnior and Beleia (2013). The phenolic content among the treatments was significantly ($P \leq 0.05$) different at 20DAH.

Root samples coated using the 1.5% xanthan treated roots decreased by 66.7% while the 2% and 2.5% xanthan treated roots decreased by 81.5% and 89.1% to 11.68 mg/100g

GAE, 6.48 mg/100g GAE and 3.83 mg/100g GAE respectively. There were significant ($P \leq 0.05$) differences among these treatments at 20DAH. The 1% xanthan/ guar gum treated roots decreased by 52.6% to 16.64 mg/100g GAE while 1.5% and 2% xanthan/guar gum treated roots decreased by 74.0% and 69.7% to 9.12 mg/100g GAE and 10.6 mg/100g GAE at 20DAH.

The treated root samples varied in their delay in phenol reduction and this may have been due to the different efficiencies of the coating solutions to delay PPD and oxygen depletion which caused enzyme inactivation (Salcedo & Siritunga, 2011). There was also notable delay in the browning of the coated cassava roots which may have been due to the inhibition of oxygen penetration by the coating solution as was reported by Baraiya *et al* (2015).

The effect of phenols on PPD is due to oxidation by polyphenol oxidase (Blagbrough *et al*., 2010; Iyer *et al*., 2010). After harvesting cassava, polyphenol oxidase causes oxidation and polymerization of the total phenols leading to the visible symptoms of blue/black discoloration on the vascular bundles as stated by Saravanan *et al* (2015). By inhibiting oxygen penetration to the cassava root sample by coating, this process was deterred hence delayed PPD development.

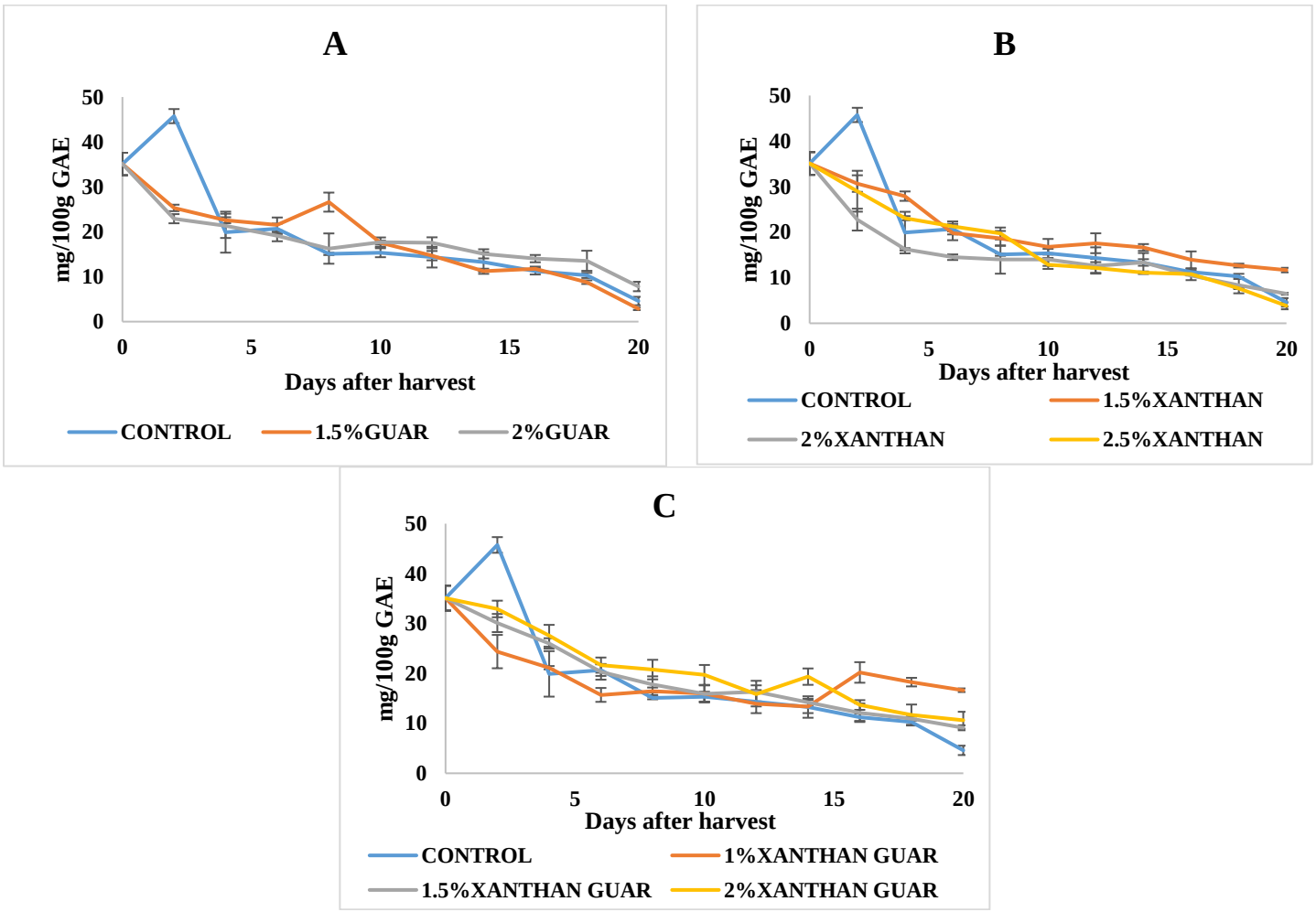


Figure 4-7: Changes in total phenolic content of cassava during storage when coated by guar gum(A), xanthan gum(B) and xanthan guar gum combination (C). *Each value is the mean for 3 replicates. The vertical bars indicates the standard error.

4.3.8 Total cyanide content

There was a decline in the total cyanide content of the root samples as shown in Figure 4-8. This was affected by the storage duration and PPD development as was reported by Salcedo & Siritunga (2011). The decline was between 73.6% and 76.8% for the 1.5% guar gum treated root and the 2% guar gum coated root. The 1.5% xanthan treated root had a decline of 85.4% at the 20th day while the 2% and 2.5% xanthan treated root had 79.1% and 70.2% respectively which were significantly ($P \leq 0.05$) different from the control. The 1% xanthan/guar gum treated root had a decline in cyanide content of

89.5%, while the 1.5% and 2% xanthan guar gum treated samples 86.3% and 86.9% respectively. However, the control root sample had a decline of 62.4% which was the least recorded.

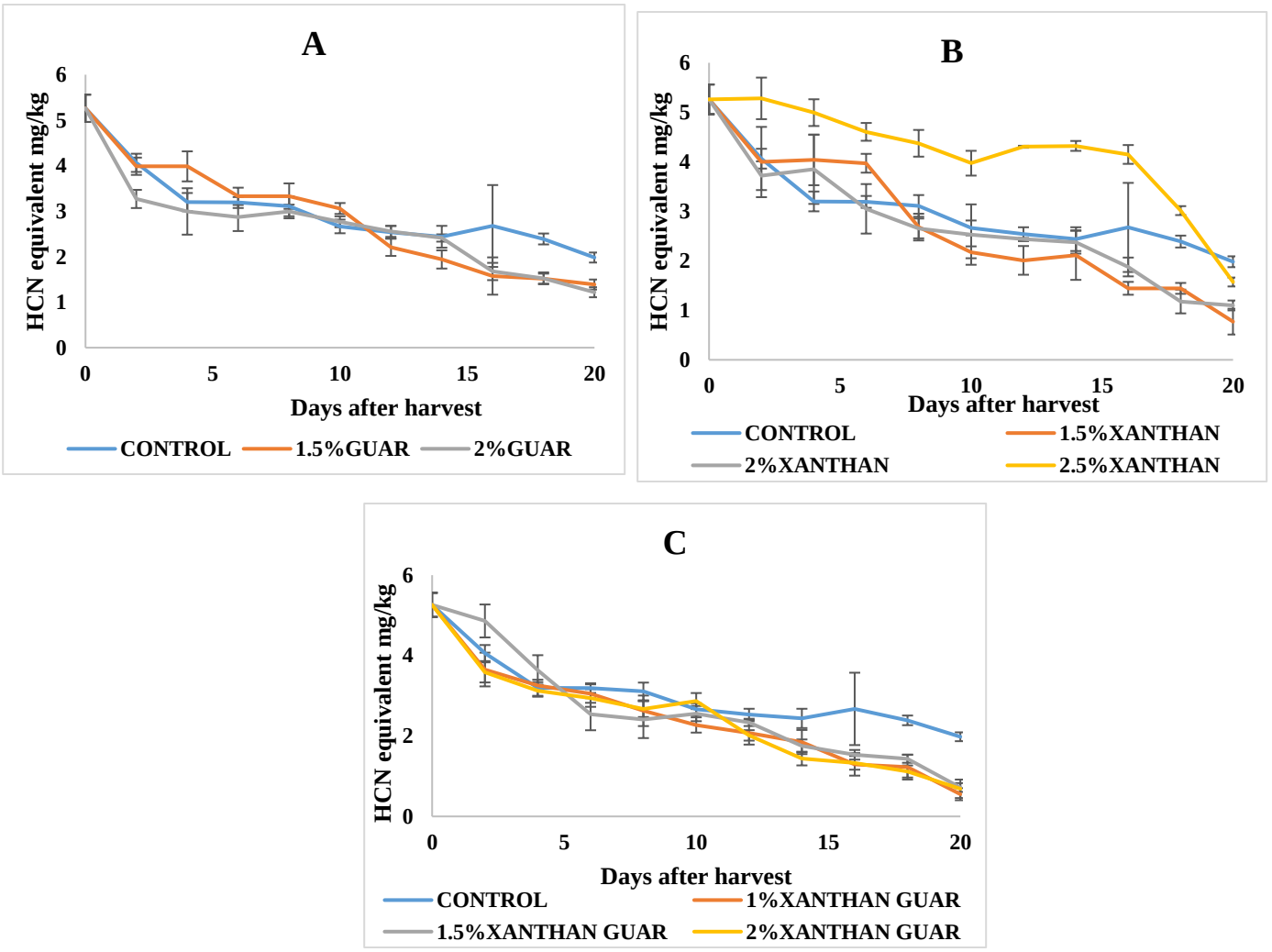


Figure 4-8: Changes in total cyanide content of cassava during storage when coated by guar gum(A), xanthan gum(B) and xanthan guar gum combination (C). *Each value is the mean for 3 replicates. The vertical bars indicates the standard error.

The total cyanide content in both the coated and treated samples was below the acceptable limit given by WHO which is 10mg/kg (Burns *et al*., 2012).Cassava samples have two different forms of cyanogenic glucosides which is linamarin and lotaustralin (Kamalu & Oghome, 2012). The main cyanogenic glucoside that leads to cyanogenesis is linamarin and it is found in higher concentrations in the skin of the cassava. Linamarin reacts with the linamarase enzyme leading to production of cyanide just after the cassava has been harvested. This may explain the high cyanide content that was recorded during the first days of the analysis. The burst in production of the cyanide during the early days after harvest leads to inhibition of normal biological reactions that occur in the mitochondrial electron transfer chain of the cassava root leading to production of reactive oxygen species (ROS) which induce the onset of PPD (Zidenga, 2012).

The general decline in the cyanide content may have also been due to the hydrolysis of the hydrogen cyanide (Famurewa & Emuekele, 2014).

4.3.9 Sensory evaluation

Treated roots were evaluated for six sensory attributes at 20DAH. The effects of the used coating solutions on the sensory characteristics of the cassava are as shown in Fig. 4-9.

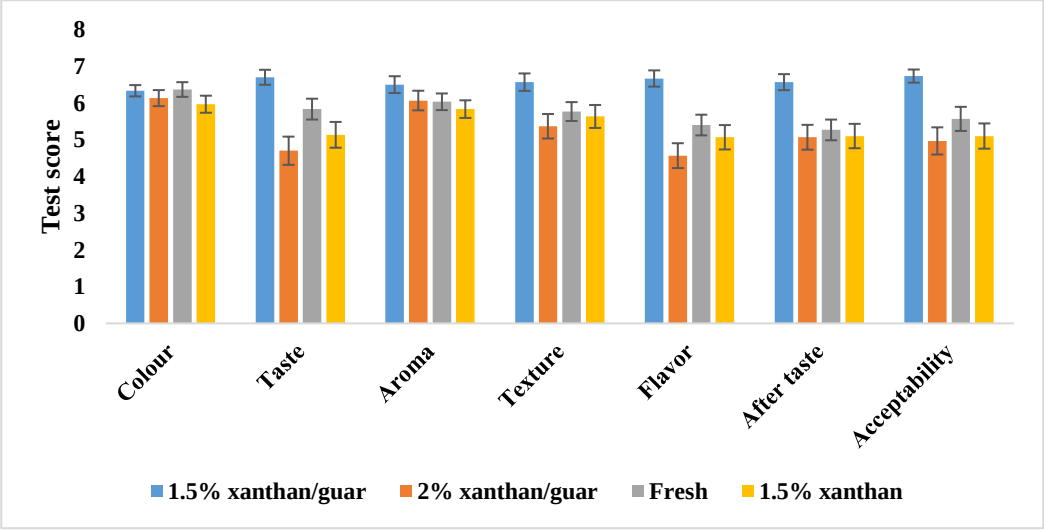


Figure 4-9: Effect of coating on the sensory attributes of whole cassava root.

The general acceptability of a product is the key factor in the consumption of the final product. The 1.5% xanthan/guar treated cassava roots proved to be the most acceptable with a test score of 6.7 followed by the control sample that had a test score of 5.6 while the least preferred was the 2% xanthan/guar treated roots that had a test score of 5.0. The after-taste of the cassava samples, flavor, texture and taste had a neutral score of neither being disliked nor liked by the panelists while the colour and aroma of the various treated roots had a test score of 6.2 and 6.1 respectively. The best colour was recorded in the fresh samples while the best taste, aroma, texture, flavor, after-taste and overall acceptability was recorded in the 1.5% xanthan/guar treated roots with test scores of 6.7, 6.5, .6, 6.7, 6.6 and 6.7 respectively. Apart from the root coated using the 1.5% xanthan/guar gum, there was a loss in aroma, taste, flavor, after taste and acceptability of the other coated cassava roots as reported by the panelists. The variation in the taste scores of the treated roots might have been due to the differing efficacies of the different coating solutions. Among the treated roots, the 1.5% xanthan/guar gum treated roots had significantly ($P \leq 0.05$) better sensory traits as compared to the other roots after 20 days of storage. The other treated roots were generally not preferred by the panelists.

Coating is a form of value addition to a food product (Hui, 2007). The film formed due to the application of coating solutions should be able to maintain the sensory attributes of food. According to USDA, coatings can bring about changes in the sensory attributes of a food product in addition to being of nutritional and preservatory value (Hui, 2007; Lin & Zhao, 2007; Andrade *et al*., 2012). Sometimes there is a drop in the sensory quality of a food product due to coating (Nieto, 2009) as was recorded for both the 1.5% xanthan and 2% xanthan/ guar coated cassava. The decline in sensory attributes was also reported by Hernández-Muñoz *et al* (2008) on the strawberry fruit. The change in flavor of a coated product may be due to incorporation of existing flavor of coating solution into the food product or due to anaerobic respiration. The positive change in sensory attributes of the 1.5% xanthan/guar gum coated roots may have been due to the formulation which may have been a good carrier of flavor as was reported by Andrade *et al* (2012)Thick films have also been reported as one of the major contributors to

anaerobic respiration and production of off flavor. The anti-browning effects of coating solutions may positively affect sensory attributes of colour even after long storage durations (Nieto, 2009) as was recorded in the 1.5% xanthan/guar gum treated root.

4.3.10 Correlation

Variables	Correlation coefficient (r)	P-value
Phenols and cyanide	0.712	0.000
Phenols and colour	0.489	0.000
Respiration and ethylene	-0.064	0.248
Weight loss and dry matter content	0.564	0.000
Firmness and weight loss	-0.751	0.000

Table 4-1: Correlation between various variables

The respiration rate and ethylene production rate had were inversely correlated in that as respiration increased to attain its respiration peak, there was a decrease in the ethylene production rate. This was not statistically significant and hence there might have been other factors that led to this reaction. The firmness and weight loss also had an inverse relation which was statistically ($P \leq 0.05$) significantly. An increase in weight loss led to a decrease in firmness. The relationship between phenols and cyanide, phenols and colour and weight loss and dry matter content were both positive and statistically significant at 0.05. An increase in the weight loss, led to an increased dry matter content while a decrease in the phenol content led to a decrease in both the colour and cyanide content. The relation between the phenolic content and cyanide content was higher and stronger as compared to the other variables.

4.4. Conclusion

The 1.5% xanthan/guar gum coating combinations was able to extend the shelf life of the cassava sample for upto 20 days at room temperature. The change in colour,

firmness, weight loss and dry matter was significantly delayed by the application of the coating solutions. CO_2 and ethylene production were suppressed in the coated samples hence a delay in the PPD onset. The decrease in the total phenolic content of the coated roots was delayed whereas the total cyanide content synthesis in the same roots was suppressed. The 1.5% xanthan/guar gum treated root had better sensory attributes after 20 days of storage.

This study recommends the use of 1.5% xanthan/guar gum coating as an effective strategy in delaying the PPD onset with minimal alterations to the quality of the cassava.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS, RECOMMENDATIONS

5.1 General Discussion

During the comparison of the dipping versus the spraying mode of application on the cassava root, there were differences based on the various properties being investigated. The coating process delayed the change in quality attributes of the cassava root though this was dependent on the coating solution applied. The colour of the cassava roots changed from white to blue/black stripes with increased storage duration as was reported by Djabou *et al* (2017). This change in colour of the cassava root flesh is due to the oxidation and polymerization of the total phenols especially scopoletin which gives rise to the blue/black discoloration (Freire *et al*., 2015). The dry matter content and the weight loss gradually increased as was recorded by Quevedo *et al* (2014). This is due to the loss in moisture from the sample as the storage days progressed. The increase in the dry matter content was negatively correlated to the change in colour as the PPD progressed. The total phenolic content and total cyanide content decreased with time of storage. The decrease in cyanide content might have been due to hydrolysis of the hydrogen cyanide (Kamalu *et al*., 2012) while the decrease in total phenols may be attributed to the oxidation of the total phenols. The total cyanide content and the total phenols showed a positive correlation with increased storage duration. Flesh firmness of the roots increased during the first few days and then gradually decreased towards zero. This decline in flesh firmness may have been as a result of the onset of microbial deterioration which begins at the 4-5 days after harvest for the samples that are not coated and increased enzyme activity which disrupts the flesh integrity of the cassava root (Ampe & Brauman, 1995) while the increased flesh firmness was due to the water loss which caused hardening of the flesh (Akely *et al*., 2016). The respiration rate led to formation of two respiratory peaks reported to be due to wounding and biochemical changes. Ethylene production rate was high during the first day and this decreased and later formed a peak. The high initial ethylene production has been attributed to the

production of wound ethylene (Raju *et al*., 2016). The different coating solutions applied affected the sensory qualities of the cassava roots differently.

5.2 Conclusions

The two commonly used modes of coating application are dipping and spraying. Both the dipping and spraying methods of application had no significant differences in their activity. The dipping method of application proved to be easier in application and hence it was adapted for use in the study. Spraying technique is dependent on the coating solution used as it should have the capacity to pass through the nozzles hence can't be used on highly viscous solutions. The highly concentrated coating solutions proved difficult to pass through the nozzles. The performances of the two methods were evaluated based on their effect on the physical, physiological and chemical characteristics of the cassava roots. The two different application methods compared in this study had significant differences based on the cassava property being observed. The choice of which application method to be used was concluded to be dependent on the type of coating solution and ease of application.

The flesh firmness, color, total cyanide content and total phenolic content of the treated roots declined at a significantly lower rate as compared to the control cassava roots. The weight loss and dry matter content gradually increased in all the treated cassava roots, though this was slightly higher in the control cassava samples. The coated cassava root crops also displayed a delay in the respiration and ethylene production rates. The use of 1.5% xanthan/guar gum coating solution extended the shelf life of the cassava root crop by up to 20 days when stored at room temperature. The storage time and treatment induced had effects on the postharvest quality of the cassava roots. Failure to treat the roots after harvest proved that the cassava roots deteriorated two days after harvest. It was observed that at high concentration levels of the xanthan gum, the cassava root skin shriveled and this led to eventual flesh breakdown and an increase it the PPD development. The coating technology slightly affected the flavor and overall acceptability of the cassava roots. However, the 1.5% xanthan/guar gum coated cassava

had an improved flavor and acceptability as compared to the control cassava root samples. The various coating solutions used in the study only retarded and reduced the severity of the PPD occurrence, but they did not stop the process. It was therefore concluded that the use of surface coatings had a significant effect on cassava properties and eventual shelf life extension.

5.3 Recommendations

The coating technology has been found to have effects on the flavor of the products. There's therefore a need to identify specific flavors that can be incorporated into the coating solutions depending on the food product. This is because there's very minimal studies that have been done on the sensory evaluation of edible films and coatings. This will ensure that the coating solutions impart no off-flavors on the cassava root crop. There is also need for studies on the improvement of the coating adhesion abilities and durability on the surface of the product. This will further improve on the shelf life elongation properties of the coating solutions.

There is a greater need of scaling up this technology in an industrial set-up. This will ensure that the technology is taken up by both the small scale farmers and commercialization sector. The technology can be easily adapted by farmers due to its ease of implementation, cost effectiveness, minimal mechanization and local availability. This will improve consumption due to an improved market access hence improve the income of people throughout the cassava value chain.

There is need for sensitization of both farmers, producers and extension workers to adopt the practice as it will be economically beneficial to them. There is also need to educate them on the whole coating process. A demonstration farm can also be set up to ensure that the farmers appreciate the innovation technology and adapt it too.

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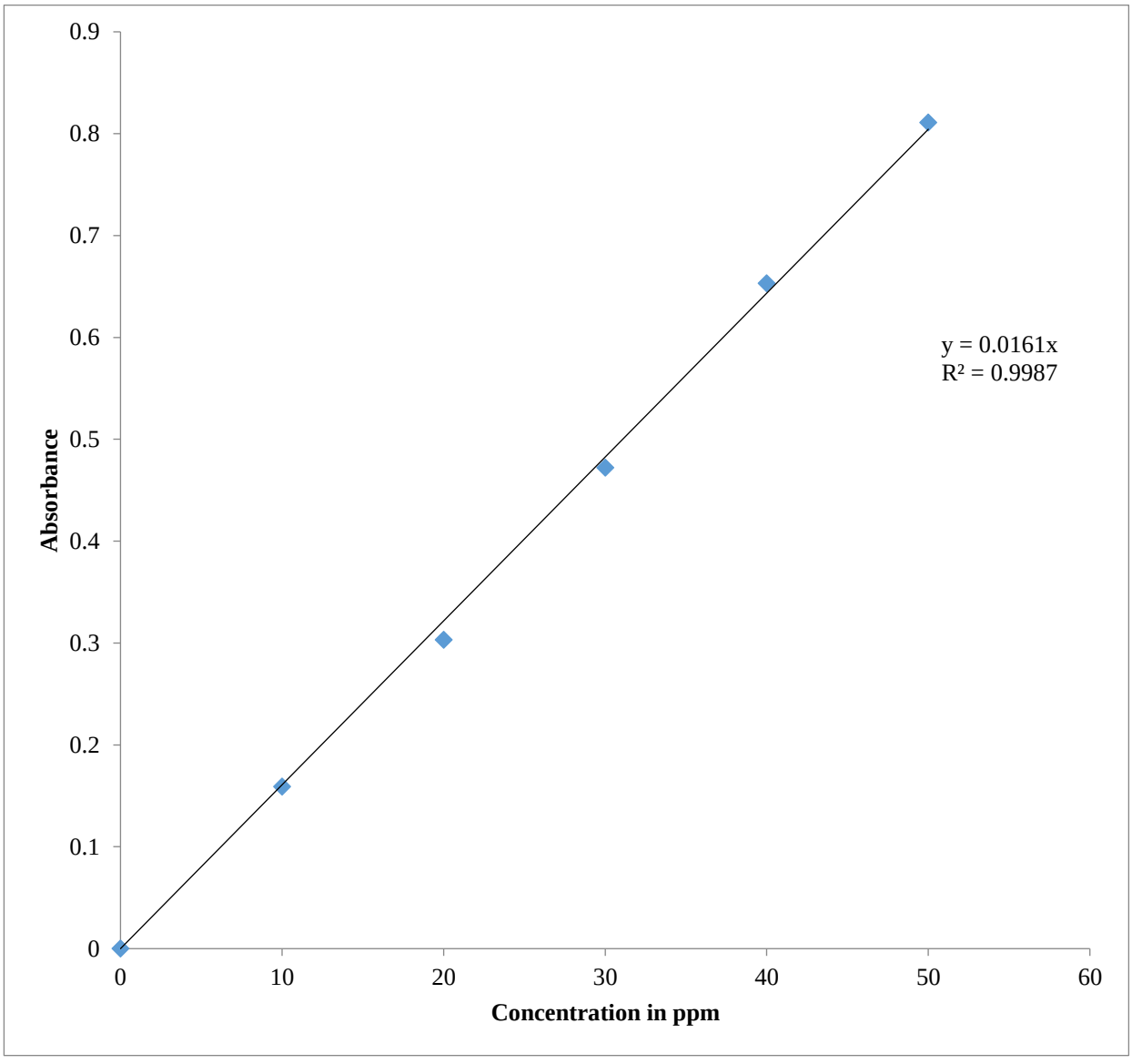
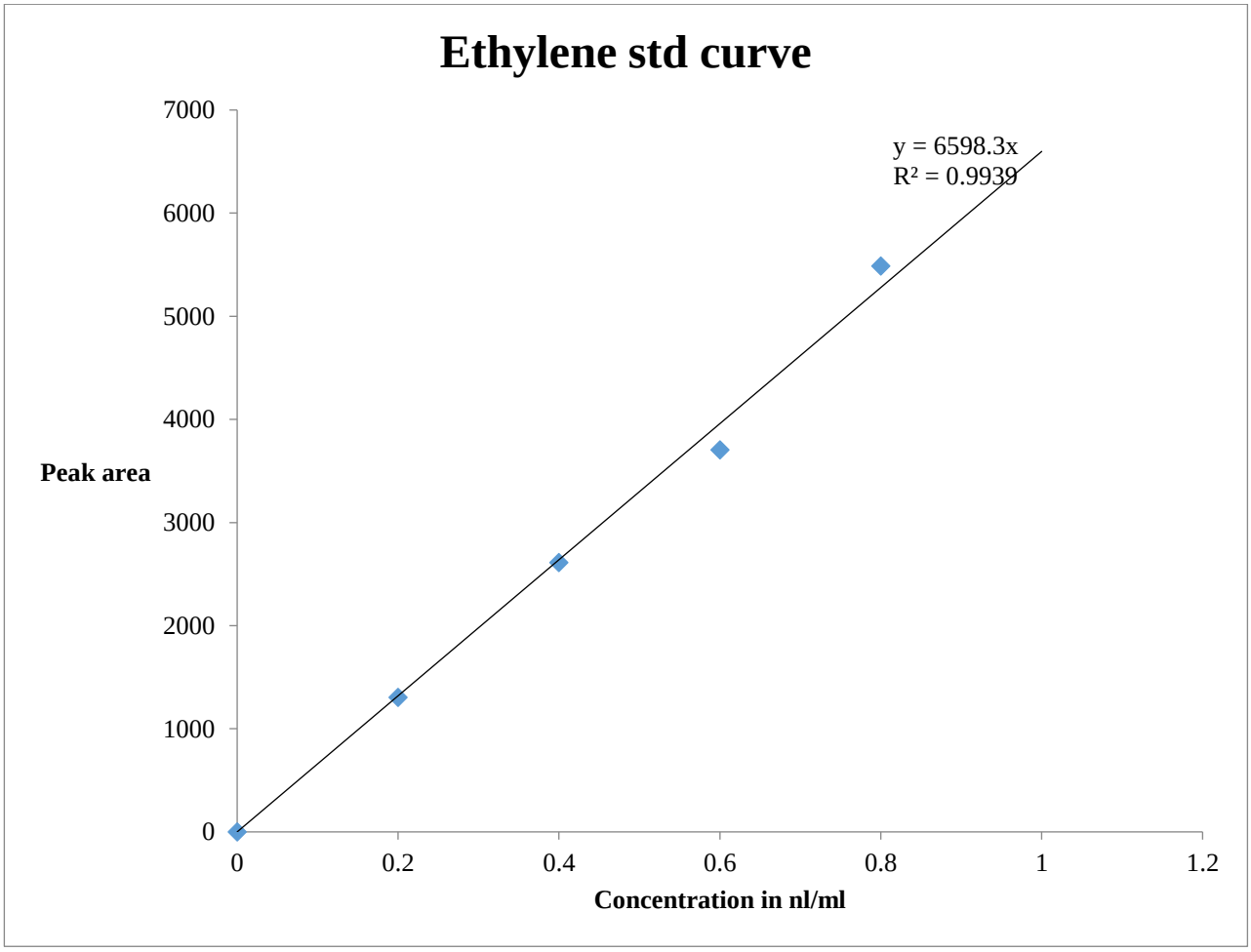
APPENDICES

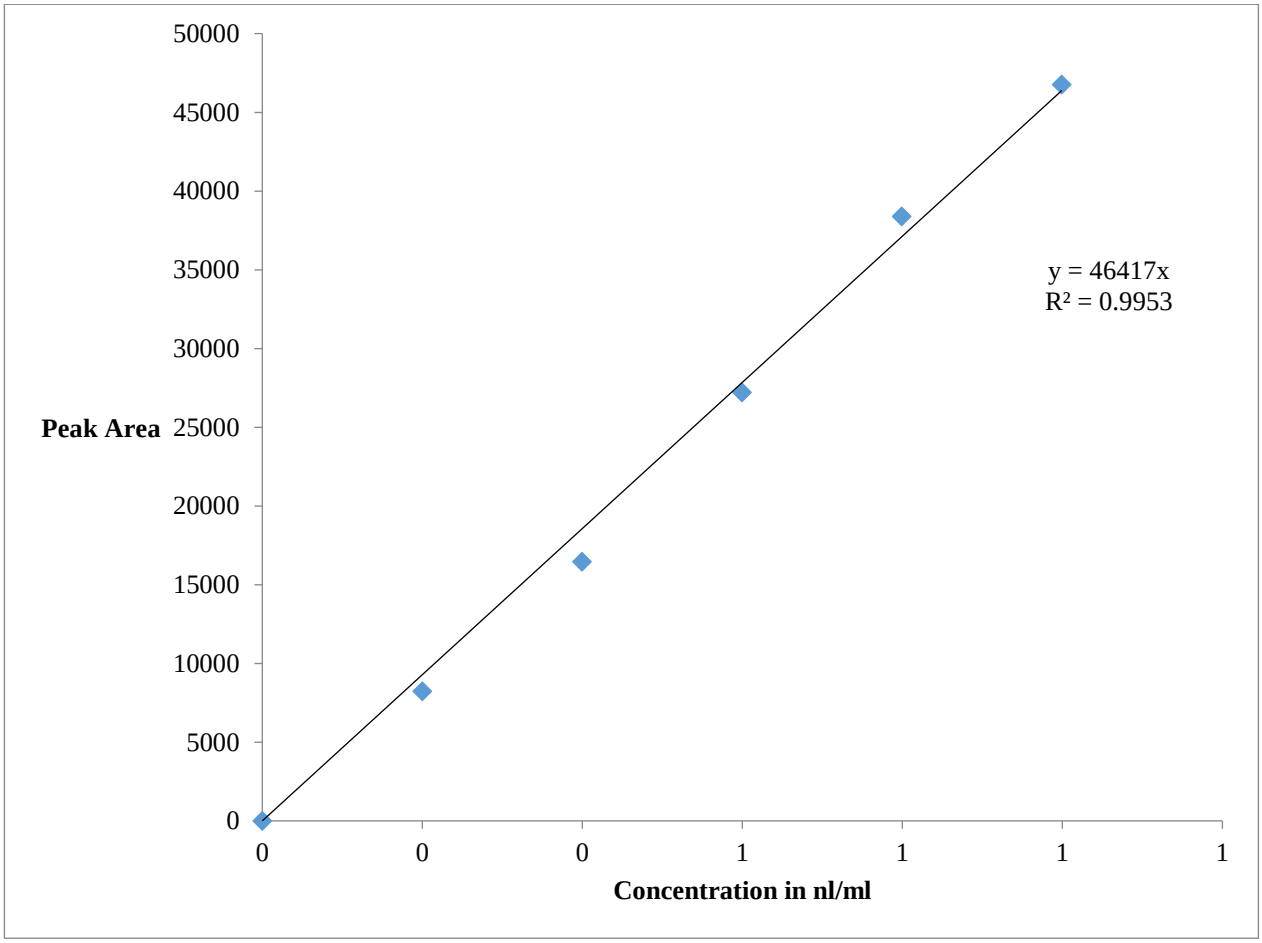
Appendix 1: Total phenols standard curve



Appendix 2: Ethylene standard curve



Appendix 3: CO_2 standard curve



Appendix 4: Consent form and Sensory evaluation Questionnaire

CONSENT FORM

Sensory evaluation of Coated Cassava

You are invited to participate in a research study of perception of boiled cassava. Kindly read this form and ask any questions that you may have before agreeing to be in the study.

This is a voluntary exercise to determine acceptability of coated cassava roots.

The results of your performance as a panelist will be kept strictly confidential.

Kindly fill in your details in the section below

The results of your performance as a panelist will be kept strictly confidential.

Kindly fill in your details in the section below

Gender

Male ☐ Female ☐

AGE:

Less or equal to 20; ☐ 21-25; ☐ 26-30; ☐ 31-35; ☐

36-40; 41 and above; ☐ ☐

How often do you consume cassava?

☐Daily; ☐Weekly; ☐ Fortnightly; ☐ Monthly; ☐Never

STATEMENT OF CONSENT

I have read the information about the conditions of this sensory evaluation and all my concerns about the study have been addressed. I hereby give my voluntary consent for participation in this study.

Name: _____ Date: __ __ 2017

Signature: _____

SENSORY EVALUATION QUESTIONNAIRE

Instructions

You have been provided with four samples of cassava.
Please take a sip of water to clean your palate before and after tasting the sample.
Taste the cassava and hold in the mouth while chewing for 5 seconds.
Record your perception by using the scale below. Please look and taste each of the (4) coded cassava samples. Indicate how much you like or dislike each sample by checking the appropriate sample attribute and indicating your reference number (1-9) in the column against each attribute.

9 – Like extremely

8 – Like very much

7- Like moderately

6- Like

5- Neither like nor dislike

4- Dislike

3- Dislike moderately

2- Dislike very much

1-Dislike extremely

Attributes	Sample Codes			
	S01	S02	S03	S04
Colour/Appearance				
Taste				
Aroma				
Texture				
Flavor				
After taste				
Overall acceptability				
Would you prefer to buy this product?	Yes/ No	Yes/ No	Yes/ No	Yes/ No

Additional comments:-

Thank you for participating in the study

Appendix 5: Preliminary work

The preliminary experiment was done for a period of ten days. Physical properties of the cassava were used to determine the efficiency of the various coating solutions. According to Tezotto-uliana *et al* (2014), the physical attributes of a perishable product are the first determinant of its consumer acceptability hence there was need to first determine the best combination of the coating solutions that would lead to maximum maintenance of these attributes. The attributes investigated included colour, firmness, weight loss and dry matter content. Too low or too high concentration of certain coating solutions led to anaerobic respiration which was manifested b shriveling on the cassava root skin. Very low concentrations (below 1%) led to formation of lowly viscous solutions that could not form a film during the coating process. The 2.5% xanthan gum and 2.5% xanthan/guar gums led to shriveling hence it was opted that the solutions to be used had to be less than the two concentration for both solutions.

Colour

Colour is the main attribute of the cassava root that is used to determine its freshness (Ukenye *et al*., 2013). The cassava colour declines from 100 (white) to 0 (black). From this experiment, the best solutions that did not lead to a very drastic loss in colour was 1.5% and 2%guar, 1%,1.5%,2% and 2.5% xanthan and 1%,1.5% and 2% xanthan/guar gum which ranged from 80.8 in roots coated with 2.5% xanthan to 89.4 in roots coated with 1.5% xanthan/guar gum.

DAH	TREATMENTS											
	1% guar	1.5% guar	2% guar	2.5% guar	1% xanthan	1.5% xanthan	2% xanthan	2.5% xanthan	1% xanthan/ guar	1.5% xanthan/ guar	2% xanthan/ guar	2.5% xanthan/ guar
2	89.3±0.1^{a}	90.2±0.1^{ab} c	91.2±0.25^{c} d	90.6±0.5^{abc} d	89.9±0.2^{a} bc	90.6±0.1^{abc} d	91±0.2^{bcd}	89.4±0.5^{a} b	90.2±0.3^{a} bc	92.1±0.05 d	90.5±0.4a^{b} cd	89.7± 0.25^{abc}
4	87.8±0.15^{b}	90.0±0.15 c	90.3±0.60^{c}	76.4±0.45^{a}	88.0±0.14 b	90.3±0.15^{c}	90.5±0.35^{c}	87.4±0.5 b	90.0±0.5^{c}	90.9±0.15 c	90.5± 0.35^{c}	86.8±0.4^{b}
6	79.1± 0.3^{b}	89.4±0.25 e	89.0± 0.2^{e}	74.9± 0.2^{a}	87.1±0.3^{d}	89.5±0.4^{e}	86.8±0.35 d	87± 0.2^{d}	90.0±0.35 e	90.3±0.35 e	86.8± 0.35^{e}	85.1± 0.06^{c}
8	75.1±0.01^{b}	88.4±0.05 fg	88.9± 0.2^{a}	69.5± 0.3^{a}	86.7±0.25 e	89.2±0.25^{f} g	88.3±0.2^{f}	85±0.15^{d}	88.5±0.4^{f}	90.1±0.05 g	89.3±0.55^{f} g	78.3± 0.3^{b}
10	67±0.1^{b}	86.3±0.45 f	88.1±0.15^{f} gh	61.3± 0.6^{a}	84.0±0.2^{e}	87.6±0.35^{f} g	86.3±0.2^{f}	80.8±0.4 d	87.2±0.35 f	89.4±0.3^{h}	88.3±0.2^{gh}	62.1±0.45^{b}

Colour change with storage duration

Weight loss

DAH	TREATMENTS											
	1% guar	1.5% guar	2% guar	2.5% guar	1% xanthan	1.5% xanthan	2% xanthan	2.5% xanthan	1% xanthan/ guar	1.5% xanthan/ guar	2% xanthan/ guar	2.5% xanthan/ guar
2	5.1±0.2^{a}	5.5±0.2^{a}	1.91±0.04^{a}	2.02±0.03^{a}	3.52±0.34^{a}	3.0±0.06^{a}	0.41±0.06^{a}	1.63±0.11^{a}	0.59±0.08^{a}	3.03±0.04^{a}	0.23±0.05^{a}	2.65±0.25^{a}
4	12.3±0.26^{g}	7.43±0.44^{def}	2.25±0.08^{b}	5.3±0.19^{c}	8.09±0.04^{ef}	5.88±0.07^{cd}	3.2±0.5^{b}	8.41±0.26^{f}	5.4±0.26^{c}	5.6±0.36^{c}	0.66±0.09^{a}	6.55±0.35^{cde}
6	18.4±0.23^{e}	8.58±0.03^{c}	8.62±0.1^{c}	8.38±0.23^{c}	11.2±0.14^{d}	6.69±0.17^{b}	5.6±0.33^{b}	12.3±0.44^{d}	8.47±0.15^{c}	6.53±0.33^{b}	1.06±0.05^{a}	9.51±0.01^{c}
8	25.1±0.01^{g}	10.5±0.01^{d}	11.4±0.17^{c}	13.1±0.07^{d}	14.3±0.04^{e}	7.51±0.22^{b}	8.09±0.05^{b}	16.8±0.11^{f}	12.0±0.05^{d}	7.45±0.29^{b}	1.5±0.1^{a}	13.9±0.14^{d}
10	32.0±0.37^{i}	11.4±0.2^{cd}	12.2±0.21^{de}	27.8±0.21^{i}	22.3±0.21^{h}	8.71±0.02^{b}	10.5±0.3^{c}	22.1±0.05^{h}	16.2±0.19^{g}	8.68±0.05^{b}	2.14±0.05^{a}	21.7±0.15^{h}

Changes in weight loss with storage duration

The weight lost is due to loss of water from the cassava root. The higher the effectiveness of the film formed, the lower the rate of water loss hence a reduced weight lost. The least recorded weight loss at 10DAH was in the 2% xanthan/guar gum which had 2.14% while the highest weigh lost was in the 1.5% guar gum with 32.0%. The most effective coating solution with regards to reduction of weight loss was 2% xanthan/guar, 1.5% xanthan/guar and 1.5% xanthan gum at 10DAH.

Dry matter content

DAH	TREATMENTS											
	1% guar	1.5% guar	2% guar	2.5% guar	1% xanthan	1.5% xanthan	2% xanthan	2.5% xanthan	1% xanthan/ guar	1.5% xanthan/ guar	2% xanthan/ guar	2.5% xanthan/ guar
2	47.5±0.45^{d}	42.8±0.1^{b}	42.2±0.17^{a}	44.5±0.19^{c}	53.4±0.14^{e}	53.5±0.08^{e}	56.1±0.16^{f}	57.1±0.13^{f}	42.4±0.13^{b}	41.2±0.11^{a}	41.9±0.08^{ab}	44.6±0.33^{c}
4	55.2±0.2^{cd}	45.1±0.09^{a}	54.2±0.3^{c}	55.2±0.06^{cd}	54.2±0.38^{c}	56.4±0.25^{d}	61.7±0.13^{e}	61.7±0.53^{e}	56.5±0.4^{d}	54.5±0.47^{c}	44.1±0.09^{a}	51.2±0.18^{b}
6	71.0±0.08^{h}	46.3±0.06^{a}	57.4±0.17^{d}	65.2±0.16^{f}	55.2±0.11^{bc}	56.3±0.34^{bcd}	65.1±0.17^{f}	61.4±0.27^{e}	69.2±0.17^{g}	56.5±0.09^{cd}	55.0±0.52^{b}	57.9±0.01^{d}
8	73.3±0.01^{f}	47.7±0.01^{b}	59.1±0.17^{g}	77.1±0.06^{g}	58.9±0.2^{ab}	57.6±0.1^{a}	72.8±0.13^{ef}	71.0±0.3^{d}	71.5±0.52^{de}	57.7±0.53^{ab}	58.6±0.07^{ab}	63.8±0.32^{c}
10	78.0±0.13^{e}	57.1±0.05^{a}	60.1±0.07^{b}	80.1±0.5^{f}	60.6±0.25^{c}	58.2±0.19^{ab}	79.0±0.91^{ef}	71.4±0.11^{d}	72.0±0.18^{d}	60.5±0.22^{c}	60.5±0.3^{c}	77.7±0.42^{e}

Changes in dry matter content with storage duration

Dry matter content is positively correlated to the loss of flesh colour and therefore also positively correlated to the PPD occurrence. A higher rate of production of the dry matter content will mean that the film formed is not very efficient. The treatments with the least dry matter content at 10DAH included 1.5% guar with 57.1% DMC, 1.5% xanthan with 58.2% DMC, 2% guar with 60.1%, 1.5% and 2% xanthan/guar both with 60.5% DMC and 1% xanthan with 60.6% DMC.

Firmness

DAH	TREATMENTS											
	1% guar	1.5% guar	2% guar	2.5% guar	1% xanthan	1.5% xanthan	2% xanthan	2.5% xanthan	1% xanthan/ guar	1.5% xanthan/ guar	2% xanthan/ guar	2.5% xanthan/ guar
2	70.5±0.3^{a}	78.1±0.15^{c}	71.0±0.2^{a}	71.1±0.85^{a}	73.7±0.45^{b}	89.7±0.25^{e}	71.0±0.15^{a}	77.6±0.4^{c}	78.0±0.06^{c}	75.0±0.03^{b}	74.2±0.25^{b}	86.2±0.2^{d}
4	83.6±0.2^{def}	82.8±0.65^{cde}	74.2±0.26^{a}	81.0±0.5^{c}	78.1±0.2^{b}	84.9±0.2^{f}	85.4±0.45^{f}	84.4±0.5^{ef}	81.1±0.01^{c}	82.1±0.09^{c} d	75.3±0.2^{a}	92.4±0.55 g
6	84.1±0.3^{bc} de	87.3±0.35^{ef}	76.1±0.2 a	82.1±0.38^{bc}	8.2±0.75 b	90.7±0.2 g	87.3±0.55^{ef}	85.0±0.15 cde	83.5±0.4^{b} cd	86.4±0.03 def	82.4±1.5^{b} c	89.1±0.05^{f} g
8	73.4±0.04^{a}	88.5±0.01^{b}	78.2±0.15^{h}	95.4±0.3^{h}	82.2±0.4 c	90.9±0.15^{g}	88.3±0.35^{ef}	91.6±0.15 g	86.9±0.44 e	89.2±0.08^{f}	84.5±0.34^{d}	81.4±0.15^{c}
10	68.1±0.25^{a}	90.0±0.3^{g}	83.1±0.3 d	87.1±0.2^{e}	78.2±0.25^{c}	95.4±0.3 h	89.0±0.15^{fg}	84.2±0.35 d	87.6±0.36 ef	96.1±0.13 h	87.6±0.36^{ef}	70.3±0.55 b

Changes in firmness with storage duration

The flesh firmness of the cassava root had an initial increase triggered by the loss of water, followed by a decline which is said to be triggered by a decrease in pH which then triggers the activity of some endogenous enzymes. The film formed after coating leads to reduction in water loss which translates to a lower rate of the increase in firmness. This was exhibited by the 1.5% and 2% guar, and 1.5% and 2% xanthan and the 1%, 1.5% and 2% xanthan guar gum. For the other coating solutions, they had already reached their peak and had the decline in firmness caused due to enzyme activity and leading to loss of flesh integrity.