

**PARBOILING AND SOAKING OF CASSAVA TO REDUCE CYANIDE CONTENTS OF
CRISPS**

BY

CAROLYNE KALIMI KAKWU (B.Sc. Nairobi)

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2018

DECLARATION

I, Carolyne Kalimi Kakwu hereby declare that this dissertation is my original work and to the best of my knowledge has not been presented for an award in any other institution.

.....
Carolyne Kalimi Kakwu

.....
Date

This dissertation has been submitted for examination with our approval as University Supervisors.

.....
PROF. J.K. IMUNGI (PhD)
Department of Food Science, Nutrition, and Technology
University of Nairobi.

.....
Date

.....
DR. W.M. MUIRU (PhD)
Department of Plant Science and Crop Protection,
University of Nairobi.

.....
Date

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DEDICATION

I dedicate this dissertation to my beloved parents, Pastor Stephen Kakwu Musili and Mrs. Bibiana Kisuu Stephen, who always picked me up on time and encouraged me to go on every adventure, especially this one. This is for you.

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ACRONYMS AND ABBREVIATIONS

FAO- Food and Agriculture Organization

FAOSTAT – Food and Agriculture Organization Corporate database

HCN – Hydrogen Cyanide

KARI – Kenya Agricultural Research Institute now known as KALRO

KALRO – Kenya Agricultural & Livestock Research Organization formerly KARI

WAD – Weak Acid Dissociable Cyanide

OPERATIONAL DEFINITIONS

Acute toxicity: Adverse effects of a substance that result either from a single exposure or from multiple exposures in a short period of time

Chronic toxicity: development of adverse effects as a result of long-term exposure to a toxicant

Cyanide: chemical compound that contains the cyano group

Goitrogens: substances that disrupt the production of thyroid hormones by interfering with iodine uptake in the thyroid gland

Preprocessing: preliminary to processing

ABSTRACT

Cassava (*Manihot esculenta Crantz*) crisps have become an increasingly popular snack in urban Kenya. Processing is however mainly confined informal on the streets, although recently a few small-medium enterprises have been established especially in Nairobi. Recent studies have indicated that the crisps traded in Kenya have cyanide levels exceeding the statutory limits of 10mg/kg. Both boiling and soaking have been found to reduce cyanide levels in cassava though not to the allowed statutory levels. This study therefore was designed to evaluate the physico-chemical characteristics of market cassava crisps, assess the effect of parboiling and retting (soaking) of cassava on the cyanide, oil, and moisture contents of the crisps

For characterization of the physico- chemical characteristics of market cassava crisps, samples were collected from street vendors and supermarkets in Nairobi and Mombasa. These were analyzed for cyanide, moisture, and oil contents. All the samples had cyanide contents exceeding the statutory limits. The oil and moisture contents in majority of the samples exceeding the statutory limits.

For parboiling and soaking studies, samples of fresh cassava roots, not more than 24 hours since harvesting, were collected from three markets in Nairobi namely; Parklands, City Market, and Wakulima Market. These are the main markets where most processors purchase the roots. Each market was sampled three times within intervals of two weeks. The samples were transported transported to the laboratories of the Department of Food Science, Nutrition, and Technology within two hours and stored overnight at 4°C to await processing the next day. For processing, the roots were peeled, washed, and cut into approximately 10cm long pieces. The pieces were then randomized and divided into 7 batches, four for the parboiling and three for the soaking treatments.

For the parboiling treatment, the cassava were boiled while submerged in water for 0, 10, 20, and 30 minutes, followed by rapid cooling in running tap water. The pieces from each treatment were sliced to 1mm thickness and deep-fried in corn oil (Elianto, Bidco oils Ltd, Nairobi) at 170⁰C until light golden brown in color. For the soaking treatment, the cassava chunks were soaked submerged in water for 0, 1, and 2 days. The cassava were then sliced into 1mm thick crisps and deep-fried the same way as for the boiling experiment. The cassava chunks from both experiments were analyzed for moisture and cyanide. The crisp were analyzed for moisture, oil, and cyanide. The crisps were also subjected to sensory testing shelf life evaluations. Results showed that parboiling alone up to 30 minutes did not reduce cyanide levels to the statutory limit, the cyanide range was 5.40 to 5.94mg/kg. Boiling for 20 and 30 minutes resulted in crisp with cyanide contents below the statutory limits for all samples. At $p < 0.05$, the cyanide contents were significantly different. The moisture and oil contents were within the statutory limits and were not significantly different among the different boiling times at $p < 0.05$. Boiling for 30 minutes yielded significantly the lowest cyanide contents. Boiling for 20 minutes produced the most preferred crisps especially in terms of color and taste. The market effect on parboiled cassava and the crisps characteristics was not significant.

Soaking alone for up to two days was not sufficient to reduce cyanide in cassava chunks to levels within the statutory limits. The chunks soaked for 2 days had an average cyanide content of 17.28mg/kg. The 2-day soaking however, resulted in crisps with cyanide contents below the statutory limits in all samples. The average cyanide content in the crisps was 8.23mg/kg. At $p < 0.05$, the cyanide contents were significantly different among the different soaking durations. The moisture and oil contents remained within the statutory limits and were not significantly different among the different soaking times. Soaking for two days yielded the most acceptable

crisps in terms of color and taste. The market effect on soaked cassava and the crisps characteristics was not significant.

All the crisps from both parboiling and soaking experiments could be stored at room temperature (approximately 25⁰C) for up to ten months without detectable changes in eating quality.

The study concludes that parboiling cassava for 20 minutes and soaking for 2 days can effect production of acceptable and shelf stable crisps with cyanide contents below the statutory limit of 10mg/kg. The moisture and the oil contents of the crisps also remain within the statutory limits.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND INFORMATION

Cassava (*Manihot esculenta crantz*) locally known as *muhogo* (Swahili), yucca or tapioca in South America and manioc in Latin America is a woody shrub, native to South America, specifically Brazil (Allem, 1994). It belongs to the euphorbacea family and it is the only edible member of the *Manihot* genus (Gleado et al, 2009). It is extensively cultivated in the tropics and sub-tropics of Asia, Africa, and South America. Many cultivars of the plant have been developed to suit the climate of the region and for improved productivity. The plant was introduced to Africa in the 16th century by the Portuguese traders (O’Hair, 1995, Jarvis et al, 2012). The cassava starchy root is mainly utilized as food (Cock, 1982) the leaves are eaten as a vegetable in some regions, by preparation in various ways (Latif and Muller, 2015).

The cassava root as described by Belloti et al, (2012) is long and conical, with a firm, homogenous flesh enclosed in a detachable rind, which is usually about 1mm thick. The flesh is chalk white or yellowish depending on the variety and the coat also known as the peel is uneven, coarse, and brown on the outside. In the middle of the root is a woody cordon that runs along the entire axis. According to New World Encyclopedia, (2008), roots of commercial varieties can be 5 to 10 cm in diameter at the top, and around 5cm to 30cm long.

Cassava is a resilient crop capable of growing on marginal lands with poor soils, where other crops would perform dismally with little or no yields (El- Sharkawy, 2003), hence popularly known as the “drought” crop in the developing world. The crop is easily propagated, requiring very few agronomical practices and is drought tolerant. The plant is also tolerant to pests as reported by (Githunguri et al., 1998).

Harvesting can be delayed whereby the stems are cut off and the roots left underground. The roots can stay in this condition for up to 24 months with some varieties capable of staying for even up to 36 months (Iglesias et al, 1997). Through delayed harvesting the farmers are able to wait until market, processing or other conditions are favorable. All these factors make the cassava a very suitable crop for arid and semi- arid areas where soils are poor, the rains are scarce and unpredictable and there are many crop pests and the use of fertilizer is prohibitive due to the costs and the labour is scarce (El-Sharkawy, 2003).

According to Burns et al (2012), cassava varieties occur as bitter or sweet differentiated by the levels of cyanide which occurs in both the roots and leaves as N-glycosides, the cyanogenetic glycosides. Two cyanogenic glycosides exist in cassava, the major one linamarin at approximately 95% and small quantities of a minor one loataustralin at 5% (Burns et al, 2012). Cyanogenetic glycosides are hydrolyzed by chemicals or enzymes to yield hydrogen cyanide (HCN), a volatile and extremely toxic compound (Yeoh and Sun, 2001). The hydrolyzing enzyme for the two cyanogenetic glycosides in cassava, linamarase, coexists with its substrate in the plant. Cassava varieties are classified on the basis of the cyanide content. The bitter varieties have cyanide levels of up to 400mg/kg while the sweet varieties contain less than 50mg/kg (FAO, 1991). Bitter varieties usually yield more, however they contain a higher content of cyanogenic glycosides as compared to the lesser yielding sweet cultivars (Cock 1982). According to Ayanru and Sharma (1984), bitterness to the taste is associated with high levels of cyanide. Natural stress factors such as prolonged drought, pest infestations and low levels of potassium and phosphorous have also been implicated in causing bitterness in cassava, which coincides with increased levels of hydrogen cyanide.

Cassava is one of the most important and major staples in the developing world where it provides a basic diet for over half a billion people in these countries (FAO, 2010). It is prepared for consumption using various methods, these methods vary from one region to another and also from country to country.

In Kenya, the most common way of preparing cassava for consumption is by peeling, cutting, splitting, and coring, the chunks are consequently boiled and consumed as whole or mashed. The chunks can be eaten with or without side dish, but the mash is usually eaten with side dish of meat/vegetables. Cassava is also usually dried and milled into flour, which then can be used for preparation of *ugali* (stiff porridge) alone or in admixture with maize or sorghum and millet flours. Cassava is also industrially processed into starch for use either in cooking or in the industry. Recently also cassava is processed into crisps, which are becoming popular snack especially in the urban areas (Abong' et al., 2016).

The biggest challenge in consumption of cassava is the occurrence hydrogen cyanide which is toxic to humans (Burns et al, 2012). Consumption of cassava with high levels of HCN has been implicated in severe cases of cassava poisoning in Kenya, some of which have been fatal (Imungi et al, 1987). Before consumption the cyanogenic glucosides must be reduced to safe levels to avoid dietary cyanide exposure (Cooke, 1983). Efforts have been put in place to sensitize and train local communities on reduction of cyanide in cassava during preparation. However, reduction of these compounds to safe levels has not been achieved in most of the cases.

Cassava crisps are gaining popularity especially in the urban centers where demand for ready to eat food is usually high. People eat cassava crisps alongside the commonly consumed potato crisps. However in Kenya, during the cassava processing into crisps there is very little evidence that pre-processing cyanide management is carried out to reduce the levels to the tolerance level of 10mg/kg or below, the consumer may therefore be exposed to levels of cyanide above the

maximum recommended. This poses a public health risk. According to a study by Abong' et al, (2016), the cassava crisps sold in Nairobi and Mombasa were found to contain cyanide levels above the minimum safe levels of 10mg/kg. Of all the samples collected from Nairobi and Mombasa towns of Kenya, which are the two largest towns in the country, none of the samples were found to have cyanide content of 10mg/kg or less.

1.2 PROBLEM STATEMENT

Cassava crisps are becoming increasingly popular snack in Kenya and more people are consuming them by the day. The cyanide content in processed cassava crisps in Kenya has been found to be above the recommended maximum levels of 10mg/kg according to Abong' et al, (2016). This is probably because there is little preprocessing cyanide management to reduce the levels in the final product. Continued consumption of sub-lethal cyanide doses exposes the public to dangers of chronic cyanide toxicity and sometimes even acute toxicity especially when the levels of cyanide in the raw material are high, and especially large amounts of the crisps are consumed by an individual (Teles,2000). It has also been reported by Nhassico et al., (2008) that when processed insufficiently, cassava may cause acute intoxication. Sub - acute chronic exposure has also been associated with tropical ataxic neuropathy which is described by Osuntokun (1981) as a paralytic disease with slow onset. It has also been demonstrated that consumption of moderate levels of cyanide may precipitate goiter according to Abuye et al., (1998). This is due to the fact that detoxification of cyanide in the body produces thiocyanate, a goitrogenic compound which competes with iodine and affects the normal functioning of the thyroid gland and subsequently aggravating the severity of the symptoms of iodine deficiency (Delange et al., 1994).

1.3 JUSTIFICATION

There is dire need for information on management of cyanide to help reduce the toxin in processed crisps, to make them safer and healthier for the consuming public. This information will be useful to the processors and the Government to help process crisps which conform to the official regulatory tolerances with regard to cyanide content. This will instill confidence in the public that cassava crisps are safe to consume and will create market for the cassava farmers to increase production, earn more revenue and reduce poverty in the rural areas.

The cyanide management methods could also be adopted in processing of other cassava products such as dried slices, chips and their milled products flour to ensure that all these products have safe limits of cyanide as prescribed by law.

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1.4 OBJECTIVES

1.4.1 Main objective

To develop cassava crisps through pre-processing methods of parboiling and soaking with view to lowering the cyanide contents to safe levels, while at the same time maintaining the physico-chemical quality of the crisps

1.4.2 Specific objectives

1. To determine physico-chemical characteristics of market cassava crisps
2. To determine the physico-chemical characteristics (moisture, oil content and cyanide content) of cassava crisps processed through parboiling and soaking of cassava chunks
3. Sensory evaluation of cassava crisps.
4. Shelf-life evaluation of cassava crisps.

1.4.3 Hypothesis

H_0 = Cyanide content in cassava crisps can be effectively reduced to safe levels through parboiling and soaking.

CHAPTER TWO: LITERATURE REVIEW

2.1 CASSAVA: OVERVIEW

Cassava, (*Manihot esculenta Crantz*), is a perennial woody shrub grown mainly for its root, which is utilized as food. In some regions of the world the leaves are macerated and consumed as a vegetable, alongside with the cassava root or another type of starch. The cassava plant is mainly grown in the tropical and sub-tropical areas of the world (Allem, 1994). This can be attributed to the fact that the crop can tolerate drought and unfavorable ecological conditions which are more often associated with the tropical and subtropical climates (Nweke et al, 2002). Owing to these facts, cassava is also known as the drought crop in the developing world. The crop also offers a lot of advantages to the farmers in that it can grow in poor soils that other crops cannot perform well, it is easily propagated and requires few agronomical practices, and this translates to reduced cost of production (Osuntokun, 1981).

According to a report by FAO (2010), cassava is the third most important source of calories in the tropics, producing a source of calories to over half a billion people. It is the 6th most produced crop after sugarcane, maize, rice, wheat, and potato according to FAOSTAT (2010) data on global annual production statistics of food crops.

The most important use of cassava is utilization for food. The vast of Africa and Latin America populations utilize cassava as human food. In Africa, where food security is still a pertinent problem, the cassava provides a basic daily source of dietary energy, (Amusa et al, 2003). The roots are consumed freshly raw or boiled. They are also processed into an array of products in form of granules, pastes and flours depending on the region to mainly prolong the shelf life and product diversity (Achacha, 2001). In Africa, the leaves also form an important part of the diet,

where they are macerated and consumed as a green vegetable, providing a source of protein and vitamins A and B (Tewe and Lutaladio, 2004).

Cassava has also been used largely in the production of animal feed especially in Asia and parts of Latin America, where the cassava is made into pellets, which are utilized as animal feed (Nang'ayo et al 2005). Cassava is also used largely in production of starch, which is utilized in many industries both food and non- food. (Aryee et al, 2006).

Cassava plays a major role in efforts to alleviate the African food crisis because of its efficient production of food energy, year-round availability, tolerance to extreme stress conditions, and suitability to present farming and food systems as reported by Topouzis (2003). Cassava plays a particularly important role in agriculture in developing countries, especially in sub-Saharan Africa, because it does well on poor soils and with low rainfall, and because it is a perennial that can be harvested as required. Its wide harvesting window allows it to act as a famine reserve. It also offers flexibility to resource for poor farmers because it serves as either a subsistence or a cash crop (Githunguri et al, 2008). Through its utilization to produce cassava starch, the cassava plant has taken on an economic role where it is not only used as a food crop. This is largely so in South East Asia and Latin America. In Thailand, cassava is processed into dried pellets for use as animal feed and into starch, which is majorly exported to China (Howeler, 2006). The starch from the cassava has found use in many industries across the board both food and non-food industries. In the food industries, cassava starch is used as a stabilizer and thickener, in foods such as yoghurt, soups, and ice cream. Cassava starch is also used in production of monosodium glutamate, an important flavor potentiator used widely in Asian cuisine (Breuninger, 2009). In the non-food industries, cassava starch is majorly used as a binding agent and in production of paper and textiles. (Ukwuru et al, 2013).

In Africa, cassava is being used in partial substitution for wheat flour or full substitution for people who have gluten allergy or for people who want to omit gluten from their diets. This type of flour is earning cassava a place in the lucrative export market from Africa to the developed world, where there is a high demand for gluten free flour (Unpublished report, 2015). In Kenya, cassava is used mainly as dry flour, either singly or in admixture with maize flour for preparation of ugali a major local dish. In its big four agenda, of which one is food security, the government of Kenya is pushing for the agenda of blending flours. This will ease the pressure on overdependence of maize meal and improve overall nutrition of the populations. Cassava flour is one of the flours which will be used for making the blend. This will stimulate the production of cassava in the country. (Unpublished proceeds from the flour blending conference held in Naivasha, Kenya between 16th and 18th July, 2018). In the local open- air markets, cassava flour is sold by vendors where the flour is mixed into a composite with millet and sorghum according to the customer's desired proportions. In other instances cassava is merely boiled in water and eaten with a stew or meat accompaniment. Other forms of preparation include roasting and stewing. In Kenya, roasting is also done along the roadside especially in the low-income suburbs and areas with high populations of Indian communities such as Parklands where consumers mainly buy the cassava as a snack.

2.2 CASSAVA PRODUCTION STATISTICS: GLOBAL PERSPECTIVE

According to FAO estimates for the year 2015, the world cassava production was 277 million tons. Of these 51% was produced in Africa, making it the leading continent in terms of cassava production. Asia produced 31% while Latin America and the Caribbean accounted for 8% of the global production. The world's largest producer was Nigeria which produced a total of 52 million tons.

In Africa, cassava growing is not dedicated to plantations, instead the crop is mostly grown on small farms, where it is intercropped alongside other crops such as maize, vegetables, groundnuts and other legumes (Mlingi et al, 1994). In the Eastern parts of Kenya, cassava is also grown on terraces made in the farm to control soil erosion. Among the small-scale farmers in Africa, fertilizer use is very scarce and limited due to the high costs and unavailability. The roots are usually harvested between six months and three years after planting, the harvesting is highly dependent on factors such as market forces and the availability of other food crops, especially in areas where cassava is grown as a reserve crop. According to a report by FAOSTAT, 2000, the average yield of cassava per hectare is 10.2 tons, the lowest yields were recorded in South Sudan at 1.8 tons per hectare, while Barbados recorded the highest yields at 27.3 tons per hectare.

2.3 CASSAVA PRODUCTION IN KENYA

In Kenya, cassava growing is largely subsistence (Njeru and Munga, 2003). This is because cassava has only been grown as a reserve food crop and it is utilized when other crops have failed. However in the recent times there has been a shift and more cassava consumption has been recorded. The country has an annual production of about 540,000 tons (Githunguri et al., 2008). The total area under cassava in the country is over 90,000 ha.

The main cassava producing regions in the country are; Eastern, Western and Coastal areas (Kimathi et al, 2007). The Western region is the leading producer, producing around 60% of the countries' total production (MoA, 2008). The Eastern and Coastal regions produce 30% and 10% of the national annual production respectively. However the cassava production in Kenya is still below potential according to a study by Gethi et al, (2008). Lusweti et al (1997) attributes this below potential production to Cassava Mosaic Disease and also the presence of high levels of cyanogenic glycosides. Due to the challenges of safely detoxifying the high cyanide cassava

varieties, people opt for the lower yielding sweet varieties (Munga, 2000). The Coastal Kenya has the potential to produce 50-70 t/ha but the current yield stands at 10 tons/ha.

2.4 CASSAVA NUTRITION

Cassava roots are very rich in starch. In terms of carbohydrate yields per cultivated area, cassava is the leading crop, only surpassed by sugarcane and sugar beets (Stephenson et al, 2010). When compared to other staple food crops such as rice, corn, and wheat, cassava is a highly productive crop producing most calories per unit area per unit time at rates exceeding 250,000 calories/hectare/day (Heuberger, 2005). The cassava root is poor in protein (Chijindu and Boateng, 2008), with crude protein content of about 1-2%, however the leaves are a good source of protein, which is rich in lysine, an essential amino acid. The protein is however deficient in methionine and tryptophan. The starch content varies from about 21-31%, and the moisture content is 60-65%. The content of other vitamins and minerals is also quite low, however the roots have significant amounts of calcium, vitamin C, thiamine, nicotinic acid, and riboflavin. The cassava starch is made up of mainly of the highly branched, amylopectin at 70%, while the straight chain amylose makes up 20% of the starch. The cooked starch has a good digestibility, estimated to be over 75%.

The protein found in the cassava roots, despite of being in very low quantities is of fairly good quality due to the presence of essential amino acids according to Sayre et al, (2011). The only limiting essential amino acids are methionine and cysteine as reported by Gil and Buitrago, (2002). A complete balanced meal can be obtained from combining cassava roots and leaves with another food that contains sulphur amino acids. In Africa, Latin, and South America, a cassava meal is most commonly accompanied by a side dish of beans.

2.5 CASSAVA PROCESSING

Cassava is a highly perishable root as reported by Reilly et al, (2004), hence after harvesting the root should get to the market without delay or alternatively be processed to a shelf – stable product. The cassava roots rot within 3-4 days after harvest (Diasolua et al., 2003). The presence of cyanogenic glycosides in form of linamarin and loataustralin in the cassava is also an important aspect of cassava processing. The processing methods employed seek to reduce the level of these glycosides in the cassava, because once in the body they are hydrolyzed to hydrocyanic acid, which is a highly toxic compound to both humans and animals as reported by Wobeto et al, (2007). Processing methods to reduce cyanide content in cassava roots and leaves exist and are documented. However these methods are not controlled. Processing therefore serves the dual purpose of reducing food losses and reducing the cyanide content hence making the root safer for consumption. Some of these methods that are widely used include soaking the roots in water, drying, (both sun and oven drying) and boiling/cooking and fermentation. The effectiveness of cyanide removal varies from method to method. Different methods are used depending on the product and convenience of use.

Improperly processed cassava leads to production of unsafe food that has high levels of cyanogenic glycosides which are converted to hydrocyanic acid once in the body (Cressey et al, 2013). Hydrocyanic acid commonly known as cyanide is highly toxic. The toxicity of hydrocyanic acid is associated with the ability of the acid to link up with metal ions such as those of iron, manganese, and copper. These metal ions form the functional groups of many enzymes in the body. The enzymes are involved in biochemical processes which are impaired when the enzymes are inactivated (Dreveny et al, 2002). Consumption of improperly processed cassava foods is a pertinent issue in Africa where it has been associated with a myriad of health disorders. The disorders are more rampant among the already malnourished groups and more pronounced in

populations whose basic diets contain little or no protein. This correlation is attributable to the fact that cyanide detoxification in the body is aided by the sulphur containing amino acids, methionine and cysteine (Nzwalo & Cliff, 2011). These amino acids are essential and thus must be obtained from the diet, thus people whose diet has little or no protein lack these essential amino acids to detoxify cyanide off their systems leading to cyanide poisoning.

2.6 CYANIDE IN CASSAVA AND CYANOGENESIS

2.6.1 Cassava Toxicity and Cyanogenesis

In cassava, the hydrocyanogens and enzyme linamarase are differentially compartmentalized (White et al., 1994). According to Mkpog, (1994), the hydrocyanogens are stored in the cytoplasmic vacuoles which are found inside the cytoplasm while the enzyme is located in the cell wall outside the cytoplasm. When a cassava tissue is ruptured, the linamarase enzyme is released from its compartments. The enzyme then hydrolyses the cyanogenic glycosides to cyanohydrins and glucose. Cyanohydrins are very unstable compounds and thus they break down to form hydrogen cyanide which is a stable compound (Con 1973; Cooke 1978). This process is known as cyanogenetic. The last step in cyanogenesis is the conversion of acetone cyanohydrin to cyanide and acetone. The process is spontaneous at pH greater than 5 and temperatures above 30⁰C (White et al, 1994). It is an enzymatic process catalysed by hydroxynitrile lyase (McMahon et al, 1995).

Cyanide is acutely and chronically toxic to humans according to a study by Montagnac et al, (2008). Hydrogen cyanide can enter the body through, inhalation, ingestion, or absorption through the eyes and skin. The toxicity is dependent on the nature of exposure. Once in the body the HCN is converted to cyanide.

The cyanogenic potential in cassava is due to two cyanogenic glucosides, Linamarin, and loataustralin (Kakes, 1990). These, on hydrolysis, release hydrogen cyanide (HCN). The presence

of cyanide in cassava is of concern for human and for animal consumption. The occurrence of cyanogenic glucosides in plants is a mechanism of self-defense from herbivores, pathogens and competitors (Vetter, 2000). The concentration of the two glycosides in cassava varies considerably between varieties, and is also influenced by climatic conditions (Rosling, 1987).

During cassava processing, the enzyme linamarase hydrolyses the two cyanogenic glycosides to produce hydrocyanic acid, which is a volatile compound and thus volatilizes into the air (Tylleskar et al, 2002). This reduces the cyanogen content in the processed food to acceptable limits in most cases. However shortcut routes are often employed and these do not sufficiently lower the cyanide level to safe limits (Kakes, 1990). According to Sayre, (2000), the United Nations' Food and Agriculture Organization has established maximum recommended levels in cassava food products to be at 10mg/kg. Levels above this limit have been indicated to be injurious to human health. The Kenya Bureau of standards have also used the United Nations' limit as the safe limit for cyanide content in cassava foods and products in Kenya.

2.6.1.1 Acute Toxicity

This results from ingestion of large amounts of cyanogenic glycosides in cassava, which once in the body are hydrolyzed to HCN. The cyanide inhibits the enzyme cytochrome oxidase by binding to the ferric ion, this affects cellular respiration (Baskin et al, 2004). The acute lethal dose for hydrogen cyanide is reported to be 0.35- 0.5 mg/kg body weight according to Jones, (1998). This puts children at a higher risk of poisoning due to their weight. According to Johnson and Mellers (1988), the most common signs of acute cyanide poisoning are, rapid breathing, headache, rapid pulse accompanied by a drop in blood pressure, lack of motor coordination leading to twitching and convulsions, vomiting, mental confusion and coma may occur in severe cases of poisoning (Essers et al, 1992). Acute poisoning has caused many deaths in Kenya as reported by (Imungi,

1987). Severe cases of acute cassava poisoning have been reported in the Eastern, particularly Ukambani region, Western and Coastal parts of the country. However, (Teles, 2002), reports that cases of acute toxicity are not very frequent. This might be attributed to the fact that over time communities have acquired indigenous knowledge that enables them to identify cassava varieties which have high cyanide content and subsequently methods of detoxifying the cassava. However detoxification methods do not always reduce the cyanide to safe levels therefore there is always a risk of chronic toxicity associated with improperly processed cassava (Oluwole et al, 2000).

2.6.1.2 Chronic Toxicity

Chronic toxicity results from exposure to sub-lethal cyanide doses over a period of time. It mostly occurs among populations that consume bitter cassava heavily (Osuntokun, 1994). According to Nhassico et al (2008), chronic toxicity is well documented in cassava-consuming countries. Processing methods do not sufficiently reduce the cyanide to safe levels, thus exposing the consumer (Oluwole et al, 2000). Chronic toxicity has been linked to several health conditions among them, exacerbation of the manifestations of iodine deficiency syndromes, chiefly goiter and a rare form of cretinism known as myxedematous cretinism (Delange et al,1994), tropical ataxic neuropathy (TAN) and konzo (Ernesto et al 2002,a,b.). Osuntokun (1994) described TAN as a neurological disorder that damages the nerves affecting steadiness and coordination. Konzo also known as spastic paraparesis is described by Ernesto et al, (2002) as an irreversible paralytic disorder that affects the limbs and more so the legs more than the arms. It causes irreversible paralysis of the legs. The disease occurs mainly in children and young women of reproductive age (Howlett et al, 1990). This is highly attributed to the high nutritional demands of these two vulnerable groups. Konzo has been found to affect populations that consume bitter cassava diet which is deficient of proteins, especially the sulfur containing amino acids methionine and cystine (Banea et al, 2013). Myxedematous cretinism is a severe kind of cretinism endemic in Central

Africa, especially Zaire (Delange, 1994). It is characterised by dwarfism, acute hypothyroidism, mental retardation and a myriad of other developmental abnormalities (Stephenson et al, 2010).

2.6.2 Cyanide Detoxification in the Human Body

As reported by Sarlkowski and Penney (1994), small amounts of cyanide in the body are safely detoxified. In mammalian systems, cyanide metabolism is effected through one major metabolic pathway and a few other minor pathways. The major detoxification route is through the liver. The process is catalyzed by liver enzyme rhodanese (Rosling et al, 1994). The enzyme catalyzes the transfer of the sulfane sulfur of thiosulfate to the unbound cyanide ions. This results to the formation of thiosulfate (Aminlari et al, 2007). The thiocyanate is excreted in the urine and is relatively harmless (Sarlkowski and Penney, 1994). This route of detoxification accounts for 80% of cyanide detoxification in the body and the limiting factor is the thiocyanate (Cliff et al, 1985). Other sulfur transferases metabolize cyanide to a small extent e.g. albumin.

In excess in the body, the detoxification mechanism is overwhelmed due to depletion of sulfur Cliff et al, (1999). This completely blocks cellular respiration leading to manifestation of symptoms of acute cyanide poisoning which may eventually cause death (Baskin et al, 2004).The lethal dose for an adult is 50-100mg/kg.

2.7 MANAGEMENT OF CYANIDE IN CASSAVA DURING PROCESSING

Many processing methods do not reduce cyanide in cassava foods to acceptable levels, the levels are still sub-lethal and expose consumers to effects of chronic toxicity. Cassava is prepared and consumed as food in several ways. The most basic way of cassava preparation involves boiling the cassava and consuming it as whole or mashed. The boiling time depends on variety and age. After boiling the cassava may be eaten, or it may be cut into long chunks and deep-fried. This method of preparation is however limited to sweet cassava, because if bitter cassava is used the cyanide

levels are not effectively lowered and this poses a risk of cyanide poisoning. During cassava processing, attempts are made to reduce the cyanide content in the bitter cassava. Some cyanide management methods that have been used to achieve lower cyanide content in cassava foods include but not limited to soaking in water, boiling of the cassava, fermentation and gritting. (Vanscoceles, 1990; Dufuor, 1994)

2.7.1 Boiling

Boiling has been used as a method of cyanide reduction in cassava but studies have shown that it is not a very effective method (Montagnac, 2009). This is because of the high temperature (100⁰C) used in boiling. The high temperatures denature the linamarase enzyme which hydrolyses linamarin to cyanohydrins. Boiling 50g of cassava for 25 minutes has been reported to reduce cyanide content up to 50% (Nambisan, 1994), this level of reduction does not reduce cyanide to safe levels in bitter cassava varieties.

The effectiveness of boiling however can be further improved by using smaller pieces of cassava and increasing the volume of the boiling water (Oke, 1994). A study by Nambisan et al, (1994) demonstrated that by reducing the cassava size from 50g to 2g the cyanide retention was effectively reduced from 75% to 25% after boiling for 30 minutes. Increasing the water volume from one fold to five -fold also reduced the retention from 70% to 24%.

2.7.2 Soaking and Retting

Both processes involve soaking of cassava in water, however in retting cassava is soaked for prolonged periods of time (Montagnac et al, 2012). The extended soaking in retting results in tissue breakdown, there is also some degree of fermentation. All these activities result in reduction in total cyanide. Retting is an age-old tradition in Africa where bitter cassava roots were soaked in water ponds to detoxify them.

Soaking on the other hand is done for a shorter time. Studies have shown that soaking leaches out the soluble glucosides. Bourdoux et al, (2012) in his study reported that soaking cassava for one day reduced cyanide from 108mg/kg to 59.5mg/kg. Increasing the soaking time to 5 days further reduced the cyanide to 5.9mg/kg. From the studies we can therefore deduce that soaking is an effective method to manage cyanide in cassava foods. However there is no evidence to show that the process has been used to manage cyanide in the processing of cassava crisps, hence there is need to do further research to establish whether this method can be used to reduce cyanide during processing of cassava crisps without adversely affecting the quality of the crisps.

2.7.3 Grating and Crushing

This is a size reduction process that involves grating or crushing of the cassava roots. Grating completely ruptures the cassava cells. This results into direct contact between the linamarin and enzyme linamarase thus hydrolysis of the linamarin, resulting into reduced cyanide content in the final food product (Oke, 1994). However, grating is limited to foods that are further ground into flour or mashed and thus cannot be used as a cyanide reduction method in the processing of cassava crisps.

2.7.4 Fermentation

Fermentation has been used as a method to reduce cyanide mostly in Africa and more specifically in West Africa where there are variety of cassava foods prepared from fermented cassava. The cassava can be fermented in chunks or grated, and the fermentation can in be in water or dry fermentation though wet fermentation is more commonly utilized. The fermentation is a spontaneous lactic acid fermentation and microorganisms that are responsible for the fermentation process have been isolated. Fermentation can be short time for a day or for prolonged periods of time. A study by Blanshard et al, 1994 shows that fermentation is an effective method for cyanide reduction in cassava. In the study, cassava roots were fermented by soaking in water at 30⁰C for

48 hours. This resulted in 84% removal of total cyanogens. According to Bokanga et al, (1990), this reduction in total cyanogens during fermentation can be attributed to the softening of the roots due to microbial activity thus increased linamarin hydrolysis by linamarase and microbial α -glucosidases. The microorganisms also take up free cyanide. However fermentation leads to a drop in pH and thus may alter linamarase activity which is inhibited at pH 4 and below.

2.7.5 Cyanide Management in Cassava Crisps Processing

These are another product of cassava processing that has seen tremendous growth in recent times, especially due to urbanization. In cassava crisps processing, the roots are peeled and washed, and this is followed by slicing and frying in hot oil. The crisps are then cooled and packed (Abong et al, 2012). During the processing of cassava crisps, the processing methods do not reduce cyanide levels to the maximum set limit of 10mg/kg. There is no sufficient evidence to show that there are steps which have been designed to reduce cyanide in cassava crisps to the tolerable limits, there is therefore need to investigate a method for reducing cyanide in cassava crisps to safe levels to safeguard public health.

2.8 METHODS OF CYANIDE ANALYSIS

Several methods that can be used for cyanide analysis have been described in literature. Regardless of the method, all share common three steps as illustrated by Cagnon et al (2003) and Brito et al (2009). The first step is extraction of the cyanogenic glycosides from the plant tissue. Bradbury et al, (1994) explains how the extraction is done in a dilute acid solution. The dilute acid solution inhibits linamarase activity thus enabling the extraction.

After the extraction, the second step is the hydrolysis of the cyanogenic glycosides to yield free cyanide. The third step is the analytical determination of the free cyanide. Several methods can be used because there exists different methods of doing the analytical determination. The most commonly used methods are titration with silver nitrate (AOAC 1990) and a reaction with alkaline

picrate (Egan et al, 1998). The titration with silver nitrate is a titrimetric analysis while the reaction with an alkaline picrate is a colorimetric analysis. Proper precautions should always be taken regardless of the method used, i.e. colorimetric, titrimetric, and electrochemical, because all are prone to interference (ATDSR, 1989)

2.8.1 Picrate Paper Method

This is a colorimetric method developed by Bradbury et al 1999, it is based on the picrate method first described by Brimer (1988). It employs the use of a picrate paper kit to determine the total cyanogens. Different kits exist for different plants such a cassava and cassava products, flax seed meal, bamboo shoots and sorghum leaves. The method is based on the reduction of sodium picrate by cyanide forming a coloured product, this is measured colorimetrically.

The first step in the method is the hydrolysis of the cyanoglycosides to cyanohydrin, this is an enzyme-catalyzed reaction effected by linamarase that occurs in the cassava plant. This is followed by a base catalyzed reaction where the cyanohydrin is further broken down to cyanide. The free cyanide is in form of HCN. The HCN is then reacted with the picrate paper. The reaction leads to a colour change on the paper.

The paper is then immersed in water for about 30 minutes. Absorbance is measured and the total cyanogens determined according to a linear Beer's law relation (Bradley et al 1999; Egan et al., 1998) over the range of 0-800mg HCN equivalent per kg of cassava.

The method is simple and makes use of readily available chemicals and equipment, it is also very accurate and reproducible, because only cyanide can reduce picric acid. The only limiting factor to the method is that it is limited to plants which have the enzyme for hydrolyzing the cyanoglyosides.

2.8.2 Picric Acid in Solution Method

This is a colorimetric method that employs a similar principle to the picrate paper kit method. It determines the concentration of weak acid dissociable cyanide (WAD). The WAD is first freed from metal complexes by the use of a chemical ligand. The free cyanide then reacts with the picric acid reducing it to the coloured isopropyl acid. The colour intensity is directly proportional to the concentration of free cyanide. The method can be used for all cyanide metal complexes except those of silver and cobalt.

The method gives reliable results for WAD cyanide concentration above 0.5mg/L. It is however prone to interference by sulphide compounds, thus samples should always be pretreated with lead carbonate/acetate to precipitate out any sulphides. The presence of sulphides is indicated by a greyish precipitate upon addition of lead carbonate/acetate. This should be filtered out. The method is also very pH sensitive, it should be maintained between 9-9.5 because outside this pH bracket, the intensity of colour development varies markedly. Dry form picric acid is explosive and thus should be handled carefully during the analysis.

2.8.3 Alkaline Titration Method

This method is described in AOAC (1990). It is one of the most popularly used cyanide assay methods. It measures free cyanide also known as titratable cyanide when the dominant ion is CN^- (Heath et al 1993). Potassium iodide at a concentration of 5% is used as the indicator. At the end point of titration the solution changes colour from clear to turbid.

Silver ions are added to the solution. The ions react with the cyanide to form a complex. When all the cyanide has been used up, the excess silver ions bring about colour change indicating end point. The colour change is due to formation of diamine silver (ii) complex (Courtney, 2008).

CHAPTER THREE: STUDY DESIGN AND METHODOLOGY

3.1 STUDY DESIGN

The study design consisted of two phases.

3.1.1 Phase 1

Involved characterization of the market crisps samples in terms of cyanide content, oil and moisture content. The samples were collected from vendors in Nairobi and Mombasa.

3.1.2 Phase 2

Involved the processing intervention. Market cassava was obtained from 3 markets in Nairobi namely, Parklands, City Market and Wakulima market at 3 different times with an interval of two weeks between each collection. These samples were used for the study of preprocessing cyanide management. The design for phase 2 is as shown in Figure 1.

[T1 = Control, T2 + parboiling, T3 = Soaking/retting]

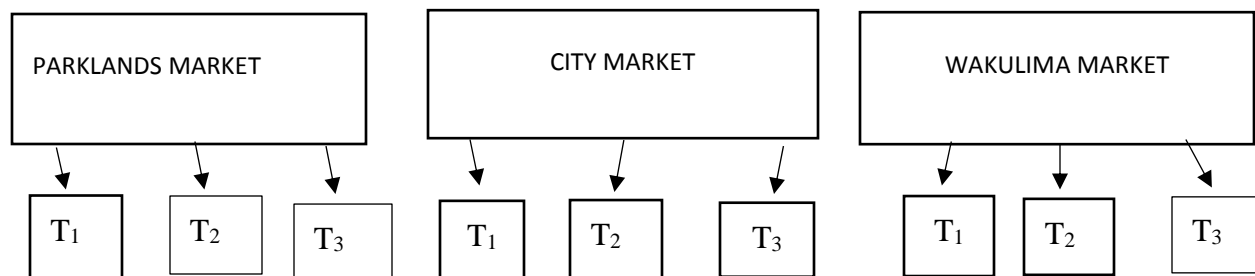


Figure 1: Design for phase 2 of the study

3.2 METHODOLOGY

3.2.1 Characterization of market samples

3.2.1.1 Sample Collection from the Markets

Samples of cassava crisps were collected from the markets in Nairobi and Mombasa. Exhaustive sampling was done because there were not many brands of cassava crisps in the market. Both branded and unbranded samples were collected. In Mombasa the cassava crisps were collected from the street vendors, while in Nairobi the crisps were collected from both street vendors and supermarkets. The crisps samples were all packaged in plastic (gauge 350) bags with approximately 50g per packet. Ten samples per vendor were collected from --six- informal vendors.in Mombasa and –4 informal processors- in Nairobi, while 10 samples per brand were collected from supermarkets to represent formal processors. 4 brands were found in the market. The packages from the processors contained 250g.

3.2.1.2 Characterization of Market Crisps

The cassava crisps obtained from the market were characterized for physical attributes in terms of slice thickness, crisp diameter and for quality characteristics; cyanide content, moisture content and oil content.

3.2.2 Intervention Processing

This involved processing cassava crisps with a view to reduce cyanide contents by parboiling and soaking before cutting for frying.

3.2.2.1 Raw Materials

The cassava samples used in this study were purchased from three markets in Nairobi namely: Parklands, City, and Wakulima markets. The markets were purposively chosen because they were identified as the main markets where cassava crisps processors source their raw materials. The

reagents used in the laboratory analyses were of analytical grade and were obtained from local Manufacturers' Agents.

3.2.2.2 Preprocessing preparation of cassava

The raw cassava roots were transported to the Department of Food Science, Nutrition and Technology, University of Nairobi. The roots were cleaned with water to rid them off the mud and dirt. They were peeled and trimmed. The roots were then cut into approximately 10cm pieces and their diameters measured. The pieces from each market, which weighed a total of approximately 14kg, were randomized and divided into seven equal batches. The batches represented four treatments of boiling time of 0, 10, 20, and 30 minutes and three soaking treatments of 0,1 and 2 days.

3.2.2.3 Parboiling treatments

The cassava pieces in each batch were placed in an aluminum pot and 6 liters of clean tap water added. The water was heated to boil, at which point the timing was started. After boiling, the pieces were cooled under cold running water to a temperature of approximately 20 °C then placed on aluminum foil to await crisping.

3.2.2.4 Soaking treatments

The cassava chunks were placed into 20-liter plastic buckets. Soaking was done in a cassava: water ratio of 1:5. The soaked cassava was rinsed under running water and crisped as the one for boiling experiment.

3.2.2.5 Frying of the crisps

The cassava pieces were sliced to 1 mm thickness and deep-fried at 170 °C until light golden in color. The cassava crisps were air-cooled, packaged in 7*9 inch plastic bags (gauge 300), and stored in a cabinet at ambient temperature to await analysis.

3.3 ANALYTICAL METHODS

The raw cassava pieces had their diameter measured in centimeters; the boiled pieces and the crisps were analyzed for moisture and cyanide contents. Additionally the crisps were analyzed for oil contents and evaluated for sensory characteristics and shelf life. The moisture, cyanide, and oil contents were analyzed in duplicates.

3.3.1 Diameter Measurement of cassava chunks and crisps

The diameters of the raw cassava pieces and the crisps were measured in millimeters using a Vernier caliper (Electronic Digital Caliper). Two measurements were taken in perpendicular direction of the diagonal and the average calculated.

3.3.2 Determination of moisture content

Moisture was determined according to AOAC official method 935.29 (AOAC, 2007). Approximately 5g of the sample, previously crushed to fine homogenous in a mortar with pestle, were accurately weighed on an aluminum moisture dish and placed in a thermostatically controlled air-oven at 105⁰C, and dried to constant weight (approximately 5 hours). The loss in weight of the sample was calculated as percent moisture content against the weight of the sample.

3.3.3 Determination of cyanide contents

Cyanide content was determined in the fresh, boiled cassava, soaked cassava and all resultant crisps by alkaline titration according to AOAC official method 915:03B (2005). Approximately 10g of the sample, previously crushed to fine homogenous in a mortar and pestle, were accurately

weighed and placed in a Kjeldahltech distillation flask and mixed with 100ml distilled water. The mixture was allowed to stand for at least 2 hours. The distillation flask was then connected to a distillation system and the distillate collected to the mark in a 200ml volumetric flask containing 25ml of 2.5% sodium hydroxide solution. Then 100ml of the distillate was placed in a 300ml Erlenmeyer flask, 8ml potassium iodide solution added and mixed. The mixture was then titrated against 0.02N silver nitrate solution. The end point is indicated by the appearance of a faint permanent turbidity. .By this method, 1ml titer represents 1.08mg HCN. This relationship was used to calculate the cyanide content of the sample as mg/kg.

3.3.4 Determination of Oil Content of the crisps

The oil content of the crisps was determined by AOAC (2005) official method 945.16 by Soxhlet continuous distillation. The crisps were ground in a grinder to a coarse homogenous powder for the analysis. The oil contents were expressed as a percentage of the weight of crisps.

3.3.5 Sensory evaluation

Sensory evaluation was carried out in the sensory evaluation room of the Department of Food Science, Nutrition, and Technology, University of Nairobi. The panel consisted of 14 members drawn from the students and staff of the Faculty of Agriculture who were familiar with the products. A 7-point hedonic rating scale (1 = dislike very much and 7 = like very much) according to Larmond (1977) was used to evaluate the products against the attributes, color, appearance, flavor (odour and taste), crunchiness and overall acceptability. Coded samples were presented to each panelist separately in similar plates at 12:30 Pm. Water was provided in plastic tumblers to rinse mouth before and between testing samples.

3.3.6 Shelf Life Evaluation of Crisps

Accelerated shelf life was done. The crisps from both soaking and boiling treatments were packed in 50g quantities in plastic bags (150 microns gauge). The samples were stored in an air oven at 55⁰C. One-day storage at this temperature represents one-month normal storage at 25⁰C (Manzocco et al, 2016). A sample from each treatment was drawn from the oven every day and presented to a panel of six individuals to sniff to detect any off odours and then taste to detect any changes in crunchiness of the product.

3.4 DATA ANALYSIS

Data collected was analyzed using GenStat® Discovery 15th Edition software. Descriptive data (means, frequencies, and standard deviations) of moisture, oil, and cyanide contents were generated. One-way Analysis of variance (ANOVA) was done for moisture and oil contents of the crisps while two way ANOVA was done for cyanide contents of the chunks and crisps. A 95% confidence interval (P- value ≤ 0.05) was used. Least Significant Difference (LSD) test was used to separate different means.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 PHYSICO CHEMICAL CHARACTERISTICS OF MARKET CRISPS

The physico-chemical characteristics of the market crisps analyzed included moisture, oil and cyanide contents, and diameters. The moisture, oil, and cyanide contents of the crisps are shown in Table 1.

Table 1: Moisture, Oil, and Cyanide Contents of Market Crisps

Market	Physico- chemical Attributes		
	Moisture %	Oil content %	Cyanide content(mg/kg)
Nairobi formal			
1	6.03±0.01 ^d	21.01±1.46 ^c	34.56±3.06 ^{ab}
2	5.14±0.13 ^e	30.51±0.39 ^a	28.08±3.06 ^{de}
3	4.83±0.04 ^e	31.27±2.48 ^a	23.22±2.29 ^e
4	4.92±0.02 ^e	23.58±1.48 ^c	29.16±1.53 ^{cd}
Mean	5.73±1.01 ^d	26.59±4.86 ^{ac}	28.76±4.72 ^{de}
Nairobi informal			
1	6.05±0.04 ^d	30.12±0.35 ^a	37.24±1.06 ^a
2	6.03±0.09 ^d	28.3±0.42 ^{ab}	34.23±3.06 ^{de}
3	6.24±0.02 ^c	24.52±2.06 ^{bc}	29.63±2.42 ^c
4	5.02±0.03 ^e	23.58±1.48 ^c	32.43±0.55 ^{bcd}
Mean	5.84±0.55 ^d	26.61±3.12 ^{bc}	33.38±3.19 ^{de}
Mombasa			
1	6.53±0.04 ^b	21.89±0.66 ^c	35.64±3.06 ^{ab}
2	6.25±0.07 ^c	28.99±0.81 ^{ab}	37.26±2.29 ^a
3	6.20±0.00 ^{cd}	31.02±0.00 ^a	33.48±1.53 ^{abc}
4	6.07±0.04 ^d	30.80±1.75 ^a	31.86±0.76 ^{bcd}
5	7.10±0.16 ^a	25.14±2.69 ^{bc}	30.78±0.76 ^{bcd}
6	7.04±0.08 ^a	29.09±3.54 ^{ab}	35.1±2.29 ^{ab}
Mean	6.53±0.43 ^b	27.82±3.75 ^{ab}	34.02±2.74 ^{ab}

* mean ±SD (n = 5)

Values with the same letter superscript within the column are not significantly different at p<0.05

4.1.1 Moisture contents

As Table 1 shows, the moisture contents of the market crisps ranged from 4.83% to 7.10%. There was significant difference ($p < 0.05$) between samples from different processors. Only two samples from Nairobi were within the EAS guidelines of moisture content in cassava crisps, which should not exceed 5% (EAS, 2010). The differences in the moisture contents are highly attributable to the frying techniques of the processors and the packaging materials used.

During the sample collection, it was noted that most of the processors were not adequately frying the crisps as described by Elfinash et al (2011), whereby frying should be done until bubbling stops. This leads to inadequate dehydration and thus high moisture content in the resultant products. Due to the recent ban of the use of plastic carrier bags in the country, most of the small-scale processors were packaging their products in Kraft paper. Kraft paper is highly permeable to moisture, thus the products might have absorbed moisture from the environment leading to increased moisture levels in the products.

High moisture content results to poor keeping quality and thus reduced shelf life. High moisture in crisps also impairs their eating quality as their crunchiness is markedly reduced.

4.1.2 Oil contents

Table 1 shows that the oil content ranged from 21.89% to 31.27%. At $p < 0.05$, there were significant differences in the oil content of different crisps. However the oil content of most of the samples was within the East Africa guidelines on cassava crisps oil content which should not exceed 30 % (EAS, 2010). The results are in agreement with a study by Abong' et al, 2016. Oil content in the crisps is an important processing parameter because very high oil content contributes to increased oxidative rancidity and this adversely affects the shelf life of the product. On the other hand, very high oil content results into products which are soggy and unattractive to consumers.

4.1.3 Cyanide content.

Finally, Table 1 shows that the cyanide content ranged from 23.22% to 37.26%. The cyanide content from the different market samples were significantly different at $p < 0.05$. All the samples had cyanide content above 10mg/kg which is the maximum recommended limit according to regulations set by the Kenya Bureau of Standards (KEBS 2010). On average, the samples from Mombasa had higher cyanide levels than those from Nairobi.

The high cyanide content in the crisps is attributable to the fact that there is no preprocessing cyanide management during the production of the cassava crisps. This was corroborated by the processors during sample collection. The processors had no idea that the cyanide can be managed during processing of crisps. The street vendors in Nairobi had no knowledge about occurrence of cyanide in cassava while those in Mombasa had little knowledge about it, however they did not have any knowledge on how the cyanide levels can be reduced during processing of cassava crisps. The results were consistent with the laboratory analysis results which showed that if there is no pre-processing cyanide management, frying alone was unable to reduce cyanide levels to safe limits even in cassava with below 50mg/kg HCN.

Sub lethal exposure of cyanide expose the consumer to cyanide toxicity (Akinpelu, 2011). Chronic cyanide toxicity has been associated with nervous disorders and exacerbation of the manifestation of goiter (Bradbury et al, 2013).

Owing to the increasing popularity of cassava crisps as a snack especially for school going children, there is need to protect the public from the adverse effects of chronic cyanide poisoning. There is need to ensure that the cassava crisps in the market are safe for consumption by the general public. This can be achieved through a preprocessing cyanide management method that effectively reduces cyanide to levels such that the final product will have cyanide contents not exceeding 10mg/kg.

4.1.4 Diameter of the market crisps

The diameters of the cassava crisps were also measured. The diameters had a narrow range of 3cm to 6.5cm for both the informally marketed and the formally marketed crisps. The mean diameter was 4.2cm. These results indicate that the cassava used for processing of crisps both in the streets and the formal industries in both Mombasa and Nairobi are of a definite maximum diameter, probably determined by the length of the cutter blade.

4.2 PROCESSING OF CRISPS WITH PARBOILING AND SOAKING OF CASSAVA

The processing of crisps was carried out with the preprocessing of parboiling and soaking or retting as means of reducing the cyanide levels of the final product. For the two preprocessing treatments, the cassava was cut into pieces of approximately 10cm.

4.2.1 Diameter of the Cassava pieces for parboiling and soaking

The diameter of raw cassava pieces for parboiling and soaking trials ranged between 5cm and 9cm. Cassava roots of larger size than this were rarely found in the market. Usually cassava roots have been reported to grow to diameters of up to 15cm, but such size of cassava was rarely found in the market. It is possible that the limit of size found in the market was the preferred by the processors as they tried to mimic the size of the potato crisps, or the size of the cassava was delimited by the size of the cutter. The larger size cassava would probably be purchased for roasting as cut strips or chunks, the other products that are commonly but more rarely found selling on the street sides. Sometimes it is not uncommon to find street vendors who deal in crisps and fried or roasted strips or chunks.

4.2.2 Preprocessing by Parboiling

4.2.2.1 Moisture Contents

The distribution of moisture contents of parboiled chunks by market and boiling time are shown in Table 2, while the same distribution for the crisps is shown in Table 3.

Table 2: Mean Moisture Content of Cassava Chunks by Market and Boiling Time

Market	Boiling time in minutes and corresponding moisture content (%)			
	0	10	20	30
Parklands	61.96±0.57 ^a	64.49±6.55 ^a	67.95±0.44 ^b	74.31±6.98 ^c
City market	60.62±1.48 ^a	64.54±0.10 ^a	68.03±0.38 ^b	75.64±10.14 ^c
Wakulima	61.36±0.21 ^a	62.15±2.29 ^a	67.97±2.28 ^b	70.70±2.33 ^c
Average	61.32±0.93 ^a	63.73±3.33 ^a	67.98±10.05 ^b	73.55±6.05 ^c

*Mean ± SD (N = 3). Means with different subscripts across a row and down a column are statistically different at $p < 0.05$

As shown in Table 2, the market did not have any significant effect ($p < 0.05$) on the moisture contents of the fresh and boiled cassava chunks. The moisture content of the cassava from the three markets varied between 61 – 62%. There was significant difference between the different boiling times. There was no significant difference ($p < 0.05$) between the moisture contents of the fresh cassava and those boiled for 10 minutes. Both these moisture contents were significantly lower than the moisture contents of the cassava boiled for 20 and 30 minutes, which were also significantly different from each other. The average moisture contents increased significantly from 61.32 to 73.55 from the raw cassava to that cooked for 30 minutes. The reason for the increase in the moisture content was probably due to the leaching out some dry matter components so that the

dry matter content decreased and the cassava was able to accommodate more water. The swelling of starch during boiling could also have led to absorption of more water by the cassava.

The cassava boiled for 30 minutes recorded the highest moisture content and was the softest. This softness presented challenges during slicing due to excessive breakage. The slices were not of uniform size due to breakage and therefore boiling for 20 minutes was taken as maximum for ease of slicing to produce good quality crisps.

Table 3: Mean Moisture Contents of Crisps by Market and Boiling Time

<i>Market</i>	Boiling time (mins) and corresponding moisture contents (%)			
	0	10	20	30
<i>Parklands</i>	3.21±0.01 ^a	3.24±0.04 ^a	3.41±0.45 ^a	3.47±0.08 ^a
<i>City market</i>	3.63±0.54 ^a	3.61±0.44 ^a	3.62±0.23 ^a	3.31±0.47 ^a
<i>Wakulima</i>	3.21±0.23 ^a	3.42±0.52 ^a	3.58±0.46 ^a	3.63±0.03 ^a
<i>Average</i>	3.35±0.34 ^a	3.42±0.35 ^a	3.53±0.32 ^a	3.47±0.25 ^a

*Mean±SD (N = 3)

Values with different superscripts across rows and down the column are statistically different at $p < 0.05$

As Table 3 shows market and boiling had no significant ($p < 0.05$) effect on the moisture contents of the crisps. The mean moisture content of the cassava crisps across markets ranged between 3.21% and 3.63%. The mean moisture contents of the crisps across boiling temperatures ranged between 3.24% and 3.62%, with the average moisture content across boiling ranging between 3.42% and 3.63%. There was no significant difference ($p < 0.05$) between the averages across markets and the averages across the boiling temperatures.

4.2.2.2 Oil content

The oil content of the crisps were as shown in Table 4.

Table 4: Mean Oil Contents of the Crisps by Market and Boiling Time

<i>Market</i>	<i>Boiling time (min) and corresponding oil contents (%)</i>			
	0	10	20	30
<i>Parklands</i>	24.52±0.15 ^a	18.58±0.93 ^a	26.80±0.64 ^a	25.08±5.16 ^a
<i>City market</i>	23.27±1.00 ^a	22.61±2.93 ^a	21.68±0.51 ^a	25.94±0.38 ^a
<i>Wakulima</i>	22.31±1.95 ^a	20.48±1.74 ^a	21.59±4.12 ^a	22.20±0.51 ^a
<i>Average</i>	23.37±1.40 ^a	20.56±2.40 ^a	23.35±3.26 ^a	24.41±2.91 ^a

*Mean ± SD (N = 3)

Values with the same superscripts across a row and down a column are not statistically different at $p < 0.05$

The oil content of the crisps across markets and across the boiling temperatures. There were no significant market and boiling time effects on the oil contents of the crisps. The oil content varied between 18.58% and 26.8%.

Notable is that the oil contents were within the East Africa Standard requirements of not more than 30% (EAS, 2010). Oil content in crisps is one of the crucial quality indicators as it influences the eating and keeping quality. Process optimization should therefore be done to ensure the oil content is within acceptable limits (Abong' et al, 2011). When the oil content is too high, the resultant product is soggy and non-appealing. The shelf life is also markedly reduced due to increased propensity to develop off flavors due to oxidative rancidity. (Wrolstad, 2013). Increased awareness on lifestyle-associated diseases has also led to consumers demanding for products that are not too oily, which increases energy intake. Therefore, for a product to compete effectively in the market, the processor has to ensure that the oil content is within acceptable limits. On the other hand, very low oil content also results in hard crisps, which are non-appealing to the consumer. Therefore, any pre-processing method should not negatively affect the oil content of the resultant crisps.

4.2.2.3 Cyanide in boiled cassava chunks

The mean cyanide contents of boiled cassava pieces are shown in Table 5. Market had no significant effects on the cyanide contents, but boiling had significant effects on the cyanide contents ($p < 0.05$). All the fresh cassava roots contained cyanide levels slightly above 50mg/ kg, the boundary value between sweet and bitter cassava. The highest mean cyanide content was 59.4mg/kg in cassava from City Market and the lowest 54.54mg/kg in cassava from Wakulima market.

Boiling rapidly lowered the cyanide contents. At $P < 0.05$, there was significant difference in the cyanide contents from different boiling times. Boiling for 30 minutes resulted in the highest cyanide reduction. There was no significant difference in the cyanide contents of the roots from different markets

Table 5 : Mean Cyanide Content of Chunks by Market and Boiling Time

<i>Market</i>	<i>Boiling time (min) and corresponding cyanide contents(mg/kg)</i>			
	0	10	20	30
<i>Parklands</i>	56.70±3.82 ^a	21.6±3.06 ^b	15.12±4.58 ^b	13.50±3.82 ^c
<i>City Market</i>	59.40±1.53 ^a	15.66±0.76 ^b	15.12±1.53 ^b	14.04±1.53 ^c
<i>Wakulima</i>	54.54±2.29 ^a	16.20±1.53 ^b	12.96±0.00 ^c	11.88±1.53 ^c
<i>Average</i>	56.88±3.03 ^a	17.82±3.33 ^b	14.40±2.43 ^{bc}	13.14±2.21 ^c

*Mean ±SD (N = 3)

Values with different letters across a row and along a column are statistically different at $p < 0.05$

The results indicate that boiling significantly reduces cyanide in cassava. This agrees with study by Nambisan et al, (1994). However to increase the efficiency of boiling as a method of cyanide reduction, the cassava size should be reduced. Water volume is also a crucial factor. In the study it was reported that water should be five-fold to reduce the retention to at least 24%.

4.2.2.4 Cyanide in Crisps

The mean cyanide contents of the crisps from the three markets and boiling for 0, 10, 20 and 30 minutes are shown in Table 6.

Table 6: Mean Cyanide Contents of the Crisps by Market and Boiling Time

<i>Market</i>	<i>Boiling time (mins) and corresponding cyanide content(mg/kg)</i>			
	0	10	20	30
<i>Parklands</i>	31.86±0.76 ^a	9.72±1.53 ^b	9.18±0.76 ^b	5.94±2.29 ^c
<i>City Market</i>	34.02±0.76 ^a	9.72±0.00 ^b	9.72±1.53 ^b	5.40±0.00 ^c
<i>Wakulima</i>	34.56±1.53 ^a	11.34±0.76 ^b	9.18±0.76 ^b	5.40±1.53 ^c
<i>Average</i>	33.48±1.53 ^a	10.26±1.13 ^b	9.36±0.88 ^b	5.58±1.26 ^c

*Mean ± SD (N = 3)

Values with different superscripts across a row and down a column for an attribute are statistically different at $p < 0.05$

The mean cyanide contents of the crisps from the unboiled cassava fell by 41.1% from 56.88 mg/kg to 33.48mg/kg. The mean cyanide level of the crisps however still remained above the tolerable level of 10mg/kg

The overall mean cyanide contents across markets dropped drastically due to boiling for 10, 20, and 30 minutes to 10.26, 9.36, and 5.58 mg/kg respectively. At $P < 0.05$, there was significant difference between the boiling times. However, there was no significant difference between boiling for 10 and 20 minutes, which were significantly different from 30 minutes. However, overall boiling for 20 minutes resulted in lower cyanide levels than boiling for 10 minutes. All the samples boiled for 20 and 30 minutes had cyanide levels below 10mg/kg while 10 minutes boil had some samples slightly above 10mg/kg. It can therefore be concluded that boiling the cassava for 20– 30 minutes results in levels of cyanide, which are within the tolerable limits, by law.

4.2.2.5 Sensory Evaluation

The sensory attributes scores of the crisps are shown in Table 7. For sensory evaluation, the crisp from each market with the same boiling time were combined. This was possible because market was found to have no significant ($p < 0.05$) effect on all characteristics studied.

As Table 7 shows, all the crisps from all boiling times were acceptable in all attributes (scores more than 4). However, the crisps from the raw cassava were not acceptable in the attributes of color and appearance, and only borderline scores in flavor and overall acceptance. The score of the crisps on crunchiness was however, not significantly different from the scores of the same attribute of the boiled crisps, showing that boiling does not influence the attribute. Boiling produced acceptable crisps in all the attributes tested, and there was no significant difference ($p < 0.05$) in all attributes within the same boiling time.

Table 7: Means of Sensory Attributes Scores by Boiling Time

<i>Boiling time (minutes)</i>	<i>Sensory Attributes</i>				
	<i>Appearance</i>	<i>Colour</i>	<i>Crunchiness</i>	<i>Flavor</i>	<i>Overall acceptability</i>
0	3.64±2.17 ^a	3.86±1.61 ^a	5.29±1.14 ^{ab}	4.07±1.77 ^{ab}	4.29±0.99 ^a
10	5.79±1.58 ^b	5.50±1.45 ^{bc}	5.36±1.69 ^{ab}	5.07±1.27 ^{bc}	5.57±1.22 ^{bc}
20	5.93±0.62 ^b	6.21±0.80 ^c	6.43±0.65 ^c	6.29±0.73 ^d	6.14±0.95 ^c
30	5.36±1.50 ^b	5.71±1.38 ^c	6.14±0.95 ^{bc}	6.14±1.10 ^d	6.07±0.73 ^c

*Mean ±SD (N = 14)

Values with different superscripts along a column or row are statistically different at $p < 0.05$.

The crisps from the parboiled cassava were more preferred in all the attributes. The 20-minute boil scored highest for overall acceptability with a mean of 6.14. The panelists indicated that the crisps from the boiled cassava had a nice golden colour that was even throughout the surface. This is attributable to the fact that boiling hydrolyses some starch to produce some reducing sugars that participate in the browning during frying. The 30-minute boil cassava presented a challenge during

crisping whereby the cassava had become difficult to slice so that most of the slices got broken were not fully round. In fact, the panelists described these crisps as too broken.

The crisps from the raw unboiled cassava scored poorly in appearance and colour due to the formation of a dark brown ring on the edges and panelists found this unappealing. The surface immediately below the peel is known to contain much higher cyanogenetic glycoside contents, which decreases into the flesh as described by Zidenga et al (2017). The high temperature of the frying oil and the water in the fresh cassava may have caused hydrolysis of the cyanogen releasing the sugar, which caramelized to deepen the color of the rind more than the general surface of the crisp. The crisps also had some bitter taste, and this is due to the significantly higher levels of cyanide as shown in Table 5. This was also regarded as a negative attribute and lead to a poor score for flavor.

4.2.3 Preprocessing By Soaking

4.2.3.1 Moisture content

The distribution of moisture contents of soaked chunks and crisps by market and soaking time are shown in Table 8, while the same distribution for the crisps is shown in Table 9

TABLE 8 MEAN MOISTURE CONTENTS OF SOAKED CHUNKS BY MARKET AND SOAKING DAYS

Market	Soaking period (days) and corresponding moisture content (%)		
	0	1	2
Parklands	59.12±2.79 ^a	64.44±0.48 ^b	70.14±2.61 ^c
City market	63.63±1.26 ^a	66.08±0.91 ^b	71.29±1.34 ^c
Wakulima	61.64±1.66 ^a	67.07±0.23 ^b	70.70±1.09 ^c
Average	61.46±2.55 ^a	65.86±1.28 ^b	70.71±1.49 ^c

*Mean ± SD (N = 3)

Values with different superscripts across a row and down a column for an attribute are statistically different at p<0.05

The moisture of the cassava ranged from 59.12% to 71.29%. There was significant differences at $p < 0.5$ in moisture content for the different days of soaking. Therefore soaking had a significant effect on the moisture content of the cassava. At $p < 0.05$, the market had no effect on the moisture content of the cassava. The unsoaked cassava corresponding with zero days of soaking had the lowest moisture content while cassava soaked for two days has the highest moisture content. This indicates that, as the cassava continued soaking, the moisture content increased. During soaking, the cassava absorbed more water into the tissues and thus the increased moisture content.

The moisture content of the cassava affected the slicing of the cassava and thus was a crucial processing aspect. Up to 2 days of soaking, the cassava was sliced without difficulties. It was noted that cassava soaked for 3 days became mushy and disintegrated during slicing. Therefore two days of soaking were the maximum number of days the cassava could be soaked for processing into crisps.

Table 9 shows the distribution of mean moisture contents of the crisps by market and soaking days.

Table 9: Mean Moisture Contents of the Crisps by Market and Soaking Days

Market	Soaking period (days) and corresponding moisture content (%)		
	0	1	2
Parklands	3.75±0.50 ^a	3.78±0.11 ^a	3.44±0.28 ^a
City market	3.56±0.48 ^a	3.33±0.17 ^a	3.62±0.86 ^a
Wakulima	3.51±0.50 ^a	3.09±0.08 ^a	3.79±0.04 ^a
Average	3.61±0.40 ^a	3.40±0.33 ^a	3.62±0.43 ^a

*Mean ± SD (N = 3)

Values with different superscripts across a row and down a column for an attribute are statistically different at $p < 0.05$

The mean moisture content of the cassava crisps ranged between 3.79% and 3.09%. At $P < 0.05$, there was no significant difference in moisture content in samples from different soaking periods

and in all the samples across the three markets This shows that moisture content is not affected by the soaking treatment. Therefore soaking of cassava can be incorporated as a preprocessing step without affecting the moisture content of the final product.

The moisture content is within acceptable limits of the EAS standards which prescribe cassava crisps to have moisture not exceeding 5%. Moisture content is an important factor in keeping quality of food. High moisture foods are highly perishable due to the high water activity that supports microbial growth and other biochemical reactions. (Sewald and De Vries, 2014)

4.2.3.2 Oil content

The results of the oil contents of the crisps by market and soaking days were as shown in table 10.

Table 10: Means of Oil Content in Crisps by Market and Soaking Days

Market	Soaking period (days) and corresponding oil content (%)		
	0	1	2
Parklands	28.20±5.09 ^a	28.99±0.62 ^a	28.50±1.56 ^a
City market	31.19±0.83 ^a	28.18±2.33 ^a	27.24±0.65 ^a
Wakulima	30.45±1.20 ^a	30.15±1.49 ^a	26.45±2.76 ^a
Average	28.61±3.26 ^a	27.44±5.61 ^a	27.40±2.38 ^a

*Mean ± SD (N = 3). Values with different superscripts across a row and down a column for an attribute are statistically different at p<0.05

The oil content ranged from 26.45% to 31.19%. At p<0.05, there was no significant differences in the oil content in samples from different soaking periods. The market effect was not significantly different. The oil contents were mostly within the EAS guidelines of not more than 30% oil content in cassava crisps, with exception of a few, this can be attributed to processing variations and accuracy of the analytical method.

4.2.3.3 Cyanide content in soaked cassava chunks

The distribution of cyanide contents in soaked cassava chunks by market and soaking days are shown in table 11.

Table 11: Cyanide Contents in Soaked Cassava Chunks by Market and Soaking Days

Market	Soaking period (Days) and corresponding cyanide content (mg/kg)		
	0	1	2
Parklands	50.22±2.29 ^a	27.00±7.64 ^b	14.04±1.53 ^c
City Market	56.70±3.82 ^a	37.80±0.00 ^b	17.28±6.11 ^c
Wakulima	54.54±12.98 ^a	35.64±6.11 ^b	20.52±3.06 ^c
Average	53.82±6.81 ^a	33.48±6.73 ^b	17.28±4.27 ^c

*Mean ± SD (N = 3)

Values with different superscripts across a row and down a column for an attribute are statistically different at $p < 0.05$

The cyanide content range was from 14.04mg/kg to 56.7mg/kg. At $P < 0.05$, there was significant difference of cyanide content at different soaking periods. The fresh cassava chunks which were not soaked recorded the highest cyanide levels. Soaking for two days markedly reduced the cyanide content overall.

During soaking, soluble glucosides leach out (Bourdoux, 2012). This reduces cyanide content in the cassava. There is also some tissue breakdown and fermentation according to Montagnac et al (2013). All these activities further reduce the cyanide content in the cassava. To increase the efficiency of soaking, the water for soaking should entirely cover the cassava and the chunks should be of small size.

Soaking as a method of cyanide reduction can be effectively adopted by small-scale processors. This will provide a double benefit because the processors will be able to reduce cyanide in the

crisps and prolong the shelf life of the cassava. Soaking cassava in water prolongs the shelf life and is one of the methods which has been widely adopted in rural areas for preservation.

During the preliminary study, it was noted that soaking cassava for more than two days resulted into cassava that was soft and mushy and disintegrated during handling. Prolonged soaking could have resulted into cassava with lower cyanide levels (Bradbury et al, 2012). However, for the processing of crisps it was not possible to go beyond the two-day soak.

Soaking however did not lower cyanide levels to below 10mg/kg, therefore to achieve levels of cyanide below 10mg/kg in cassava, the soaking period has to exceed two days. However in the processing of crisps, the soaking is a preprocessing step and more cyanide is lost during frying, therefore, the overall effect of the efficacy of soaking can only be concluded after the frying step.

4.2.3.4 Cyanide content in crisps

Table 12 shows the cyanide content of the resultant crisps.

Table 12: Means of Cyanide Contents in Crisps by Market and Soaking Days

Market	Soaking period (days) and corresponding cyanide content (mg/kg)		
	0	1	2
Parklands	32.40±1.53 ^a	14.58±2.29 ^b	8.18±0.76 ^c
City Market	37.80±7.64 ^a	20.30±3.82 ^b	8.72±1.53 ^c
Wakulima	32.94±2.29 ^a	21.06±2.29 ^b	7.80±1.53 ^c
Average	34.38±4.50 ^a	18.6±4.96 ^b	8.23±1.26 ^c

*Mean ± SD (N = 3). Values with different superscripts across a row and down a column for an attribute are statistically different at p<0.05

Soaking significantly reduced the cyanide content in the crisps. At p<0.05, the soaking effect was significantly different. Soaking for 2 days had the largest cyanide drop overall. The average cyanide in the 2-day soak was 8.23mg/kg. One-day soak produced crisps with average cyanide

content of 18.6mg/kg. The crisps from the 2 day soak produced crisps with cyanide below 10mg/kg, the maximum recommended level of cyanide in cassava crisps. This therefore intimates that, soaking cassava chunks for 2 days can effectively reduce the overall cyanide in cassava crisps to safe acceptable levels.

4.2.3.5 Sensory evaluation

The results of sensory attributes scores are presented in table 13. The sensory parameters that were scored are appearance, colour, crunchiness, and flavor. Overall acceptability was also scored.

Table 13: Means of Sensory Attribute Scores by Soaking Time

Soaking period in (days)	Sensory Parameters				
	Appearance	Colour	Crunchiness	Flavour	Overall acceptability
0	3.64±2.17 ^a	3.64±1.61 ^a	5.29±1.14 ^b	3.86±1.77 ^a	4.21±0.99 ^a
1	4.07±1.90 ^a	5.64±1.55 ^b	5.14±0.77 ^b	4.07±1.66 ^a	5.29±1.31 ^b
2	5.29±1.33 ^b	5.86±1.17 ^b	5.64±1.28 ^b	5.00±1.66 ^b	5.57±1.27 ^b

*Mean ±SD (N = 14)

Values with different superscripts along a column are statistically different at $p < 0.05$.

Crisps from the unsoaked fresh cassava scored poorer compared to the crisps from the soaked cassava in all attributes except in crunchiness, which did not exhibit any significant difference across all samples. At $p < 0.05$, there was significant difference in the overall acceptance of crisps from soaked and unsoaked cassava. The 2 two day soak produced the most desirable crisps in all attributes.

The crisps from the unsoaked cassava had a brown ring on the outer surface, this can be attributed to the high cyanide levels on the outer area bordering the peel, which has very high cyanide contents (Zidenga et al, 2017). During frying glucosides undergo hydrolysis, producing sugars

which are caramelized, resulting into the browning effect. During soaking, the cyanide levels reduced significantly and thus the resultant crisps did not have the brown ring.

The panelists most preferred the crisps from the two day soak due to their colour and taste. Some panelists described the crisps as “sweet” compared to the crisps from the unsoaked cassava, which were described as bitter.

4.2.4 Shelf Life Evaluation

About shelf life evaluation by accelerated method, none of the panelists detected any off flavors until the 12th day of storage, when three panelists could detect some off odours from two to three of the four samples for each panelist. The off odour was characteristic of was indication of rancidity due to fat autoxidation. One day under this kind of rancidity represents 1 month of storage at 25 °C. It can therefore be concluded with a high degree of assurance that the crisps will have a shelf life of 10 months at this temperature.

During frying, crisps absorb considerable amounts of fat as shown in tables 3 and 8. The oil content can be as high as 35% (EAS, 2010). During storage, there is fat oxidation mainly due to the presence of oxygen entrapped if the package is not evacuated, or from permeability into the package. (Bassama et al, 2015). The oxidation produces volatile compounds that are detected as off flavours. This is an indicator of product quality deterioration.

After storage for 10 months equivalent, the crunchiness of the crisps had slightly decreased but not to levels that made them unacceptable. The frying process also results into rapid moisture loss (Esturk et al, 2000). This is also shown in Tables 1, 2, 7 and 8. Moisture content is a paramount determinant of shelf life (Perera et al, 2013). High moisture levels lead to faster rate of quality loss including loss of sensory attributes of crunchiness. Crisps are usually hygroscopic because of the low moisture content. They can therefore absorb moisture from the atmosphere if the package is

permeable to water, thereby reducing crunchiness. It is therefore, important to select packages with low moisture permeability in order to ensure long shelf life of the crisps.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

Both parboiling and soaking can effectively be incorporated as preprocessing steps in production of cassava crisps to produce crisps with cyanide contents below the statutory maximum levels of 10mg/kg. The most suitable parboiling time is 20 minutes while for soaking is 2 days. Boiling for 20 minutes produced the best results in terms of the overall acceptability compared to those from the boiled. In terms of acceptability, the poorest scoring crisps were those from the fresh cassava. Marketed cassava crisps in Nairobi and Mombasa have high cyanide levels exceeding the maximum recommended levels by up to three fold. Their moisture and oil contents were also exceeding the regulatory limits.

The resultant crisps from both parboiling and soaking of cassava can be stored for up to 10 months without detectable changes in organoleptic quality.

5.2 RECOMMENDATIONS

From the findings of the study, the following is recommended

- The cassava crisps processors to adopt a preprocessing method that can lower cyanide to below 10mg/kg in cassava crisps
- Cassava crisps processors to be trained on the importance of producing low cyanide crisps.
- The government regulatory bodies to increase monitoring and surveillance of the cassava crisps sold in the country to ensure they comply with statutory requirements.

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