QUALITY AND SAFETY OF SUN-DRIED CASSAVA CHIPS AND FLOUR IN KENYAN MARKETS AND TENT SOLAR DRIED CASSAVA CHIPS

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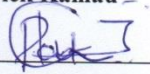
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DEDICATION

This Dissertation is especially dedicated to my dear parents; Simon Gacheru Kamau and

Rosemary Wanjiru, my sister Edna Wangari and my friend Brian Ngare.

DECLARATION

I hereby declare that this Dissertation is my original work and has not been presented for the award of a degree in any other University.

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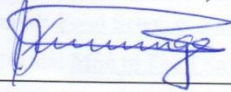
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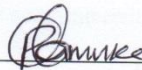Department of Food Science, Nutrition and Technology

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ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

CAC: Codex Alimentarius Commission

DW: Dry weight

DM: Dry matter

ELISA: Enzyme-linked Immunoabsorbent Assay

EMB: Eosin Methylene Blue

FAO: Food and Agriculture Organization of the United Nations

GAP: Good Agricultural Practices

GHP: Good Hygiene Practices

HACCP: Hazard Analysis and Critical Control Points

HCN: Hydrogen Cyanide

HQCF: High Quality Cassava Flour

IITA: International Institute of Tropical Agriculture

KALRO: Kenya Agricultural and Livestock Research Organization

MOA: Ministry of Agriculture, Kenya

MOH: Ministry of Health, Kenya

MT: Metric Tonnes

TDI: Tolerable Daily Intake

TRV: Tolerable Reference Values

WHO: World Health Organization

OPERATIONAL DEFINITION OF TERMS

Contamination: Abnormal presence of substances or microorganisms in food or food environment.

Food Safety Hazard: Any biological, chemical or physical agent in food, or condition of food with the potential to cause an adverse health effect.

Food Safety: Concept/ assurance that food will not cause harm to the consumer when it is prepared and/or eaten according to its intended use.

Pathogen: A microorganism (bacteria, parasite, viruses or fungi) that is infectious and causes disease.

Mycotoxin: Fungal poisons, and are toxic secondary metabolites produced by organisms of the fungal kingdom commonly known as mould.

ABSTRACT

Cassava is rich in carbohydrates and is the third most important source of calories in the tropics. However, it poses food safety risks to the consumers due to naturally occurring cyanogenic glucosides and the handling and processing practices employed which may expose it to microbial contamination. This study aimed at determination of the levels of microbiological contamination, cyanide and mycotoxin levels of cassava chips and flour in Coastal (Mombasa) and Nairobi markets and assessment of tent solar drying and size of chips on safety and quality of cassava chips. A comprehensive survey of cassava flour and dried cassava chips in markets in the study sites was carried out and subjected to experimental analysis methods to determine levels of microbial contamination (total viable count, *staphylococcus aureus*, yeast and mould, total coliforms and *E. coli*) and chemical (hydrogen cyanide, aflatoxin contamination) and physical analysis (colour). A tent solar drier was also fabricated and used for drying raw cassava and the progress recorded with the dried cassava chips being finally analysed for hydrogen cyanide, moisture content and colour. Thirty six samples of cassava products from Nairobi and Mombasa markets were evaluated; one sample tested positive for *E. coli*, 87% of cassava flour and 77% of cassava chips samples tested positive for *Staphylococcus aureus*. The HCN in both the dried cassava chips and cassava flour had levels that were above 10 mg/kg while moisture content was below 12%. Dried cassava chips sold in the markets had low L* values hence less white; with the flours having high L* values indicating very white flours. Three cultivars of cassava (Fumba chai, MH95/0183, MM96/2480) from KALRO-Kakamega farm, were peeled and chopped into 3 thicknesses; 1, 3 and 5 mm. The percentage loss in HCN ranged from 20.2% to 50.1% but the residual HCN was higher than 10 mg/kg. The final MC was below 12% with high L* values hence predominantly white in colour. The 5 mm thick cassava chips exhibited the highest percentage loss of HCN and moisture. This study intimates that the flour in the market may be of

good aesthetic quality but unsafe for consumption due to high level of microbial contamination and high residual HCN; also that the tent solar dried cassava chips were good quality: with low moisture content levels and white in colour, but had high residual HCN). It is recommended that farmers and processors are trained on good hygienic practices, adoption of best practices in processing, soaking and washing of cassava raw cassava tubers after chipping and prior to drying. The 5 mm thick chips are recommended on the basis of high moisture as well as high HCN loss.

CHAPTER 1

1.0 INTRODUCTION

1.1 Background Information

Cassava (*Manihot esculenta* Crantz) is an important food crop that provides a large and important source of carbohydrates (the roots contain 20-25% starch) in the diet of people in Kenya. It is however, deficient in protein. Cassava was introduced to Africa in the 16th century and became established at various locations on the continent in the subsequent centuries. In the beginning of the 20th century, cassava cultivation became widespread in small farm systems and in some cases; cassava clearly took over from other staple foods e.g. bananas in East Africa and maize and sorghum in southern Africa (Lynam, 1991). The Western and Nyanza regions of Kenya are the main cassava producing regions (Kimathi et al., 2007); and most of the cassava is produced by small scale farmers using traditional farming systems (Githunguri et al., 2007). According to Kiura et al. (2005), about 38% of the cassava produced in the coastal lowlands of Kenya is consumed at household level and 51% of the farmers make dried chips for domestic use, sale to starch and feed factories or as an intermediate material for production of flour.

Over the years, there has been mounting recognition of the contribution that cassava could make to increasing food security, incomes and generating employment opportunities in the rural sector. However, a substantial quantity of anti-nutrient factor cyanogenic glucosides, linamarin and a small amount of lotaustralin are also present in cassava (Burns et al., 2012; Kalenga Saka et al., 2012), which interfere, with digestion and uptake of nutrients (Bandna, 2012/13). Cyanide content ranges from 10 to 500 mg HCN equivalents/kg dry weight (DW) (Dufour, 1988) in root parenchyma. Cassava roots have a short post-harvest life of less than 24-72 hours (Abera and

Rakshit, 2003; Reilly et al., 2004). Cassava is associated with labour intensive farming and low-cost produce unlike other root and tuber crops (Benesi, 2004). This fact combined with the perishability of fresh cassava leads to shortcut processing techniques so as to rush the cassava to the market and hence poor quality products.

Cassava roots are bulky with about 70% moisture content, and therefore transportation of the tubers to urban markets is difficult and expensive (Dolodolotawake et al., 2011). Drying of cassava throughout the year implies that the products are exposed to varying weather conditions e.g. rainy seasons; this sun drying is cost effective, but slow and often the products may not easily dry due to high humidity, inadequate sunshine and exposure to rain thus encourages the growth of mould and other microorganisms. Mould growth may lead to production of mycotoxins, which are toxic secondary metabolites. According to Williams et al. (2004), mycotoxin exposure contributes to more than 40% of the global disease burden; in Africa, the reduction of the average human life span has been correlated with exposure to mycotoxins (Miller, 1996). Several fatal cases of aflatoxin ingestion have occurred in sub-Saharan Africa, including the recent events in Kenya, where more than 125 deaths were attributed to acute aflatoxin poisoning (Azziz-Baumgartner et al., 2005).

The presence of *Staphylococcus aureus* and *E. coli* is usually an indicator of unhygienic production conditions; they are pathogens, thus are disease causing microorganisms that may enter the body through the ingestion of food, causing food borne illnesses which are a leading cause of illness globally killing an estimated 2.1 million people annually, most of whom are children in the developing world (WHO, 2001). These microorganisms may be found in cassava chips and flour due to poor handling during harvesting, processing (especially fermentation where the quality of water used would impact greatly on the type of microorganisms that are

present in the products), storage or transportation. Due to poor microbiological properties of sundried cassava products, improved drying methods for chips which reduce the duration of the drying period to about two days would be a great advantage (Tewe and Iyayi, 1989; FAO, 2010). Solar dryers, such as the cabinet dryer, and tent solar drier can be constructed from locally available materials; they enhance the insulation effect and contribute towards the generation of higher temperatures and lower relative humidity, both of which are conducive to increased drying rates and lower final moisture content of the dried crop or product, the higher temperatures also deter insect and microbial infestation (IITA, 1990). The objective of this study was to determine the quality and safety of dried cassava chips and cassava flour in markets in the coastal and Nairobi regions as well as to assess the quality of tent solar dried cassava chips.

1.2   PROBLEM STATEMENT AND JUSTIFICATION

Cassava is a food rich in carbohydrates, some vitamins and minerals however, handling methods during drying and processing leads to food safety problems. Farmers and other processors use indigenous technologies such as sun drying and fermentation which are poorly controlled.

Cassava is harvested and sun-dried on virtually any surface in the open air such as flat rocks in the field, on the shoulders of paved roads, on flat rooftops, in a flat basket, or more commonly on bare ground (FAO, 2005) and the drying process may take from one day to three weeks (Essers et al., 1995). A study by Mlingi et al. (1995) in Tanzania reported that prolonged sun drying of cassava roots is not sufficient to reduce the cyanogenic glucosides in bitter cultivars to safe maximum level of 10 mg/kg. The sun-drying process of cassava lasting for 1 to 2 weeks initiates fermentation before the drying is completed hence compromising the quality of the dried product (Jensen et al., 1999). Sun drying cassava on the ground exposes the crop to contamination with

soil, dust, moulds and other foreign matter as this practice promotes contact between the products and the soil which is a primary source of moulds (Diener et al., 1987).

The conditions under which cassava is handled enable mould growth to occur leading to discolouration and changes in flavour (Knoth, 1993). During rainy season, when traditional sun drying methods are used, it takes long to dry the chips, leading to contamination and discolouration of the chips as well as formation of noxious odours and off-flavours that are unacceptable to the consumer (FAO, 2010). In cases where fermentation is used as method of processing, there are risks of contamination of the cassava chips by pathogens through the water that may be used while the sun-dried cassava is also of low quality and is often unsuitable for the production of high value products such as cassava flour (Jensen et al., 1999).

Due to poor quality and safety of traditionally sundried cassava products, improved drying methods for cassava, which reduce the duration of the drying period and ensure optimal cyanide detoxification, would be of great advantage (Tewe and Iyayi, 1989; FAO, 2010).

1.3 OBJECTIVES

1.3.1 Overall Objective
To determine microbiological contamination, cyanide and mycotoxin levels of cassava chips and flour in Coastal (Mombasa) and Nairobi markets and to assess the quality and safety of tent solar dried cassava chips.

1.3.2 Specific Objectives

i. To determine quality and safety of dried cassava chips and cassava flour available in the Coastal (Mombasa) and Nairobi region markets by investigating levels of microbial contamination, cyanide and aflatoxins.

ii. To design and assess the impact of a tent solar dryer on safety and quality of cassava chips in regard to level of cyanide, moisture content and colour.

1.4 RESEARCH QUESTIONS

i. What are the levels of microbial contaminants, cyanide and aflatoxins in the cassava products in the markets; are the levels within the recommended acceptable levels in available standards?

ii. What impact do the sizes of cassava chips and the tent solar drying have on cyanide, moisture content and colour of the end products?

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Cassava production in Kenya: global, African and Kenyan trends

Cassava is an important crop with sufficient amounts of carbohydrates, calcium, vitamins B and C, and essential minerals that are important in the development of healthy individuals. In Africa (sub-Saharan Africa), the diffusion of cassava can be described as a self-spreading innovation. Cassava was introduced into Africa by Portuguese traders from Brazil in the 16th century (Okigbo, 1980). Cassava is cultivated in around 40 African countries, stretching through a wide belt from Madagascar in the Southeast to Senegal and to Cape Verde in the Northwest (FAO, 2005).

About 70% of Africa's cassava output is harvested in Nigeria, the Congo and Tanzania (FAO /IFAD, 2000). Africa is a continent in crisis; it is racked with hunger, poverty and the HIV/AIDS pandemic, it is also the region with the fastest population growth, the most fragile natural resource base and the weakest set of agricultural research and extension institutions (FAO, 2005) therefore cassava being a nutritive and hardy crop could be able to help Africa towards the journey of attaining food secure status. Without question, domestic food production and/or food imports will have to be increased to meet Africa's growing food demand. Therefore, the urgent challenge before African nations is to increase domestic food production.

Cassava is an important starchy root crop, eaten and used by millions of people in West Africa and parts of eastern and central Africa (Amusa et al., 2003). Production in Africa has increased, as the crop produces even under growth limiting conditions (Ndung'u et al., 2012), this has seen the area of cassava production under unfavourable environments increasing continuously (El-

Sharkawy, 1993).In Benin, cassava is among the most important root crops with about 4 million tons produced in 2004 (FAO, 2005).According to CADDP (2010) in 2008, Nigeria produced close to 45 million MT, DRC produced15 million MT, Tanzania and Uganda had outputs of 6.6 million MT and 5 million MT respectively; while neighboring Rwanda and Kenya's production levels were much lower at 978,000 MT and 751,000 MT respectively.

Cassava is the second most important food root crop after Irish potato in Kenya; however, due to its narrow production base it is ranked number 36 out of 50 in KARI's 1991 priority setting exercise (KARI, 1995).Cassava cultivation is a major factor in food security across sub-Saharan Africa; when harvesting, it offers farmers an advantage of flexibility, as they can keep the roots in the ground until needed (Iglesias et al., 1997) this in a way ensures its availability as a food. Cassava can grow in marginal lands, requires low inputs, and is tolerant to pests and drought (Githunguri et al., 1998; Nweke et al., 2002). According to Bradbury and Holloway (1988), in times of drought, the leaves of the plant drop off, but the plant is kept alive by its large roots, sprouting again when the rains come. In Kenya cassava is grown in over 90,000 ha with an annual production of about 540,000 tons (Githunguri et al., 2008).

Cassava production in the country is concentrated in three main regions; coastal, central and western regions; western region of Kenya grows and consumes 60% of national cassava production (MoA, 2008). According to Githunguri et al. (2008) the importance of cassava as a food and cash crop in the central Kenya is however increasing. The western (former Western and Nyanza Provinces), coastal (former Coast Province) and eastern (former Central and Eastern Provinces) regions of Kenya account for 60%, 30% and 10% of production, respectively; it is second only to maize in importance in western and coastal regions of Kenya (Njeru and Munga, 2003).The crop is grown by small holder poor households for subsistence and is an important

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food security crop. In the coastal lowlands of Kenya the productivity of cassava is at 10tons/ha (Munga, 2000) compared to the potential yield of 50-70 t /ha fresh root (Gethi et al., 2008). One of the reasons for low productivity is the use of low yielding varieties (Munga, 2000).

Despite its great potential as a food security and income generation crop among the rural poor in marginal lands, its utilization remains low in Kenya. In addition, it can be safely left in the ground for a period of 7 to 24 months after planting and then harvested as needed.

2.2   Cassava utilization in Kenya

Total world consumption is predicted to reach 275 million MT by 2020; Thailand dominates the export market, with 70% of the world's dried cassava exports (4.6 million MT at US$122/MT in 2007) and 90% of cassava starch exports (1.4 million MT at US$275/MT in 2007) (FAO, 2010). The main destinations for dried cassava exports are China (69%) and the EU (24%), while the main importers of cassava starch are China and southeast Asian countries (Indonesia, Japan and Malaysia) which together account for 75% of the total imports; in recent years, there has been a significant shift in target markets from food to animal feed (CAADP, 2010). In Brazil, the congress passed a law making it mandatory for bread to contain at least 20% cassava flour and 40% in case of pizzas; the main reason is to reduce imports of wheat in order to develop cassava potential as a commercial crop. In Fiji cassava is one of the most important root crops; it has been reported that 59.2% of the Fijian population consumes cassava on a daily basis while 31% of the Indian population consumes cassava on a weekly basis (Bandna, 2012/13).

Cassava is a major source of calories for roughly two out of every five African people and in some countries, cassava is consumed daily and sometimes more than once a day; in the Congo for instance, cassava contributes more than 1000 calories per person per day to the average diet and many families eat cassava for breakfast, lunch and dinner (FAO, 2005). A report by Okigbo (1980) noted that the calorific value of cassava is high compared to most staples. About 50% and 6% of the mature plant are constituted of cassava roots and leaves respectively and are the nutritionally valuable parts of the plant (Tewe and Lutaladio, 2004); according to Wheatley and Chuzel (1993) and Harris and Koomson (2011) the edible starchy flesh comprises 80-90% total weight of the root.

Virtually all cassava produced in Africa is used for human consumption, about 70% of the amount consumed is processed into a large variety of products such as paste, flour and chips, and is cooked into foods serving both rural and urban populations as a basic daily source of dietary energy; other cassava based food products include cassava flakes, macaroni, fufu, gaplek, and gari. A report by Baafi and Safo-Kantanka (2007) intimated that in Ghana, most cassava is consumed fresh as fufu, though there are many small-scale and a few medium to large scale enterprises that process cassava into diverse food products and starch for industrial use. Nigeria is another West African state where Gari is the most consumed and traded of all the food products from cassava; its wide consumption is attributed to its relatively longer shelf life and ease of preparation as compared to other food products (Karim and Fasasi, 2009).

In several African countries, cassava is being perceived more and more not only as a food security crop, but also as a raw material for various types of industries; indeed cassava can be converted into a large number of products ranging from traditional and novel food products, to livestock feeds, ethanol and starch and its numerous derivatives (Nang'ayo et al., 2005; Aryee et

al., 2006). According to a report by Aderemi and Nworgu (2007), products such as cassava peels and sievate (chaff from processing cassava roots into "fufu") are used as poultry feeds, even though they are high in fibre thus limiting their utilization due to their high water holding capacity. A study by Nang'ayo et al. (2005) reported that in Nigeria, demand for HQCF (high quality cassava flour) for use by food industry offers enormous potential for small scale producers of cassava flour; the challenge however, is the emerging urbanisation and quality and safety issues that go with the production of HQCF.

In Kenya, cassava tubers are used as human food as well as animal feed. According to Githunguri et al. (2008) the leaves are also a popular vegetable among the locals; the roots are either boiled or fried before consumption. About 38% of the cassava produced is for domestic consumption and 51% of the farmers make chips for domestic use or sale to starch or feed factories, or as an intermediate for flour production (Kiura et al., 2005). The use of blended cassava flour for making bread, porridge, chapattis (unleavened flat bread) and mahamri has also been successfully demonstrated.

Although, world over, cassava is widely used in feeding pigs, cattle, sheep and poultry, utilization of cassava in animal feeds is still low in Kenya. With the advanced dairy and poultry industry in the country, cassava chips have the potential to replace 10-30 % of maize grains in animal feed rations. Utilization in Kenya is limited to roasting and boiling of fresh roots for consumption in most growing areas. However, in the former Nyanza and Western provinces of Kenya, roots are also peeled, chopped into small pieces (cassava chips), dried and milled into flour for ugali; this is normally in combination with a cereal (maize or sorghum) (Mburu, 2013). In the Coast region, cassava leaves are used as vegetable (Khaemba, 1983); while in eastern Kenya (Machakos and Kitui), raw or boiled cassava roots are chewed as a snack (Githunguri,

1995). According to Githunguri et al. (2008) most of the people at the coastal, eastern and western regions use cassava roots as family food and for sale at the local markets. A report by Anon (1998) intimated that in the western region of Kenya, cassava is a staple food, and it is intercropped with beans, maize and bananas; this region grows and consumes 60% of national cassava production; however, the presence of hydrogen cyanide has been reported to lower the quality of cassava roots, this has been a major reason for the rejection of cassava in eastern Kenya plus other 'boil and eat' societies like the coastal region (Githunguri, 1995; Nweke, 1996).

2.3 Common hazards in cassava products

The conservation of cassava is hindered by their highly perishable nature and the roots are easily contaminated by fungi (Wareing et al., 2001) and bacteria (Babajide et al., 2006). The most economical and common method of traditional preservation is sun drying; this drying is usually carried out under unhygienic conditions resulting in contamination thus products of low quality in terms of hygiene (Kwaisa, 1988). The drying is done on virtually any open surface; thus exposing the drying crop to dust, insects, fermentation, animal contamination and other environmental hazards (Ogori and Jana, 2013). There have been widespread observations of *staphylococcus* from animal and human sources due to the close association of animals with food, poor sanitation, contaminated surfaces used for drying, packaging material during storage and a polluted environment charged with spoilage and pathogenic flora (Norris, 1989); conditions that are present during handling and processing of cassava products.

African countries have a climate that is conducive to the growth of fungi and subsequent toxin production (mycotoxin) (Bankole and Adebanjo, 2003). Mycotoxin production can occur at any

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stage during production of foodstuffs in the field, during harvest, processing, storage or shipment (Jensen et al., 1999); in a study in Tanzania and Congo, mycotoxin contamination was observed on processed cassava chips and hence regular quality control is necessary (Manjula et al., 2009).

Cassava chips are subject to attacks by fungi such as *Aspergillus* and *Fusarium* species (Wareing et al., 2001). Studies in Uganda have shown that cassava can be contaminated with aflatoxins (Kaaya and Eboku, 2010) produced in ideal conditions by the *Aspergillus* species of fungi; while Wareing et al. (2001), isolated predominantly *Fusarium* species on dried Ghanaian cassava chips which may lead to fumonisin contamination. It is reported that fumonisin contamination is strongly influenced by several environmental factors including temperature, humidity, drought stress, and rainfall during pre-harvest and harvest periods (Fandohan et al., 2005) all of which are common occurrences in Africa. The most common mycotoxins are aflatoxins, produced by certain strains of the fungi *Aspergillus flavus* and *Aspergillus parasiticus*; aflatoxins pose the greatest risk to health in tropical Africa due to their widespread prevalence and high toxicity (Manjula et al., 2009). According to Kaaya and Eboku (2010) most of the moulds identified in cassava products are soil borne; implying that farmer practice of drying these products on bare ground predisposes them to fungal infection; fungal contamination can lead to discoloration of the chips, give rise to mouldy taste and produce off odours (Gwinner et al., 1996); this leads to poor quality and safety of products available in markets.

Aspergillus parasiticus produced large amounts of aflatoxin on processed cassava products at 40% moisture; and *Aspergillus flavus* were reported to have produced the highest aflatoxin levels at water activity of 0.996 and temperature of 30^0C at between 5-15 days of storage (Gqaleni et al., 1997). The optimum temperatures for aflatoxin production are between $24\text{-}30^oC$ with variation between strains and substrates (Klich, 2007), these temperatures are normal in Kenya

and other sub-Saharan countries, thus predisposing the stored cassava crop to mycotoxin contamination.

Cassava contains substantial quantity of anti-nutrient factor cyanogenic glucosides in the form of linamarin and a small amount of lotaustralin that interfere with digestion and uptake of nutrients (Burns et al., 2012; Kalenga Saka et al., 2012); they are useful to the plant for defense against herbivores (Jones, 1998; Vetter, 2000). The presence of cyanogenic glucosides therefore acts as a limiting factor to the human or animal consumption of cassava roots (Kakes, 1990). These cyanogenic glucosides are present in all parts of the cassava except the seeds. The cyanogenic glucosides are synthesized in the leaves and transported to the roots (Wheatley and Chuzel, 1993); the cyanogenic glucosides are present in large amounts in the leaves and the peel of the roots (900-2000 mg HCN/Kg) (Cardoso et al., 2005). According to Yeoh and Sun (2001) both compounds are hydrolyzed by plant's endogenous linamarase to release free cyanide which is a toxic compound to humans and animals and can cause serious health problems.

According to Rosling (1987), the cyanide yielding capacity of cassava roots is not only dependent on the genetic character of the genotype grown, but also on several environmental and growth factors; consequently, movement of a genotype from one location to another could alter its cyanogenic potential because of differences in climate and soil characteristics (Grace, 1977; TRIP, 1993). "Bitter" varieties of cassava have a cyanide level exceeding the Food and Agriculture Organization/World Health Organization (FAO, 1991) recommendation of a maximum of 10 mg/kg DW, which according to Montagnac et al. (2008) makes cassava acutely toxic to humans. There are a lot of scientific and medical based studies that show evidence associating consumption of high cyanide cassava with toxic effects in humans (Lundquist, 1992). According to Ballantyne (1983); Johnson and Mellors (1988), most common signs of acute

cyanide poisoning include; tachypnoea, headache, vertigo, lack of motor coordination, weak pulse, cardiac arrhythmias, vomiting, stupor, convulsions, and coma.Women and young children are often involved in the processing of cassava, placing them at a higher risk for inhalation and ingestion of cyanide.

The extent of cyanide in cassava products which are widely consumed worldwide was highlighted by a study in Fiji, by Bandna (2012/13) who reported that about 58% of cassava products sampled in the market had higher cyanide levels than levels accepted by Codex Alimentarius; ten samples of various cassava chips produced in Fiji by a single manufacturer and bought from Fijian supermarkets were analysed giving values of about 20 mg HCN/kg of fried cassava chips (Dolodolotawake et al., 2011).These studies showed a significant risk in food safety in terms of cyanide poisoning.

2.4   Cassava handling and processing

Farmers and other processors use indigenous technologies such as sun drying and fermentation which are inadequately controlled. Cassava is harvested and sun-dried on virtually any surface in the open air such as flat rocks in the field, on the shoulders of paved roads, on flat rooftops, in a flat basket, or more commonly on bare ground (FAO, 2005) and the drying process may take from one day to three weeks (Essers et al., 1995). Small scale processors are not able to meet costs like stainless steel equipment for production which are a part of HACCP requirements. Women and young children are often involved in the processing of cassava, placing them at a higher risk of inhalation and ingestion of cyanide. Due to the lack of proper set procedures for the harvesting, processing (including transporting), and storage of cassava, there arises food

safety concerns that need to be addressed so as to protect the consumers from hazards that may occur then occur.

The availability of safe food is a prerequisite for the well-being of citizens and development of national economies; low quality and safety of foods in Africa have a significant impact on human and animal health, and are a major constraint to growers who need access to more remunerating markets (Manjula et al., 2009). Some of the factors that are a threat to food safety and quality include poor physical quality, chemical contamination, bacterial or mycotoxin contamination (Bankole and Adebanjo, 2003); these usually occur in the course of processing, where handling equipment as well as hygiene of handlers is not checked. Cassava roots are harvested, peeled and then cut into pieces that vary in size; the pieces of cassava roots are spread on open surface to dry under the sun or are heaped to allow fermentation before the drying process to form chips; Essers et al. (1995) observed that crushing cassava produces small sizes and leads to faster drying.

Cassava chips are hygroscopic and tend to pick up moisture during storage which promotes mould growth and other deterioration agents (Knoth, 1993). Cassava products require drying below 12% moisture (Christensen et al., 1986); Aryee et al., (2006) observed that at 12% moisture cassava products had potential for long shelf life but moisture content greater than 12% allows microbial growth; safe moisture content is one of the prerequisites in preventing mycotoxins using the HACCP approach as the availability of water is essential for both mould growth and aflatoxin production (Klich, 2007). Poor handling and storage methods may also contribute to an accumulation of mycotoxins (Setamou et al., 1997); according to FAO (2005), available structures and methods for storage of cassava chips are inadequate for ensuring quality and safety of foodstuffs making pathogen contamination more likely to occur.

Typical mature cassava roots have an average composition of 60 – 70% water, (Breuninger et al., 2009); and cyanogenic glucosides of about 15-400 mg/kg varying in the different cassava varieties (Ndung'u, 2012). Processing cassava is important to ensure the safety and quality of the final products and hence this has led to traditional processing methods to obtain different relatively stable intermediate as well as final products for various food applications (Wilhemina, 2009); these include dried cassava chips which are further processed to cassava flour. There are several methods that are employed to reduce the cyanide levels to non-toxic levels including fermentation process where there is the washing of the cassava with clean water whose availability is scarce and hence people may end up using contaminated water, the peeled and sliced cassava roots are first surface-dried for 1-2 hours and then heaped together, covered with straw or leaves and left to ferment in air for 3-4 days until the pieces become mouldy. The fermented mouldy pieces are sun-dried after the mould has been scraped off; the processed and dried pieces (called "Makopa" in Uganda) are then milled into flour, which is prepared into a "fufu" called "kowan" in Uganda (Amey, 1987; Sauti et al., 1987). According to Aliyu and Hamisu (2009), flour is the most widely used form in which dried cassava roots can be marketed and most exporting countries produced them from cassava chips. A study by Charles et al. (2005), reported that processing cassava roots by grating, fermenting, soaking, boiling and drying reduced the cyanide content to maximum level of 10 mg/kg.

Drying has been found to reduce cyanide content, in a study by Mahungu et al. (1987) showed that slow sun drying, produces a greater loss of cyanide compared to oven drying. Studies carried out show that quick drying of cassava is advantageous in the sense that the risks of contamination and mould growth are minimized (Nghiem, 1991); another study established that 17 days of sun drying longitudinally split roots only reduces cyanogenic glucosides to 27-37%,

leaving more than 100 mg HCN equivalent per kg dry weight of flour, that is 10 times above the safe level set by FAO/WHO (Mlingi, 1995). Due to the high moisture content of cassava roots, they are perishable and hence vulnerable to spoilage, this fact affects their utilization and consumption after harvesting (Nghiem, 1991). For this reason, the cassava roots require the roots to be processed into a more stable form; the most common processing methods are direct sun drying of peeled roots for days into a product that can be stored (Mlingi, 1995). Sun-drying process of cassava lasting for 1 to 2 weeks initiates fermentation before the drying is completed hence compromising on the quality of the dried product (Jensen et al., 1999).

The colour of finished processed food is a critical quality parameter for consumer's acceptance, and its measurement has gained much attention from food scientists and industry (Oduro-Yeboah et al., 2010). During rainy season, when traditional sun drying processing method is used, it takes long to dry the chips; leading to contamination and discolouration of the chips thus detracts their appearance and noxious odours and off-flavours that are unacceptable to the consumer are usually observed (FAO, 2010). Due to poor microbiological properties of sun-dried cassava products, improved drying methods for chips which reduce the duration of the drying period to a maximum of two days and ensure optimal cyanide detoxification would be a great advantage (Tewe and Iyayi, 1989; FAO, 2010).

2.5 Sun drying and tent solar drying of cassava

Drying is the oldest and simplest method of processing cassava and is the mode of preservation used in most African countries; the use of natural sun as a drying agent is the most widespread method, as there is an abundance of solar radiation throughout the year (Weiss and Buchinger,

2002). Cassava roots are bulky with about 70% moisture content, and therefore transportation of the tubers to urban markets is difficult and expensive (Dolodolotawake et al., 2011). Drying reduces moisture, volume and cyanide content of roots, thereby prolonging product shelf life and making it less bulky and easy to transport; the objective is to produce dry cassava chips which are clean, have a white colour, and are free from extraneous matter hence can safely be stored for long periods thus ironing out the dent and seasonal fluctuations in availability not only of cassava but all types of fresh foods that are experienced due to crop failure and seasonal changes (Chiona et al., 2014).

Drying preserves by removing enough moisture from food to prevent decay and spoilage; the water content of properly dried food varies from 5-25% depending on the food involved and successful drying depends on: enough heat to draw out moisture without cooking the food; dry air to absorb the released moisture and adequate air circulation to carry off the moisture. The key to successful drying of food is the removal of moisture as fast as possible at a temperature that does not seriously affect the quality of the food (Sanni et al., 2012).

It is possible to harvest cassava at any time of the year and the crop can be left in the field for a long period of time. The roots are peeled, sliced into small pieces and sun-dried on racks or roofs (or virtually any other available place) for 4-5 days or sometimes up to 3 weeks (Essers et al., 1995), depending on the weather and the size of pieces and later, after sun drying, the products are stored in traditional storage systems such as in granaries and in huts for a period of up to one year (Kaaya and Eboku, 2010) or they are milled into flour (FAO, 2005) for preparation of local foods. This method is widely used in many areas in Africa, particularly where water supply for fermentation is seriously limited (IITA, 1988); it is very simple but the processed products contain considerable amounts of cyanide.

During rainy season, when the traditional sun drying method is used, it takes long to dry the chips, leading to the contamination and discolouration of the chips and production of noxious odours and off-flavours that are unacceptable to the consumer (FAO, 2010). When cassava is sun-dried, the quality is often unsuitable for the production of high value products such as cassava flour (Jensen et al., 1999). Solar drying is the advancement on sun drying which harnesses the solar radiation instead of the direct incidence on crop without a barrier. It has some comparative advantages; drying is faster while contamination is controlled since there is no direct exposure to the air. The structure can be very basic e.g. a box frame covered with plastic sheeting; when compared to sun and shade dryers, a solar dryer is a more controlled system because the product is placed in an enclosed space (and so not directly exposed to environment) (Sanni et al., 2012).

Solar drying is a more appropriate option than sun drying when the humidity is high since increased temperature leads to reduced relative humidity of the drying air and hence increased drying rate and shorter drying time provided there is adequate air circulation (Weiss and Buchinger, 2012). Solar dryers can be active or passive; passive types use natural convection and are appropriate for small-scale farmers because there is no need for extra energy and therefore the cost of processing is lowered, while active types use forced convection by means of a fan for improved air circulation. Solar dryers can also be classified into direct or indirect types; in the direct solar dryer, food is exposed directly to the sun's ray through the clear covering while in the indirect solar dryer, the product is dried by solar heated air only and is not in direct exposure to sun radiation; in general, an indirect solar dryer requires higher investment and more sophisticated technology than a direct solar dryer (Weiss and Buchinger, 2012).

According to Sanni et al. (2012) the lowest cost-models of dryers are passive direct solar dryers, the simplest of these being the tent dryer; it is cheap and simple to build. It consists of a frame of wood poles covered by plastic sheet. The tent driers can be taken down and stored when not in use (Weiss and Buchinger, 2012). However, it has the disadvantage of not being durable due to the plastic sheet (usually polythene) used which has to be replaced about twice a year (Jensen et al., 1999). According to Aberi (2012) who described the operation of a tent solar drier; solar radiation enters through the clear polythene sheets and is absorbed by the black surfaced polythene used on one side of the drier as well as the bottom and converted into heat; the heat absorbed heats the air inside the tent which rises and escapes through openings at the top while cooler air, enters through the bottom openings of the tent, drying the contents in the structure. The clear plastic polythene is transparent to short wave solar radiation and largely opaque to the long wave infrared radiation emitted by the black absorber surface. Thus a temperature higher than the surrounding ambient temperature is maintained inside the tent (Aberi, 2012).

2.6 Knowledge Gaps

The knowledge gaps identified in the review of literature were:

- The microbial contamination of cassava flour in markets have not been studied,

- Aflatoxin levels of cassava flour in the markets have not been clearly studied,

- Tent solar dried cassava chips have not been assessed to determine their quality and safety.

2.7 Study area

2.7.1 Coastal Region

Figure 2.1: Map of Coastal (Mombasa County) Region

It is situated in the southeast of Coast Province. It is the smallest in size covering an area of 212.5 km² The county lies between latitudes 3°56' and 4°10' south of the equator and longitudes 39°34' and 39°46' east. It is the smallest county in Kenya, covering an area of 229.7 km^2 excluding 65 km^2 of water mass. It has a population 939,370 people, 2009 population census. 30.17 ^{0}C averages per year high 22.4^{0}C low temperatures with 2,932 mean sunshine hours.

2.7.2 Nairobi Region

Figure 2.2: Map of Nairobi (County) Region

Nairobi County, The city occupies 696 km2 at 1,795 meters above sea level. According to the 2009 Census, in the administrative area of Nairobi, 3,138,295 inhabitants lived within 696 km^2.
The city lies on the Nairobi River in the southern part of country, and has an elevation of 1,795 metres (5,889 ft.) above sea level.

CHAPTER 3

3.0 Assessment of Microbial Contamination of Cassava Chips and Flour Sold in the Coastal and Nairobi Regions of Kenya

Abstract

Cassava is an important starchy root crop, eaten and used by millions of people in West Africa and parts of eastern and central Africa thus contributes to food security. However, the handling and processing practices expose it to microbial contamination. Samples from Nairobi and Coastal region of Kenya (due to their large consumer population), were evaluated for: Total viable count (TVC), S. *aureus*, total coliforms, yeast/ mould and E. *coli* to establish their safety and quality for human consumption. Results for dried cassava chips showed; TVC 5.16-8.04 log cfu/g; 4.81-7.21 log cfu/g, mould 1.00-3.86 log cfu/g; 1.00-3.28 log cfu/g and *Staphylococcus aureus* 2.69-4.36 log cfu/g; 2.90-4.71 log cfu/g for Nairobi and Coastal region respectively. Cassava flour had; TVC 5.66-7.67 log cfu/g; 5.92-8.12 log cfu/g, mould 1.00-6.73 log cfu/g; 2.65-5.08 log cfu/g, *Staphylococcus aureus* 3.77-5.79 log cfu/g; 1.00-5.73 log cfu/g, and coliforms 0-6.34; 2.00-6.27 log cfu/g for Nairobi and Coastal regions respectively. One sample tested positive for presence of E. *coli*. Eighty seven percent of cassava flour and 77% of dried cassava chips samples were confirmed for presence of *Staphylococcus aureus.* There was a significant (P≤0.05) difference in the microbial counts. Results indicate high level of microbial contamination that could be related to excessive manual handling and poor post-harvest handling practices of products hence they are of poor quality and unsafe for consumption. Proper training on good practices should be given to processors. Alternative hygienic drying methods for cassava are also recommended.

Key words: cassava flour, cassava chips, contamination

3.1 Introduction

Cassava (*Manihot esculenta* Crantz) contributes a lot to increasing food security and generating incomes and employment opportunities in the rural areas. Most of the cassava is produced by small scale farmers using traditional farming systems (Githunguri et al., 2007). About 38% of the cassava produced in the coastal lowlands of Kenya is consumed at household level and 51% of the farmers make dried chips for domestic use, sale to starch and feed factories or as an intermediate for production of flour (Kiura et al., 2005). Physiological reactions and activities of microorganisms that enter bruises caused during harvesting promote unfavourable biochemical changes and microbial deterioration in cassava. Traditional processing of cassava chips and flour is often done under unhygienic conditions. The chips are sun dried in the open surfaces such as flat rocks, roads, flat rooftops, flat baskets, or bare ground (FAO, 2005). Storage conditions after drying may also be of high humidity thus reversing the gains acquired during drying. Unhygienic conditions during production, storage and slow sun drying especially during the rainy season often results in bacteria and mould contamination (Chiona et al., 2014) like *Aspergillus* species that produce aflatoxins which are a major health concern to humans and livestock (Manjula et al., 2009). The presence of *Staphylococcus aureus* and *Escherichia coli* indicates unhygienic standards, excessive personnel handling and use of poor quality of water during processing, post-processing handling and marketing (Obadina et al., 2008). The standards Codex 176-1989 (CAC, 2013); EAS 739:2010; cassava chips specification and EAS 740:2010; on cassava flour specification set acceptable microbiological limits to be met that is, total viable count of 5.00 log cfu/g, mould maximum limit of 3.00 log cfu/g, *Staphylococcus aureus* limits 2.00 log cfu/g and coliforms should be absent from the foods. The objective of the current study was to analyse the level of contamination of cassava products that are in the market and available to consumers so as to assess the quality and safety of these products for human consumption.

3.2 Materials and Methods

3.2.1 Sampling of dried cassava chips and flour

Markets were identified in Coastal (Mombasa) and Nairobi regions as they are the largest cities (in terms of population) in Kenya, so most products are available in markets for consumers. Dried cassava chips and flour were bought randomly from retailers who operate in these markets. Mombasa region was divided into south coast, Mombasa Island region and three (3) markets were identified: Majengo (MJ), Kongowea (KON), and Marikiti (MA) markets. Nairobi region was divided into westlands, eastlands, southern and northern regions and five (5) markets were identified: Uthiru (UT), Kawangware (KAW), Githurai (GIT), Gikomba (GIK) and Muthurwa (MUT) markets. The sampling of the markets was purposive and the number of samples collected was according to their availability, thus ensuring exhaustive sampling. Thirteen (available) dried cassava chips and twenty three (available) cassava flour samples were identified and purchased from the different selected markets in the study sites. The samples were then packed in airtight sample bags to prevent any contamination during transport to the University of Nairobi microbiology and toxicology laboratories for analysis.

3.2.2 Microbial Determination

Microbial content was determined using laboratory methods and procedures as described by Harrigan and McCance (1976). Plate count technique was used whereby a known amount of the product or its dilution was mixed with a culture medium in a petri dish and after incubation, the numbers of developed colonies were counted and the viable count of the microorganisms (per gram) calculated.

3.2.2.1 Preparation of Dilutions

The samples were diluted so as to count the number of microorganisms that grow after incubation. In dried cassava chips or the cassava flour, the first dilution was made by

homogenizing 25 grams in 225 ml of diluent to obtain a 10^{-1} homogenate from which further dilutions were made where 1 ml of homogenate was mixed with 9 ml of diluent to form a 10^{-2} homogenate up until the required dilutions were achieved.

3.2.2.2 Enumeration of Total Viable Microbes

Plate Count Agar (PCA) was used to enumerate total viable microorganisms. Dilutions of the dried cassava chips and cassava flour were prepared and 1 ml of each dilution (10^{-3} to 10^{-5}) was pipetted into duplicate sterile petri dishes. The PCA was poured into the plates and mixed well (swerved clockwise and anticlockwise). The plates were incubated at $35^{0}C$ for 24-36 hours. The average counts of total viable microbes grown per product were reported in logarithmic form (log Cfu/g). If they test negative for TVC; the search is stopped.

3.2.2.3 Enumeration of yeasts and mould

Potato dextrose agar (PDA) was used to enumerate both yeasts and moulds. It was acidified by tartaric acid (pH 3.5) where about 3.5 ml was added to 40 ml of PDA. The main selective agent was the low pH, which discouraged the growth of most competitive bacteria. Dilutions of the dried cassava chips and cassava flour were prepared and 1 ml of each dilution (10^{-2} to 10^{-4}) was pipetted into duplicate sterile and disposable petri dishes. The PDA (acidified) were poured into the plates and mixed well (swerved clockwise and anticlockwise). The plates were incubated at $30^{0}C$ for 48-72 hours. The average counts of yeast and moulds were enumerated and reported in logarithmic form (log Cfu/g).

3.2.2.4 Enumeration of Staphylococcus aureus

Baird Parker Agar (BPA) selective media was used to grow and enumerate *Staphylococcus aureus*. About 3.5 ml of 3.5 % potassium tellurite was added to 1000 ml of BPA and about 25 ml of egg york was also added to the medium. The BPA was poured into the sterile plates and left

standing for 20 minutes to solidify. Dilutions of the dried cassava chips and cassava flour were prepared and 0.05 ml of each dilution range 10^{-2} to 10^{-4} were pipetted into duplicate plates and spread well. The plates were incubated at 35^{0}C for 24-36 hours. The plates selected for microscopic tests by gram staining had 20-300 well distributed colonies exhibiting the following characteristics:

- Convex, shiny black, with or without narrow grey-white margin and surrounded by clear zone extending into opaque medium or;

- Convex, shiny black, with or without narrow grey-white margin and surrounded by clear zone extending into opaque medium with an inner opaque zone or;

- Convex, shiny black, with or without narrow grey-white margin and 1mm in diameter;

The colonies that appeared under the microscope as grape like structures were deemed to be *staphylococcus*. Further confirmation tests for *Staphylococcus aureus* were carried out. At least one colony was selected and inoculated on plates of DNA-se agar by streaking. The plates were incubated at 35^{0}C for 48 hours. The DNA-se plates were flooded with 1 N HCl after the incubation period. Plates that showed clear zones on an opaque background indicating DNA decomposition confirmed *Staphylococcus aureus*. The average counts of confirmed *Staphylococcus aureus* were reported in logarithmic form (log Cfu/g).

3.2.2.5 Total Coliforms

Violet Red Bile Agar (VRBA) was used to enumerate total coliforms. Dilutions of the dried cassava chips and cassava flour were prepared and 1 ml of each dilution (10^{-2}-10^{-4}) was pipetted into duplicate sterile petri dishes. The VRBA was poured into the plates and mixed well (swerved clockwise and anticlockwise). The plates were incubated at 35^{0}C for 24-36 hours. Typical coliform colonies were indicated by red colonies with red background.

3.2.2.6 Escherichia Coli

Typical coliform colonies as indicated by red colonies with red background were transferred to E.C broth and incubated in test tubes with Durham tubes at 44^0C-45^0C in water bath for 24 hours. Gas formation observed indicated a positive result, the microbes from positive E.C tubes were streaked on Endo agar to obtain discrete colonies (indicated by red colonies with red background) and incubated at 35^0C for 18-24 hours and subjected to biochemical tests to confirm presence of E. *coli.* Characterization test was done by IMViC reaction according to Harrigan and McCance (1976).

3.2.2.7 Statistical Analysis

All the data was subjected to analysis of variance (ANOVA) and the means separated by Duncan Multiple Range Test using Genstat 15th Edition. The significance level was set at P=0.05.

3.3 Results and Discussion
3.3.1 Microbial contamination of dried cassava chips

Table 3.1 shows results of microbial counts of dried cassava chips sampled from different traders in the two study sites; Nairobi and Mombasa. The dried cassava chips samples from Nairobi were from Gikomba market and Kawangware markets and in Mombasa from Kongowea and Majengo markets**.** There was a significant (P≤ 0.05) difference in the microbial counts in the dried cassava chips samples from markets in Nairobi and Mombasa. The total viable count of samples of dried cassava chips from Nairobi and Mombasa markets ranged from 5.16 to 8.04 log cfu/g and 4.81 to 7.21 log cfu/g with mean counts of 6.57 log cfu/g and 6.12 log cfu/g, respectively.

Table 3.1: Microbial count of dried cassava chips from Nairobi and Mombasa Markets

Sample/Market	Region	TVC (log cfu/g)	Yeast and Mould(log cfu/g)	*Staphylococcus aureus* (log cfu/g)
GIK 1	Nairobi	7.19 ± 0.00^f	1.00 ± 0.00^a	3.93 ± 0.01^c
GIK 2	Nairobi	5.92 ± 0.11^c	2.15 ± 0.21^b	2.69 ± 0.12^a
GIK 3	Nairobi	5.61 ± 0.02^b	2.00 ± 0.00^b	3.03 ± 0.11^b
GIK 4	Nairobi	5.16 ± 0.06^a	1.00 ± 0.00^a	2.69 ± 0.12^a
GIK 6	Nairobi	8.04 ± 0.01^h	1.00 ± 0.00^a	4.36 ± 0.03^d
GIK 8	Nairobi	6.17 ± 0.08^d	2.15 ± 0.21^b	3.92 ± 0.11^c
KAW 1	Nairobi	6.95 ± 0.01^e	2.00 ± 0.00^b	4.27 ± 0.02^d
KAW 2	Nairobi	7.54 ± 0.07^g	3.86 ± 0.02^c	4.31 ± 0.05^d
KON 1	Mombasa	6.14 ± 0.04^c	3.28 ± 0.03^c	4.58 ± 0.18^c
KON 2	Mombasa	6.53 ± 0.05^d	3.10 ± 0.02^b	4.71 ± 0.07^c
KON 3	Mombasa	7.21 ± 0.11^e	1.00 ± 0.00^a	2.90 ± 0.00^a
KON 4	Mombasa	5.89 ± 0.02^b	3.07 ± 0.10^b	3.76 ± 0.13^b
MAJ1	Mombasa	4.81 ± 0.05^a	1.00 ± 0.00^a	3.00 ± 0.06^a

Values= Means ± Standard deviation in duplicates; Means in the same column with different superscripts are significantly different (P≤ 0.05). TVC= Total viable count.

Yeast and mould count of dried cassava chips samples collected in Nairobi and Mombasa from ranged 1.00-3.86 log cfu/g and 1.00-3.28 log cfu/g with a mean count of 1.90 log cfu/g and 2.29 log cfu/g, respectively. The yeast and mould counts reported in 87.5% of dried cassava chips from Nairobi were below the set limit. This is attributed to drying of the cassava chips to moisture content that was below 12%. One sample from Kawangware market (KAW 2) was found to have a count that was above the set limit representing 12.5% of the dried chip samples from Nairobi markets. These results agree with a report by Ogori and Gana (2013), the low counts are attributed to low moisture of ≤12% as observed in a study by Aryee et al. (2006) that limit microbial growth. About 60% of the samples of dried cassava chips collected in the Coastal

city of Mombasa had yeast and mould counts that were above the set limit in the standard and may be attributed to the moisture content in the chips that ranged between 10.15% and 11.57%.

The results of this study do not agree with those in a report by Kaaya and Eboku (2010) in Uganda that showed a mean mould count of 4.69 log cfu/g. The significance of low moisture contents in foods cannot be overemphasized as they help to enhance the shelf life of food samples and prevent rapid spoilage by microorganisms (Uriah and Izuagbe, 1990). It is important to note the highly perishable nature of the cassava roots makes it susceptible to contamination by bacteria and fungi (Wareing et al., 2001). In a study by Kaaya and Eboku (2010) samples collected were found to be contaminated with *Penicillium* (22.2%), *Aspergillus* (20.4%), and *Fusarium* species (5.6%). Fungal contamination can lead to discoloration of the chips, give rise to mouldy taste and produce off odours (Gwinner et al., 1996).

Staphylococcal count of dried cassava chips samples collected in Nairobi and Mombasa was in the range 2.69-4.36 log cfu/g and 2.90-4.71 log cfu/g with a mean count of 3.65 log cfu/g and 3.79 log cfu/g, respectively. The staphylococcal species reported in dried cassava chips are high; 77% of samples were confirmed for presence of *Staphylococcus aureus.* This can be attributed to post-harvest processing handling and exposure both at the processing sites and in the markets (Obadina et al., 2008). This is because the drying is usually done in open air where animals are reared.

3.3.2 Microbial contamination of cassava flour

Table 3.2 shows the results of microbial count for cassava flour sampled from traders in five markets in Nairobi: Gikomba, Githurai, Kawangware, Muthurwa and Uthiru markets and two markets in Mombasa; Marikiti and Majengo. There was a significant (P≤0.05) difference in the

microbial counts in the cassava flour samples amongst the traders in the markets in Nairobi and Mombasa.

Total viable count ranged from 5.66 to 7.67 log cfu/g and from 5.92 to 8.12 log cfu/g with mean count of 7.07 log cfu/g and 6.82 log cfu/g for Nairobi and Mombasa respectively. The high TVCs reported in all the cassava flour as shown in Table 3.2 were above the set acceptable limits. The results are in agreement with those in a study by Ogori and Gana (2013). The significant high bacteria load reported may be attributed to poor drying and handling methods during cassava processing.

Table 3.2: Microbial count in cassava flour from Nairobi and Mombasa markets

Sample/Market	Region	TVC(log cfu/g)	Yeast and Mould(log cfu/g)	Staphylococcus *aureus*(log cfu/g)	Total Coliforms (log cfu/g)
GIK 1	Nairobi	5.66 ± 0.03^a	1.00 ± 0.00^a	5.08 ± 0.07^d	0.00 ± 0.00^a
GIK 2	Nairobi	6.81 ± 0.04^c	3.90 ± 0.07^f	3.77 ± 0.10^a	5.76 ± 0.03^i
GIK 3	Nairobi	7.06 ± 0.01^{def}	4.26 ± 0.21^g	3.87 ± 0.04^a	6.27 ± 0.08^m
GIK 4	Nairobi	6.67 ± 0.07^b	3.66 ± 0.11^e	4.56 ± 0.06^b	6.06 ± 0.08^k
GIK 5	Nairobi	7.62 ± 0.00^j	2.97 ± 0.10^b	5.38 ± 0.03^e	5.00 ± 0.01^d
GIK 6	Nairobi	7.06 ± 0.03^{ef}	3.96 ± 0.02^f	4.45 ± 0.07^b	6.34 ± 0.02^n
GIT 1	Nairobi	7.31 ± 0.00^h	4.53 ± 0.03^h	5.79 ± 0.02^g	5.42 ± 0.00^f
KAW 1	Nairobi	7.22 ± 0.04^g	5.91 ± 0.03^j	5.44 ± 0.08^e	6.15 ± 0.00^l
KAW 3	Nairobi	6.98 ± 0.04^{de}	6.71 ± 0.04^k	5.48 ± 0.00^{ef}	0.00 ± 0.00^a
KAW 4	Nairobi	6.85 ± 0.03^c	6.73 ± 0.00^k	4.37 ± 0.24^b	5.68 ± 0.03^h
KAW 5	Nairobi	7.49 ± 0.03^i	3.24 ± 0.09^c	5.83 ± 0.04^g	5.94 ± 0.00^j
KAW 6	Nairobi	7.67 ± 0.08^j	5.55 ± 0.03^i	4.80 ± 0.10^c	5.81 ± 0.00^i
MUT 1	Nairobi	7.10 ± 0.00^f	4.69 ± 0.07^h	5.65 ± 0.00^{fg}	4.78 ± 0.00^c
UT 1	Nairobi	7.04 ± 0.08^{def}	3.52 ± 0.00^{de}	5.11 ± 0.12^d	5.58 ± 0.00^g
UT 2	Nairobi	7.61 ± 0.05^j	5.46 ± 0.11^i	5.01 ± 0.16^{cd}	4.60 ± 0.00^b
UT 3	Nairobi	7.00 ± 0.06^{de}	4.26 ± 0.12^g	5.00 ± 0.13^{cd}	5.33 ± 0.00^e
UT 4	Nairobi	6.96 ± 0.02^d	3.45 ± 0.05^d	4.86 ± 0.11^c	0.00 ± 0.00^a
MA1	Mombasa	6.40 ± 0.01^b	4.08 ± 0.02^c	3.02 ± 0.09^b	3.30 ± 0.00^b
MJ 1	Mombasa	5.92 ± 0.01^a	2.65 ± 0.07^a	4.34 ± 0.03^c	2.00 ± 0.00^a
MJ 2	Mombasa	7.32 ± 0.04^c	3.68 ± 0.09^b	5.28 ± 0.03^d	6.20 ± 0.07^d
MJ 3	Mombasa	8.12 ± 0.03^d	3.64 ± 0.01^b	5.28 ± 0.01^d	6.27 ± 0.02^d
MJ 4	Mombasa	5.94 ± 0.10^a	2.69 ± 0.12^a	1.00 ± 0.00^a	4.00 ± 0.00^c
MJ 5	Mombasa	7.18 ± 0.12^c	5.08 ± 0.09^d	5.73 ± 0.10^e	6.23 ± 0.01^d

Means $\pm$ Standard deviation; Means in the same column with different superscripts are significantly different ($P \leq 0.05$). TVC= Total Viable Count.

The yeast and mould count ranged from 1.00 to 6.73 log cfu/g and 2.65 to 5.08 log cfu/g with a

mean count of 4.34log cfu/g and 3.64log cfu/g for Nairobi and Mombasa respectively. About

88% and 67% of the flour samples from Nairobi and Mombasa respectively had counts that were above what is the allowed acceptable limit by the standard. These high mould counts may be attributed to the fact that flour is sold in open air markets and are displayed in jute bags lined with nylons and are thus exposed to rain or droplets of water and spores of various species of moulds, which are usually heavily suspended in air especially in an untidy and unhygienic environment. According to Odetunde et al. (2014) sporulating moulds easily contaminate foods that are openly displayed. The results in this study agree with those reported by Adebayo-Oyetoro et al. (2013) and Odetunde et al. (2014) that suggested high fungal growth in the samples of flour that were in markets in Nigeria. Kuku et al. (1984) and Abba–Kareem et al. (1991) isolated fungi, *Aspergillus fumigatus* and *Aspergillus niger,* from cassava flour. Moulds are potential spoilage agents (Uriah and Izuagbe, 1990) and cause off flavors in foods as well as changes in appearance of food (Elmer, 1990). The high mould counts found in the present study are an indication of potential spoilage agent and mycotoxins food poisoning (Reiss, 1978).

The Staphylococcus counts of flour samples collected from markets in Nairobi Mombasa ranged from 3.77 to 5.79 log cfu/g and from 1.00 to 5.73log cfu/g with the mean being 4.97 and 4.11 log cfu/g respectively. About 87% of cassava flour samples were confirmed for presence of *Staphylococcus aureus.* The results in the present study are in agreement with those found by Ogori and Gana (2013) who reported presence of Staphylococcus species in flour made from dried cassava "chunks" (chips) in a study site in Nigeria which could produce toxins that are a cause of external skin infection and potent infections. Liston and Matches (1976) and Guthrie (1983) reported that the most important sources of this organism in foods and beverages are the nasal canals and infected hands and that this microorganism constitutes a health hazard.

Staphylococcal spores have the ability to withstand high temperature and they produce enterotoxins which are not easily destroyed and may cause food poisoning.

Total coliform count in cassava flour samples ranged from 0.00 to 6.34log cfu/g and from 2.00 to 6.27log cfu/g with a mean count of 4.63 log cfu/g and 4.67log cfu/g in Nairobi and Mombasa markets respectively. About 82% of the samples in the present study, from markets within Nairobi had at least presence of coliforms; with one sample (GIK 4) being confirmed positive for presence of E. *coli.* The presence of coliforms is unacceptable in cassava flour according to the standard EAS 740:2010. Flour samples from Nairobi and Mombasa were found to be heavily contaminated with coliforms. The results in the present study are in agreement with those in a report by Odetunde et al. (2014) concerning similar work done in Nigeria.

The presence of coliforms in foods may indicate that foods were exposed to conditions favorable for the introduction and growth of pathogenic organisms (Odetunde et al., 2014); high counts in cassava flours may be due to coliform proliferation in the atmosphere (Okpokeri et al., 1985). The occurrence of lactose fermenters such as *Escherichia coli* suggests a degree of contamination with faecal discharges of human and animal origin (Refai, 1979; Uriah and Izuagbe, 1990; Olowoyo et al., 2001). The presence of these pathogenic microorganisms is thus an indication of microbial contamination with an incessant risk to the health of man (Odetunde et al., 2014).

3.4   Conclusion and Recommendations

High load of bacterial, Staphylococcus spp. and coliforms present in dried chips and cassava flour samples indicate excessive personnel handling and poor hygiene during post-harvest processing, handling and marketing (poor hygiene practices). High mould counts in flour indicate poor storage practices. Therefore, cassava chips and flours on the market are of low quality and unsafe for consumption.

Since presence of pathogenic microorganisms as well as other microbial contaminants is almost impossible to get rid of; it is paramount that basic hygiene and sanitary rules should be observed in the whole cassava production chain. Capacity building to farmers and processors on good practices especially good hygiene practices (GHP) and good storage practices (GSP); as well as equipping them with more affordable options of hygienic drying equipment and methods, will lead to improved quality and safety of the cassava products available in the market.

CHAPTER 4
4.0 Cyanogenic Content, Aflatoxin Level, Moisture and Colour of Dried Cassava Chips and Flour in Nairobi and Coastal Regions of Kenya

Abstract

Cassava is a staple food for approximately 800 million people in the world. However, it poses food safety risks to the consumers due to the naturally occurring cyanogenic glucosides. Thirty six samples of cassava products from Nairobi and Mombasa markets were evaluated for hydrogen cyanide (HCN), aflatoxin, moisture content and colour. The HCN content was in the range 30.00-47.12 mg/kg and 24.26-42.04 mg/kg in cassava chips; 24.01-72.17 mg/kg and 23.40-78.68 mg/kg in flour from Nairobi and Mombasa, respectively. Aflatoxin levels detected in two flour samples from Nairobi were 6.60 and 8.89 µg/kg respectively, and one sample from Mombasa had 2.84 µg/kg. Moisture content was in the range 8.62-9.98% and 8.85-11.57% in cassava chips; 8.50- 12.51% and 7.30-11.0% in cassava flour samples from Nairobi and Mombasa respectively. The L* values were in the range 83.9-92.0 and 69.0-81.7 and the colour difference from the standard white paper (ΔE*) were in the range 14.5-22.7 and 25.6-37.1 in cassava chips samples from Nairobi and Mombasa markets, respectively indicating less white dried cassava chips. The L* values for cassava flour was in the range 95.3-100.0 and 94.7-100.0 with ΔE* of 4.6-9.6 and 0.9-11.5 for Nairobi and Mombasa markets, respectively indicating very white flours. These results show that the flour in the market may be of good aesthetic (external) quality but unsafe for consumption. Plant breeders should come up with better cassava cultivars, which are relatively low in cyanogenic glucosides in the harvested raw form and the information passed on to farmers; better processing methods that would effectively play a part in achieving lower residual hydrogen cyanide in cassava products to acceptable levels as per standard requirements.

4.3 Introduction

Cassava (*Manihot esculenta* Crantz) is an important food crop due to the high carbohydrate content it provides to the diet; it is a staple food for approximately 800 million people (FAO/IFAD, 2000). The main food sources are starchy roots but the young leaves which are high in protein are also consumed (Achidi et al., 2005; Montagnac et al., 2009). However, cassava contains two cyanogenic glucosides, linamarin and lotaustralin (methyl linamarin) which are normally produced as a defence mechanism against predators as well as when the cassava tissue is crushed. These chemicals (cyanogens) are distributed widely throughout the plant, with the highest amounts occurring in the leaves and the root skin layer (root cortex), with lower amounts in the interior of the root (root parenchyma) (Cardoso et al., 2005). Cyanide inhibits cellular respiration of all aerobic organisms by blocking mitochondrial electron transport and preventing oxygen uptake (Solomonson, 1981); high exposure in humans leads to several symptoms such as nausea, vomiting, diarrhoea, dizziness, weakness and sometimes death (Akintonwa et al., 1994). The maximum safe level of cyanogens in cassava products including, dried cassava chips and flour set by the World Health Organization (WHO) is 10 mg/kg (FAO/WHO, 1991), with the limits in Indonesia set at 40 mg/kg (Damardjati et al., 1993; Djazuli and Bradbury, 1999). The East African Standards EAS 739:2010; 740:2010 sets the hydrogen cyanide limit at 10 mg/kg (EACa, 2010; EACb, 2010). Mycotoxin contamination is one of the factors that are a threat to food safety and quality; in African countries the climate is conducive to the growth of fungi and subsequent toxin production (Bankole and Adebanjo, 2003). The greatest risk to health in tropical Africa is posed by aflatoxins, due to their widespread prevalence and toxicity (Manjula et al., 2009). According to a study by Williams et al. (2004), mycotoxin exposure contributes to more than 40% of the global disease burden. The reduction of the average human life span in Africa has been correlated with exposure to mycotoxins (Miller, 1996). In Kenya, there was an

incident where more than 125 deaths were attributed to acute aflatoxin poisoning (Azziz-Baumgartner et al., 2005). Colour is a very important attribute of food, many consumers check on colour as a measure of quality and it often affects judgment on the safety; unfortunately it may be affected by the many processes used in producing cassava products (dried cassava chips/flour). In Africa, the low quality and safety of foods have a significant impact on human and animal health, as well as being a major constraint to growers who need access to more remunerating markets (Manjula et al., 2009). The aim of this study was to assess the safety and quality of commercial cassava products (dried chips and flour) in Nairobi and Coastal (Mombasa) regions of Kenya in terms of hydrogen cyanide content, aflatoxins, moisture content and colour.

4.4   Materials and methods

4.4.1   Sampling of dried cassava chips and flour
Sampling was done according to section 3.2.1. The samples were then packed in airtight sample bags and transported to the University of Nairobi microbiology and toxicology laboratories for analysis.

4.4.2   Determination of Hydrogen Cyanide content
The hydrogen cyanide (HCN) content of dried cassava chips and cassava flour were analysed using AOAC method (1990). Approximately 10 g of the sample was mixed with approximately 100 ml distilled water in a distillation flask. The distillation flask was then connected to the distillation apparatus and allowed to stand for at least two hours. The mixture was then distilled and approximately 200 ml of the distillate collected in a volumetric flask containing 25 ml of 2.5% NaOH solution; a portion of 8 ml of 5% KI solution was then added to 100 ml of distillate

and titrated against 0.02 N silver nitrate (AgNO$_3$) solution. The end point was indicated by a faint but permanent turbidity. The HCN content was calculated as: 1 ml of 0.02 N Silver Nitrate being equivalent to 1.08 mg of HCN per 10g and then expressed as HCN mg/kg of sample. Analysis was done in duplicates.

4.4.3 Determination of Aflatoxin levels

Aflatoxin was determined by ELISA Method according to technique adopted by Manjula et al. (2009). About 20 g of sample was extracted using 100 ml of 70 % methanol. The samples were filtered through Whatman filter paper and 15 ml of the extract collected. The filtrate tested using the Helica total Aflatoxin Enzyme-Linked Immunoassay (ELISA) assay kit. The limit of detection was 1 ppb. The samples were run in duplicates.

4.4.4 Determination of Moisture Content

The dried cassava chips were ground into powder using a grinder (Ramtons, model: RM /161 China) while the cassava flour was analyzed as it was. The clean and dry moisture dishes were then weighed and their weights recorded, then approximately 2 grams of the samples from the evenly mixed samples were weighed and the weights were recorded. All measurements were in duplicates. The moisture dishes containing the sample of the products were then placed in the drying oven at 105^{0}C for 3 hours, after which they were removed and cooled before being weighed. The weights of the cooled moisture dish plus the dried sample were recorded. The calculation for the moisture was then done according to AOAC (2005). The moisture content was reported as a percentage:

$$\left(\frac{(\text{Dish weight } + \text{ sample weight}) - (\text{Dish weight } + \text{ dried sample weight})}{\text{Initial sample weight}} \right) \times 100$$

4.4.5 Colour Determination

Colour was measured by colorimeter (MINOLTA CHROMA METER CR-200b) using CIELAB L*a*b* colour scale. L* indicates lightness and when closer to 100 is considered whiter, a* denotes the red/green with a positive (+) value showing a shift towards red and b* denotes the yellow/blue value with a positive (+) b* indicates a shift towards yellow. Colour readings were taken at different locations on the samples of dried cassava chips and flour. The meter was calibrated using a standard white background (L* = 100.0 a*=+0.7 b* = +0.7). ΔE value which defines the change of the total colour difference from the standard was determined. ΔE is defined by the following equation: $\Delta E = \sqrt{((\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2)}$. ΔL (lightness) = Colour difference is calculated as the sample L* value minus standard; Δa = Colour difference is calculated as the sample a* value minus standard; Δb = Colour difference is calculated as the sample b* value minus standard (Morrison and Laignelet, 1983).

4.4.6 Statistical Analysis

The statistical analysis was done by method described in section 3.2.2.7

4.5 Results and Discussion

The East African Standard EAS 739:2010 stipulates the compositional requirements for dried cassava chips that need to be conformed to for the dried chips to be considered safe for consumption. It requires that dried cassava chips have a maximum HCN content of 10 mg/kg and moisture content of 12%. The Codex Alimentarius Commission requires that aflatoxin in foods should not be more than 10 µg/kg (CAC, 2013).

4.5.1 Hydrogen cyanide, aflatoxin and moisture content in dried cassava chips and cassava flour

Table 4.1 shows the results of hydrogen cyanide (HCN), aflatoxin and moisture content of the 13 dried cassava chips samples obtained from markets in Nairobi and Mombasa. The HCN content ranged from 30.00 to 47.12 mg/kg and from 24.26 to 42.04 mg/kg (dry matter) in dried cassava

chips from Nairobi and Mombasa markets respectively. There was a significant difference (p≤0.05) in HCN among the dried cassava chips from both Nairobi and Mombasa markets. All the samples of dried cassava chips had HCN levels that were more than 10 mg/kg. These quantities are above the recommended acceptable limits with the least amounts in samples from Nairobi and Mombasa being 24.26 and 30.00 mg/kg dry matter respectively. The high levels of HCN in the cassava chips may be due to the improper processing of the cassava roots or high amounts of total cyanide levels in the raw cassava (Cardoso et al., 2005).

Table 4.1: Hydrogen cyanide, Aflatoxin and Moisture Content of Dried Cassava Chips from Nairobi and Mombasa

Sample/Market	Source	HCN (mg/kg)	Total Aflatoxin(µg/Kg)	MC (%)
GIK 1	Nairobi	41.72 ± 0.04^d	nd	9.18 ± 0.49^{ab}
GIK 2	Nairobi	30.00 ± 0.04^a	nd	9.35 ± 0.27^{ab}
GIK 3	Nairobi	40.76 ± 0.28^c	nd	9.43 ± 0.25^{ab}
GIK 4	Nairobi	35.88 ± 0.04^b	nd	9.98 ± 0.29^b
GIK 6	Nairobi	47.12 ± 0.28^e	nd	8.91 ± 0.45^{ab}
GIK 8	Nairobi	29.76 ± 0.14^a	nd	8.62 ± 0.42^a
KAW 1	Nairobi	47.29 ± 0.21^e	nd	9.60 ± 0.55^{ab}
KAW 2	Nairobi	29.80 ± 0.04^a	nd	9.68 ± 0.79^{ab}
KON1	Mombasa	24.26 ± 0.07^a	nd	11.57 ± 1.07^c
KON2	Mombasa	42.10 ± 0.04^b	nd	10.65 ± 0.14^{bc}
KON3	Mombasa	41.27 ± 0.18^b	nd	8.85 ± 0.01^a
KON4	Mombasa	23.74 ± 0.21^a	nd	9.21 ± 0.48^{ab}
MAJ1	Mombasa	42.04 ± 0.18^b	nd	10.15 ± 0.14^{abc}

Values=Means ± Standard deviation; Means in the same column with different superscripts are significantly different (P≤ 0.05); **HCN**= Hydrogen Cyanide (mg/Kg); **nd**= Not detectable within the assay used which had a maximum detectability level of 1ppb; **MC**= Moisture Content (%).

The high levels of HCN found in the present study are in agreement with what Oghenechavwuko et al. (2013) found in a study carried out in Nigeria. Similarly, Burns et al. (2011) reported that cassava chips contained as high as 262 mg/kg and an overall mean of 91 mg/kg HCN. Even though chips are usually processed further, the high HCN content shows that there is need for better processing methods to have a safe end product for human and animal consumption as well as the need of coming up with cassava varieties that have relatively lower cyanogenic glucoside content.

All the samples of dried cassava chips from markets in both study sites showed no detectable (nd) levels of total aflatoxin thus were within the limits set by the CAC (2013). The low quantities of aflatoxin in the present study may be attributed to dried chips may not be a good substrate for aflatoxin biosynthesis. The low aflatoxin content may also be attributed to shorter storage period of cassava chips as well as proper storage conditions as shown by the moisture content observed in the samples collected; according to Setamou et al. (1997) poor storage coupled with inappropriate handling methods contribute to accumulation of mycotoxins. The low or no incidences of aflatoxin contamination have also been reported in Ghana (Wareing et al., 2001) and Benin, where a report showed no aflatoxin contamination of cassava chips (Gnonlonfin et al., 2008). The results are also in agreement with those of studies done by Oluwole et al. (2004), Usman (2011) and Oghenechavwuko et al. (2013). They however are not in agreement with those in a report by Manjula et al. (2009) that indicated that all cassava chip samples collected in Tanzania contained aflatoxin though in low quantities.

The moisture content (wwb) of the dried cassava chips collected ranged from 8.62% to 9.98% in Nairobi and 8.85% to 11.57% in Mombasa markets. There was no significant difference (p>0.05) in moisture content between most of the samples from both study sites. Moisture content of

cassava chips was below 12% as recommended in the standards. Low moisture content observed in the dried cassava chips from Nairobi and Mombasa may be attributed to effective drying methods employed by the processors, as cassava is perishable and needs to be dried optimally (below 12% MC) to keep longer; thus the processors and traders avoid making losses by ensuring proper drying. The lower the moisture content, the better it would be for storage to prevent growth of microorganisms, undesirable fermentation and caking (Maltini et al., 2003). High moisture content is also a prerequisite for growth and proliferation of mould and eventual mycotoxin production. The effective drying is also preferred as water activity may be increased by moisture uptake during storage and this may lead to change in certain chemical and organoleptic properties (Eriksson et al., 2014).

Table 4.2 shows the hydrogen cyanide, aflatoxin and moisture content of the 23 flour samples obtained from Nairobi and Mombasa. There was a significant difference ($p \leq 0.05$) in the HCN content of flour among the different markets and traders in both the regions of study. The range for the HCN content in flour samples was 24.01-72.17 mg/kg dry matter in Nairobi markets and 23.40-78.68 mg/kg dry matter in Mombasa; these levels are higher than the maximum recommended level of 10 mg/kg. These results are in agreement with those in the reports by Cardoso et al. (1998) and Cardoso et al. (2005). In Indonesia, the mean cyanide content for flour was found to be 54 mg/kg (Djazuli and Bradbury, 1999). The high HCN levels may be attributed to poor processing methods for the cassava flour. A report by Cardoso et al. (2005) showed that areas of eastern, central and southern Africa, where flour is produced after sun drying dried chips, the cyanide content is high on a normal year and gets worse in low rainfall years. A report by Bokanga et al. (1994) intimated that total cyanide levels in roots increased when there was low rainfall due to water stress on the cassava plant.

Table 4.2 : Hydrogen cyanide, Aflatoxin, Moisture Content in Cassava Flour Samples from Nairobi and Mombasa

Sample/ Market	Source	HCN (mg/kg)	Total Aflatoxin (µg/Kg)	MC (%)
GIK1	Nairobi	36.31 ± 0.18^c	nd	10.55 ± 0.35^{ab}
GIK2	Nairobi	30.25 ± 0.32^b	nd	10.15 ± 0.07^{ab}
GIK3	Nairobi	30.50 ± 0.32^b	nd	10.57 ± 0.35^{ab}
GIK4	Nairobi	47.59 ± 0.18^e	nd	9.06 ± 0.37^{ab}
GIK5	Nairobi	60.29 ± 0.04^g	nd	10.55 ± 0.07^{ab}
GIK6	Nairobi	24.01 ± 0.04^a	6.60 ± 0.00	10.33 ± 0.04^{ab}
GIT1	Nairobi	48.00 ± 0.04^e	nd	10.15 ± 0.49^{ab}
KAW1	Nairobi	49.32 ± 0.00^e	nd	12.51 ± 3.20^b
KAW3	Nairobi	54.45 ± 0.00^f	8.89 ± 0.00	10.75 ± 0.07^{ab}
KAW4	Nairobi	53.11 ± 0.00^f	nd	8.50 ± 3.10^a
KAW5	Nairobi	42.33 ± 0.00^d	nd	10.83 ± 0.52^{ab}
KAW6	Nairobi	30.25 ± 0.00^b	nd	10.75 ± 0.13^{ab}
MUT1	Nairobi	42.80 ± 0.04^d	nd	11.85 ± 3.61^{ab}
UT1	Nairobi	47.50 ± 0.04^e	nd	9.20 ± 0.28^{ab}
UT2	Nairobi	60.48 ± 0.14^g	nd	10.55 ± 0.07^{ab}
UT3	Nairobi	54.64 ± 0.14^f	nd	11.05 ± 0.35^{ab}
UT4	Nairobi	72.17 ± 0.18^h	nd	10.45 ± 0.07^{ab}
MA1	Mombasa	23.40 ± 0.14^a	nd	7.30 ± 0.14^a
MJ1	Mombasa	72.70 ± 0.07^e	2.84 ± 0.00	10.95 ± 0.07^d
MJ2	Mombasa	64.71 ± 0.04^d	nd	9.72 ± 0.06^c
MJ3	Mombasa	35.69 ± 0.35^b	nd	8.53 ± 0.74^b
MJ4	Mombasa	78.68 ± 0.11^f	nd	11.00 ± 0.14^d
MJ5	Mombasa	41.05 ± 0.11^c	nd	7.85 ± 0.07^{ab}

Values=Means $\pm$ Standard deviation, means in the same column with different superscripts are significantly different (P$\leq$ 0.05); **HCN**= Hydrogen Cyanide (mg/Kg); **Nd**= Not detectable within the assay used which had a maximum detectable level of 1ppb; **MC**= Moisture Content (%).

A study by Cardoso et al. (1999) showed the effect of low rainfall of greatly increasing total cyanide content of cassava flour; hence may also be an explanation for the high levels reported in the present study. In a study by Ernosto et al. (2002b) where flour samples were collected in November 1998 and in July 1999, many cases of acute intoxication and occurrence of Konzo in the communities was attributed to the high cyanide level in flour samples. It is also important to note that the HCN contents that were recorded in this study are acceptable in some countries, for instance the limit that is acceptable in Indonesia is 40 mg/kg (Adindu et al., 2003; Cardoso et al., 2005). High HCN may lead to acute cyanide poisoning or a chronic sickness that is associated with extended use of monotonous diets of high HCN foods, Konzo or tropical ataxic neuropathy (TAN) (Mckey et al, 2010). It is clear that better cultivars of cassava should be developed and the information communicated to farmers and more effective processing protocols should be developed and the information communicated to processors to ensure the HCN levels are reduced to acceptable values.

Aflatoxin was detected in two flour samples in Nairobi; 6.60 µg/kg (GIK6) and 8.89 µg/kg (KAW3), representing 11.76% of the samples from Nairobi. In Mombasa only one flour sample MJ1 had 2.84 µg/kg of total aflatoxin. The levels reported are lower than the maximum levels set by the CAC (2013); this indicates that the cassava flours may not be good substrates for aflatoxin biosynthesis. The results in the present study are in agreement with those reported by Gnonlonfin et al. (2008) and Chiona et al. (2014) that revealed no aflatoxin contamination in Malawi, Zambia and Benin. A study in Uganda that was carried out on 10 samples of cassava flour also showed no aflatoxin contamination (Essers et al., 1995).

There was no significant difference (p>0.05) in the moisture content (MC) of flour samples from Nairobi but there was a significant difference (p≤0.05) between MC of flour samples from

Mombasa markets. The MC range was 8.50- 12.51 %, with 17.6% of the samples having below 10% in Nairobi markets; and the MC range in samples from Mombasa markets was 7.30-11.0% and were all below the upper limits recommended in the standards. Low MC of cassava flour samples from Nairobi and Mombasa markets may be attributed to effective drying processes used; moisture content of flour is influenced by extent of drying and relative humidity during the period of sun-drying (Apea-Bah et al., 2011).

Flour samples from Mombasa were relatively lower in MC than those from Nairobi region; this may be attributed to higher temperatures that are usually recorded in the Coastal areas. Transportation conditions and distances from areas of production may also play a role in the difference of the moisture content between Mombasa and Nairobi; mainly because cassava flour found in Nairobi markets is often from the coastal or western regions of Kenya, moreover, the storage conditions of the flour in the markets in both sites of study may also play a role in the different moisture contents recorded. The results in the present study are in agreement with those reported by Apea-Bah et al. (2011), Emmanuel et al. (2012) and Eriksson et al. (2014). Low moistures lead to longer shelf lives of cassava products as they reduce microbial growth and proliferation.

4.5.2 Colour of dried cassava chips and flour

Standards EAS 739:2010 and EAS 740:2010 on dried cassava chips and cassava flour respectively state that the colour of these products should be white, creamy or yellow.

Table 4.3 shows colour parameters in terms of CIE L*a*b*for 13 dried cassava chips samples that were obtained from Nairobi and Mombasa markets. There was no significant difference (p>0.05) in L* values of Cassava chips sampled from markets in both study sites with values ranging from 83.9 to 92 in Nairobi markets and from 69.0 to 81.7 in Mombasa markets.

Table 4.3: Colour Parameters of Dried Cassava Chips from Nairobi and Mombasa

Sample/Market	Source	L*	a*	b*	ΔE*
GIK1	Nairobi	92.0 ± 3.4^a	1.2 ± 0.6^{ab}	11.9 ± 2.7^{ab}	15.0
GIK2	Nairobi	90.0 ± 4.0^a	1.1 ± 0.3^{ab}	10.0 ± 1.9^a	15.2
GIK3	Nairobi	91.8 ± 1.8^a	1.2 ± 0.1^{ab}	11.1 ± 2.1^{ab}	14.5
GIK4	Nairobi	88.9 ± 2.2^a	1.4 ± 0.3^{ab}	16.5 ± 3.6^b	20.5
GIK6	Nairobi	87.5 ± 8.1^a	1.0 ± 0.6^a	11.0 ± 2.6^{ab}	17.8
GIK8	Nairobi	91.2 ± 3.3^a	1.3 ± 0.8^{ab}	13.5 ± 2.5^{ab}	16.8
KAW1	Nairobi	83.9 ± 5.9^a	2.2 ± 0.8^b	14.4 ± 3.2^{ab}	22.7
KAW2	Nairobi	88.6 ± 1.4^a	1.8 ± 0.5^{ab}	12.6 ± 3.7^{ab}	18.0
KON1	Mombasa	81.7 ± 7.1^a	2.6 ± 1.1^a	21.2 ± 3.1^b	28.9
KON2	Mombasa	71.0 ± 12.9^a	3.2 ± 0.6^a	20.8 ± 1.4^{ab}	37.1
KON3	Mombasa	69.0 ± 3.8^a	2.3 ± 0.4^a	16.1 ± 1.1^{ab}	36.6
KON4	Mombasa	80.7 ± 4.4^a	2.1 ± 0.8^a	16.9 ± 2.9^{ab}	26.8
MAJ1	Mombasa	81.4 ± 12.7^a	3.4 ± 2.2^a	15.6 ± 4.1^a	25.6

Values=Means ± Standard deviation, means in the same column with different superscript are significantly different (p≤0.05); **L***= Lightness (≤100); **a***= (-) red/green (+); **b***= (-) blue/Yellow (+); **ΔE***= Difference in colour change from the standard white background

There was no significant difference (p>0.05) in the a* values between the dried cassava chips sampled from markets in Nairobi and Mombasa, with values that ranged from +1.0 to +2.2 in Nairobi and from +2.1 to +3.4 in Mombasa markets. The b* values of the samples from markets in Nairobi and Mombasa had no significant difference (p>0.05) and ranged from +10.0 to +16.5 in Nairobi and from +15.6 to +21.2 in Mombasa markets. The total colour difference (ΔE*) between the samples from markets in both study sites and a white paper used as a standard, were found to be high and were in the range 14.5-22.7 in Nairobi and 25.6-37.1 in Mombasa.

Cassava chips sampled from Nairobi were generally white, with GIK4, GIK6, KAW1 and KAW2, showing the greatest ΔE* thus indicating they were less white compared to the white

standard paper, with samples from Mombasa having large ΔE^*, low L^* and higher $+b^*$ values. The less whiteness observed in some samples of dried cassava chips, particularly ones obtained from Mombasa markets, could be attributed to the variety, age (Oduro-Yeboah, 2010) as well as processing procedure which could include lack of thorough peeling, since natural pigments from peels may affect colour (Van Hall, 2000).

Table 4.4 shows the colour parameters for the 23 cassava flour samples from Nairobi and Mombasa markets. There was no significant difference ($p>0.05$) in the L^* values of cassava flour with values that ranged from 95.3 to 100.0 and from 94.7 to 100.0 in cassava flour from Nairobi and Mombasa markets respectively. The a^* values of the samples from the study sites were not significantly different ($p>0.05$) and ranged from $+0.3$ to $+1.3$ and from $+0.9$ to $+1.5$ in Nairobi and Mombasa respectively, while b^* values of the samples obtained were significantly different ($p\leq0.05$) and ranged from $+4.7$ to $+8.2$ in Nairobi and from $+0.1$ to $+10.7$ in Mombasa markets.

Table 4.4: Colour Parameters of Cassava Flour from Nairobi and Mombasa Markets

Sample/Market	Source	L*	a*	b*	ΔE
GIK1	Nairobi	99.6 ± 0.2^d	0.5 ± 0.1^{bcde}	5.7 ± 0.1^b	5.6
GIK2	Nairobi	99.8 ± 0.4^d	0.3 ± 0.2^{ab}	6.0 ± 0.3^{bc}	5.8
GIK3	Nairobi	99.4 ± 0.7^{cd}	0.5 ± 0.2^{bcde}	6.5 ± 0.3^{cd}	6.4
GIK4	Nairobi	97.6 ± 2.2^{abcd}	0.8 ± 0.3^f	4.7 ± 0.3^a	5.9
GIK5	Nairobi	100.0 ± 0.0^d	0.5 ± 0.1^{abcde}	4.8 ± 0.2^a	4.6
GIK6	Nairobi	99.6 ± 0.3^d	0.3 ± 0.2^a	7.1 ± 0.2^d	6.8
GIT1	Nairobi	97.6 ± 1.2^{abcd}	0.4 ± 0.1^{abc}	6.2 ± 0.2^{bc}	7.1
KAW1	Nairobi	95.9 ± 0.6^{ab}	0.4 ± 0.1^{abcd}	8.0 ± 0.3^e	9.5
KAW3	Nairobi	95.3 ± 5.1^a	0.5 ± 0.1^{bcde}	6.3 ± 0.3^{bc}	8.8
KAW4	Nairobi	97.2 ± 1.3^{abcd}	0.7 ± 0.1^{def}	6.0 ± 0.5^{bc}	7.2
KAW5	Nairobi	96.1 ± 0.9^{abc}	0.6 ± 0.2^{cdef}	8.0 ± 0.6^e	9.3
KAW6	Nairobi	96.1 ± 0.4^{ab}	0.5 ± 0.1^{abcde}	8.2 ± 0.3^e	9.6
MUT1	Nairobi	96.8 ± 3.0^{abcd}	1.3 ± 0.1^g	6.2 ± 0.6^{bc}	7.6
UT1	Nairobi	98.7 ± 0.4^{bcd}	0.5 ± 0.0^{abcde}	7.1 ± 0.3^d	7.2
UT2	Nairobi	95.7 ± 0.7^{ab}	0.8 ± 0.1^f	5.7 ± 0.1^b	8.0
UT3	Nairobi	97.6 ± 2.0^{abcd}	0.7 ± 0.0^{ef}	5.9 ± 0.7^{bc}	6.8
UT4	Nairobi	98.4 ± 0.3^{abcd}	0.8 ± 0.1^f	5.8 ± 0.3^b	6.3
MA1	Mombasa	100.0 ± 0.6^b	1.3 ± 0.1^{cd}	0.1 ± 0.1^a	0.9
MJ1	Mombasa	96.7 ± 0.4^a	1.2 ± 0.3^{bc}	8.6 ± 0.1^b	9.6
MJ2	Mombasa	97.0 ± 0.3^a	1.0 ± 0.2^{ab}	9.5 ± 0.1^c	10.1
MJ3	Mombasa	96.3 ± 2.9^a	1.5 ± 0.1^d	10.7 ± 1.0^d	11.5
MJ4	Mombasa	96.7 ± 0.4^a	0.9 ± 0.1^a	8.4 ± 0.1^b	9.3
MJ5	Mombasa	94.7 ± 2.4^a	1.3 ± 0.1^{cd}	9.6 ± 0.5^c	11.5

Values=Means ± Standard deviation, means in the same column with different superscript are significantly different (p≤0.05); **L***= Lightness (≤100); **a***= (-) red/green (+); **b***= (-) blue/Yellow (+); **ΔE***= Difference in colour change from the standard white background

The ΔE* values of the cassava flour samples from Nairobi markets ranged from 4.6 to 9.6 while those from Mombasa markets ranged from 0.9 to 11.5. The cassava flour samples collected

from markets in Nairobi and Mombasa had high L* values and low $\Delta E*$ indicating that they were very white, compared to the standard white paper. Consumers generally would look at how white flour is, as an indicator of quality and hence better processing procedure should be adopted to ensure the whiteness. However, since consumers use this parameter as a measure of quality and safety, they purchase products that are white but unsafe due to high residual HCN.

Natural pigments from peels may affect the colour of chips/flour; the older the cassava at the time of processing the less white its product appears to be (Van Hall, 2000). The whiteness of the cassava chips and flour (Table 4.3; Table 4.4) could be attributed to the non-fermentation as indicated in a report by Eriksson et al. (2014) which is in agreement with the results in the present study. The results in the present study are also in agreement with the values of colour parameters in a report by Hongbete et al. (2009) which also intimated that there was an increase in ΔE and b* for traditionally processed cassava flour, and further processing of flour made it whiter with a significant decrease in $\Delta E*$ and b*.

4.6 Conclusion and Recommendations

This study revealed that there is a wide range of cyanide concentrations in dried cassava chips and cassava flour available in the markets in Nairobi and Mombasa. The negative impacts of excess cyanide consumption are well documented and known including acute poisoning. Aflatoxin levels in the cassava products are acceptable and within the recommendations of standards, indicating that cassava is not a good substrate for aflatoxin biosynthesis. Moisture contents in the cassava products is below 12% indicating proper drying processes thus increasing postharvest quality, while the colour of the products is mostly white thus fitting customer

demands. Cassava products in this study are of good quality in terms of aflatoxin levels, moisture content and colour but unsafe for consumption due to their high residual hydrogen cyanide.

The recommendations from this study are: for plant breeders to come up with better cassava cultivars, which are relatively low in cyanogenic glucosides in the harvested raw form and the information passed on to farmers; better processing methods that would effectively play a part in achieving lower residual hydrogen cyanide in cassava products to acceptable levels as per standard requirements.

CHAPTER 5

5.0 Safety and Quality of Dried Cassava Chips from a Tent Solar Drier

Abstract

Cassava (*Manihot esculenta Crantz*) is a major staple food in tropical countries; its roots cannot be stored for long in fresh form as they are highly perishable. It is necessary to develop methods of hygienically preserving cassava to ensure quality and safety of products. This study was undertaken to determine safety and quality of dried cassava chips from a tent solar drier. Three cultivars of cassava (Fumba chai, MH95/0183, MM96/2480) from KALRO-Kakamega farm, were peeled and chopped into 3 thicknesses; 1, 3 and 5 mm. A tent solar drier was fabricated and used for drying the chips. Hydrogen cyanide (HCN), moisture content, and colour of the dried chips were analysed. There was a significant difference ($p \leq 0.05$) in the percentage loss of HCN between the different thicknesses ranging from 20.2% to 50.1%; residual HCN ranged from 32.3 to 51.8 mg/kg. The percentage loss of moisture among thicknesses ranged from 32.3% to 83.3%, over a 3 day drying period; with final MC ranging from 9.81 to 11.67%. Colour parameters showed no significant difference ($p > 0.05$) between the different thicknesses, and they were predominantly white in colour (L* 81.1-94.8). The 5 mm thick cassava chips showed the highest percentage loss of HCN and moisture, indicating it as an optimum size for effective drying and reduction of hydrogen cyanide in the tent solar drier. The tent solar dried cassava chips, were thus of good quality but unsafe for consumption in the raw form due to high residual HCN. It is however, expected that the residual HCN will be reduced to acceptable safe levels after milling process (in case of flour) and finally by cooking methods that involve boiling.

Key words: Cassava flour, Cassava chips, Hydrogen cyanide, Tent solar drier, Colour
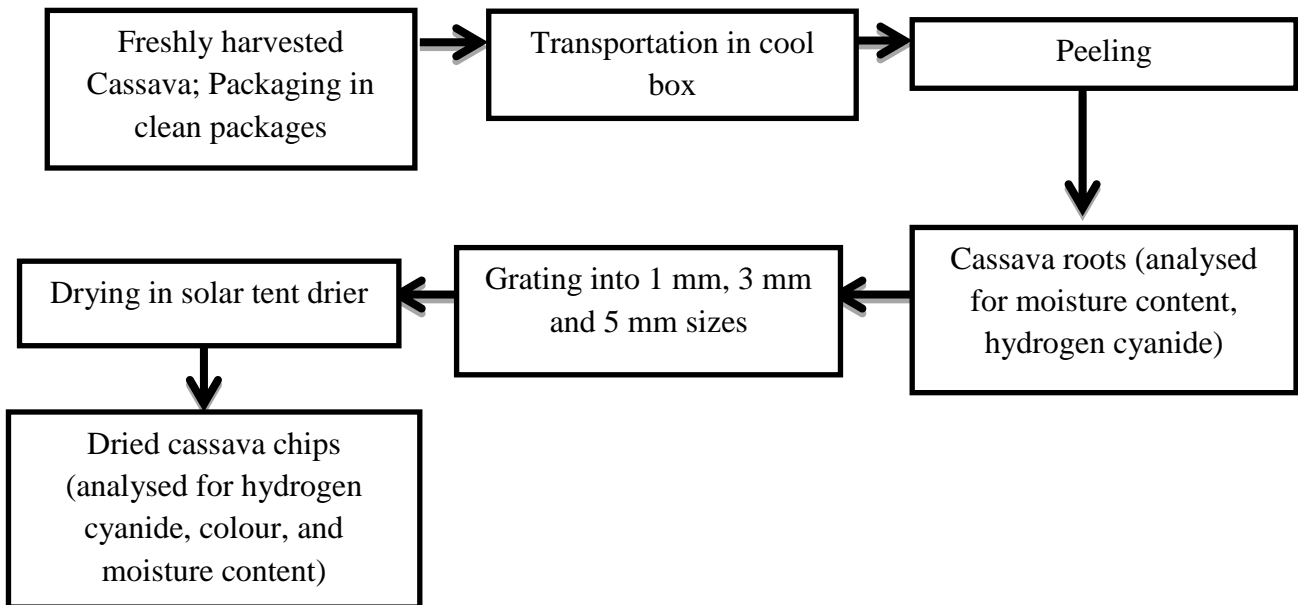
5.1 Introduction

Cassava (*Manihot esculenta* Crantz) is an important food security crop for poor rural communities; particularly in Africa (Ndung'u et al., 2012). About 70 million people obtain more than 500 calories per day from the crop (Cock, 1985; Kawano et al., 1998). Cassava roots are important for their nutritional value and are hence the main part of the plant consumed (Emmanuel et al., 2012). Cassava contains naturally occurring cyanogenic glucosides; according to Ndung'u et al. (2012), all the cassava tissues, except seeds, contain cyanogenic glucosides in the form of linamarin and lotaustralin and most varieties will contain in the range of 15-400 mg cyanide content/kg fresh material. When cassava plant tissues are damaged, for instance by cutting during harvesting, cyanogenesis is initiated. This is the breakdown of the cyanogenic glucosides by endogenic enzyme called linamarase to cyanohydrin and eventually hydrogen cyanide (Mahon et al., 1995); this implies that cassava may be toxic to human and animal populations especially to the populations that rely on cassava or cassava-based diets as a subsistence and low ingestion of protein (Ndung'u et al., 2012). In Africa, village level agro-processing activities are responsible for the preservation and distribution of the bulk of the agricultural produce; they are usually very simple and convenient for small scale production. These traditional methods and technologies are labour intensive, slow and low yielding and in the end give products of relatively low quality (Oduro and Clarke, 1999; Dziedzoave, 2012). Fresh cassava has high moisture and hence does not store well after harvest; traditionally, it is dried by spreading on the roofs of houses, edges of roads or paved ground hence exposed to contamination by dust, insect attack, animal excrement, enzymatic reactions and infection by micro-organisms (Akintunde and Tunde-Akintunde, 2013), the other disadvantages of sun drying include changes in weather conditions and slowness of the sun drying process. The objective of this study was to determine safety and quality of dried cassava chips from a tent solar drier.

5.1 Materials and methods

5.1.1 Sampling

Fresh cassava cultivars (*Manihot esculenta* Crantz) from the Kenya Agricultural and Livestock

Research Organization (KALRO) farm in Kakamega were harvested carefully to avoid damage.

Random samples of three cassava cultivars grown in the farm were collected purposively. The

cultivars were: Fumba chai (Local), MH95/0183 and MM96/2480 (Improved) and were

harvested at 12 months of age. The samples were chosen as they are the most widely distributed

varieties to farmers from the research institute. The harvested cassava roots were stored in a cool

box maintained at about 10^0C and transported to the University of Nairobi, Department of Food

science, Nutrition and Technology for processing and analysis.

The processing of cassava rootsFigure 5.1 Figure 5.1: shows a flow chart of the processing that
was done from the raw cassava roots.

Figure 5.1: Flow chart for processing cassava into dried chips

5.1.2 Determination of Hydrogen Cyanide content

The hydrogen cyanide (HCN) content of raw cassava and dried cassava chips were analysed according to AOAC method (1990) as described in section 4.4.2. Analysis was done in duplicates.

5.1.3 Determination Moisture Content

The raw cassava roots were grated using a kitchen grater to about 1 mm thickness, the dried cassava chips were ground into powder using a motor and pestle before analysis. The moisture determination and calculation of moisture content as described in section 4.4.4. All measurements were in duplicates.

5.1.4 Tent solar drier

Materials used in fabrication of the drier were: wood, food grade polythene; black and clear in colour and thickness of 1000 gauge, bolts, net.

Figure 5.2: Tent solar drier in operation

Figure 5.3: Tent solar drier in operation

It was fabricated at the University of Nairobi and consisted of a tent like structure with a wooden framework. The air circulation points, covering the width of the drier at the bottom and top of the structure both measured 6 inches and were covered using chicken mesh to avoid entry of insects but allow air to move in contributing to convection. Black polythene covered the base and the side facing south of the drier to absorb heat. The clear polythene covered the rest of the drier. A bed raised two feet from the ground and covered with a net to allow air movement thus aiding removal of moisture from the cassava chips being dried, was included. The exhaust air passed through the 6 inch air vent at the top of the drier. Temperature and relative humidity readings were taken three times a day at 09.30hrs, 13.30hrs and 17.30hrs using a hygrometer and a non-mercury thermometer.

5.1.5 Colour Determination

Colour of dried cassava chips of different thicknesses (1mm, 3mm, 5mm) were measured by colorimeter (MINOLTA CHROMA METER CR-200b) using CIELAB L*a*b* colour scale as described in section 4.4.5.

5.1.6 Statistical Analysis

The statistical analysis was done by method described in section 3.2.2.7

5.2 Results and Discussion

Table 5.1 shows temperatures and relative humidity (RH) in the tent solar drier on three different days as well as at different times of the day that drying of the cassava chips took place.

Table 5.1: Temperatures and Relative humidity's in the tent solar drier

Day	Dry bulb temperature ^{0}C	Wet bulb temperature ^{0}C	Relative humidity %
Day 1	32^a	25^a	57^a
Day 2	32^a	26^a	64^a
Day 3	32^a	26^a	70^a
Time			
09.30 hrs.	30^a	25^{ab}	67^b
13.30 hrs.	37^b	29^b	54^a
17.30 hrs.	28^a	24^a	71^b

Values=Means ± Standard deviation, means in the same column with different superscripts are significantly different (P≤ 0.05).

There was no significant differences (p>0.05) in the dry bulb temperature, wet bulb temperature and RH readings in the three days of drying. The temperature range was 28-37^{0}C and 24-29^{0}C, for the dry and wet temperatures respectively, while the RH ranged between 54%and 71%. Average temperature for the three days was 32^{0}C and 26^{0}C for the dry and wet bulb temperature readings respectively, with the average RH for the three days being 64%. The dry bulb

temperature at 13.30 hrs.' was significantly higher while RH was significantly lower (p≤0.05) than the temperatures and RH at 09.30hrs and 17.30hrs in the tent solar drier.

Table 5.2 shows results of analysis of the three cassava cultivars used in the current study. There was no significant difference (p>0.05) in the HCN among the different cultivars. MH95/0183 had a significantly lower (p≤0.05) moisture content than Fumba chai and MM96/2480.

Table 5.2: Hydrogen cyanide and Moisture content of 3 varieties of raw cassava

Variety	HCN (mg/kg) (wwb)	% M.C (wwb)
Fumba Chai	56.26 ± 3.79^a	61.80 ± 0.16^b
MH95/0183	63.11 ± 1.51^a	54.40 ± 0.42^a
MM96/2480	64.87 ± 0.20^a	59.71 ± 1.58^b

Values=Means ± Standard deviation, means in the same column with different superscripts are significantly different (P≤ 0.05); HCN= Hydrogen Cyanide; MC= Moisture Content.

The HCN content on a wet weight basis (wwb) was 56.26 mg/kg, 63.11 mg/kg and 64.87 mg/kg for Fumba chai, MH95/0183 and MM96/2480, respectively. The moisture content was 54.40%, 59.71% and 61.80% for MH95/0183, MM96/2480 and Fumba chai, respectively. The cyanide content of the raw cassava roots recorded in the current study may be categorised as moderately poisonous; and are in agreement with those found in a study by Mburu (2013) that showed cassava roots grown in Kakamega area had HCN content of between 56.65 mg/kg and 127.03 mg/kg; according to Mburu (2013), these variations can be attributed to variation of key components of soil like potassium, calcium and magnesium ions that adversely affect uptake of cyanide by cassava. Cardoso et al. (2005) also noted that cultivars, the environment among other factors, known to determine the total cyanide content of cassava parenchyma.

The cassava roots in the present study in their raw form may be poisonous for consumption and require further processing. Water content for cassava tubers range from 60.3% to 87.1% (Zvinavashe et al., 2011), thus making it perishable; deteriorating within 24-72 hours of harvesting (Abera and Rakshit, 2003; Reilly et al., 2004) and for this reason cassava roots should be processed immediately after harvest to ensure quality and safety. Dry matter influences processing quality as preparation of cassava products such as cassava flour is dependent on DM content; it is also important since nutrition and energy calculation is based on magnitude and nature of DM content (Fakir et al., 2012). High DM content (88-90%) is good for cassava flour production (IITA, 2011).losses.

Table 5.3 Table 5.3 shows the percentage loss of hydrogen cyanide from raw cassava roots chipped into three different thicknesses and the level of residual HCN after drying in the tent solar drier. There was a significant difference (p≤0.05) in the percentage loss of hydrogen cyanide and residual HCN between the three different thicknesses in all the three cultivars after drying, with the 5 mm thick chips recording significantly higher HCN percentage losses.

Table 5.3: Percentage loss of hydrogen cyanide and residual HCN (wwb) after drying

	Variety 1 MM96/2480		Variety 2 MH95/0183		Variety 3 Fumba Chai	
Size	**%HCN Loss**	**HCN mg/kg**	**%HCN Loss**	**HCN mg/kg**	**%HCN Loss**	**HCN mg/kg**
1mm	20.2 ± 0.1^a	51.8 ± 0.2^c	21.5 ± 1.7^a	49.5 ± 0.1^a	14.1 ± 5.3^a	48.2 ± 0.0^c
3mm	36.4 ± 1.0^b	41.3 ± 0.8^b	31.8 ± 1.6^b	43.0 ± 0.0^b	23.5 ± 5.2^{ab}	43.0 ± 0.0^b
5mm	50.1 ± 0.2^c	32.4 ± 0.2^a	48.7 ± 1.4^c	32.4 ± 0.1^a	42.4 ± 3.9^b	32.3 ± 0.3^a

Values=Means ± Standard deviation, means in the same column with different superscripts are significantly different (P≤ 0.05)

The percentage HCN loss ranged from 14.1 to 21.5%, 23.5 to 36.4% and 42.4 to 50.1%, with the residual HCN ranging from 48.2 to 51.8 mg/kg, 41.3 to 43.0 mg/kg and 32.3 to 32.4 mg/kg for the 1 mm, 3 mm and 5 mm thick dried cassava chips respectively. Rajaguru (1975) reported that drying of chips resulted in about 50% loss of cyanide; this is in agreement with the results of the current study. The 5 mm thick cassava chips lost the highest percentage of hydrogen cyanide and had the least residual HCN after drying. This may be attributed to the slower rate of moisture loss for the 5 mm thick chips relative to the 1 mm and 3 mm chips as seen in Table 5.4; this result is in agreement with a report by Bourdoux (1982) that intimated that 3 mm thick chips retained more cyanide than thicker chips, as a result of faster moisture loss thus reducing contact time between linamarase and cyanoglucosides. Also according to a report by Oghenechavwuko et al. (2013) faster drying reduced the contact time between linamarase and glycosides.

Aberi (2012) reported that simple processing (grating and drying) significantly reduces the cyanide content of cassava cultivars; this, according to reports by Essers et al. (1996) and Iwuoha et al. (1997) was due to the cell disruption during grating (chipping) which enhances contact between linamarase and cyanogenic glucosides that are hydrolysed to glucose and cyanohydrins which are further decomposed to produce ketones and toxic hydrogen cyanide. Chipping and then drying in the tent solar dryer was therefore a factor in the reduction of the volatile HCN. Kaaya and Eboku (2010) reported a farmers practice of drying chips after peeling and chopping without washing; then spreading on bare ground or other surfaces in open air sunshine to dry for 1-2 weeks, a drying practice which was also reported by Khakasa (2014). However, in the present study HCN was not reduced to the acceptable limit set by FAO/WHO (1991) maximum of 10mg/kg, having residual quantities that are 3-5 times higher than the acceptable safe limit; thus the need for further processing. High levels of HCN may lead to acute

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cyanide poisoning or chronic sicknesses associated with extended use of monotonous diets of high HCN foods; that is konzo or tropical ataxic neuropathy (Mckey et al., 2010).

Table 5.4 Shows results of percentage loss of moisture of raw cassava roots chipped into three thicknesses and dried using a tent solar drier over a 3 day period. There was no significant difference (p>0.05) in the percentage loss of moisture between the different thicknesses of cassava chips of the same cultivars over the three days of drying.

Table 5.4: Percentage moisture loss of Cassava chips over 3 days of drying in a solar tent drier

Size	Day 1			Day 2			Day 3		
	MM	MH	FC	MM	MH	FC	MM	MH	FC
1 mm	36.5 ± 2.3^a	49.2 ± 2.9^b	39.4 ± 4.7^a	74.7 ± 0.6^b	80.2 ± 0.7^b	82.3 ± 0.8^a	83.3 ± 2.0^a	81.9 ± 1.3^a	84.1 ± 0.4^b
3 mm	32.3 ± 7.4^a	43.3 ± 0.8^b	36.3 ± 7.3^a	71.8 ± 0.8^b	79.2 ± 0.6^b	79.1 ± 0.4^a	83.1 ± 1.0^a	79.7 ± 0.5^a	83.3 ± 0.9^{ab}
5 mm	26.3 ± 1.5^a	26.6 ± 0.3^a	30.3 ± 0.9^a	55.3 ± 5.1^a	71.2 ± 0.3^a	61.4 ± 10.3^a	80.6 ± 0.7^a	80.2 ± 1.4^a	81.1 ± 0.0^a

Values=Means ± Standard deviation, means in the same column with different superscripts are significantly different (P≤ 0.05)**; MM**=Cultivar MM96/2480, **MH**=Cultivar MH95/0183, **FC**=Cultivar Fumba chai

The percentage loss of moisture ranged from 36.5 to 84.1%, 32.3 to 83.3% and from 26.3 to 81.1% for 1 mm, 3 mm and 5 mm thick chips respectively. The 5 mm thick chips for MH95/0183 had significantly lower percentage moisture loss over 2 days (D1-D2) of drying while MM96/2480s' 5 mm thick chip exhibited a significantly lower percentage loss after the second day of drying (p≤0.05).

Table 5.5 shows the moisture content of dried cassava chips from the tent solar drier. The moisture content ranged from 9.81 to 11.67% with the 1 mm thick cassava chips having the lowest moisture content after drying, as less thick chips have larger areas exposed to heat and air flow thus loosing moisture faster.

Table 5.5: Moisture content (wwb) of dried cassava chips

Size	Variety 1 MM96/2480 MC%	Variety 2 MH95/0183 MC%	Variety 3 Fumba Chai MC%
1mm	9.96 ± 0.94^a	10.79 ± 0.64^a	9.81 ± 0.21^a
3mm	10.10 ± 0.30^a	11.04 ± 0.36^a	10.31 ± 0.51^{ab}
5mm	11.61 ± 0.10^a	10.80 ± 0.83^a	11.67 ± 0.05^b

Values=Means ± Standard deviation, means in the same column with different superscripts are significantly different (P≤ 0.05); MC= Moisture Content.

Chipping and drying reduced the moisture content by high percentages, giving dried chips of moisture range that are below the recommended acceptable limit by the East African Standard (EASa, 2010) of ≤12%; this shows the efficiency of the drier in reducing the moisture levels to recommended levels. According to Kajuna et al. (2001) quick drying is advantageous in the sense that risks of contamination and mould growth are minimized, drying also reduces the levels of hydrogen cyanide as seen in the present study.

Table 5.6 shows results of percentage loss of moisture and HCN for 3 thicknesses of cassava chips after 3 days of drying. There was no significant difference (p>0.05) in the percentage loss of moisture between the 3 sizes of cassava chips after the three days of drying.

Table 5.6: Percentage HCN and Moisture loss of cassava chips dried in a solar tent drier as affected by thickness

	Variety 1 MM96/2480		Variety 2 MH95/0183		Variety 3 Fumba Chai	
Size	%HCN LOSS	%MC LOSS	%HCN LOSS	%MC LOSS	%HCN LOSS	%MC LOSS
1mm	20.2 ± 0.1^a	80.6 ± 0.7^a	21.5 ± 1.7^a	80.2 ± 1.4^a	14.1 ± 5.3^a	84.1 ± 0.4^b
3mm	36.4 ± 1.0^b	83.1 ± 1.0^a	31.8 ± 1.6^b	79.7 ± 0.5^a	23.5 ± 5.2^{ab}	83.3 ± 0.9^{ab}
5mm	50.1 ± 0.2^c	83.3 ± 2.0^a	48.7 ± 1.4^c	81.9 ± 1.3^a	42.4 ± 3.9^b	81.1 ± 0.0^a

Values=Means ± Standard deviation, means in the same column with different superscripts are significantly different (P≤ 0.05)

The 5 mm thick chips exhibited significantly higher percentage loss in HCN, coupled with high moisture loss ranging 81.1 to 83.3% after three days of drying in a solar tent drier. It can be seen that 5 mm thick cassava chips had the highest combination of moisture and HCN loss over the three day drying period; followed by the 3 mm and 1 mm thick chips respectively. From the results the 5 mm thick cassava chip was the optimum sized chip in terms of the combination of high percentage loss in hydrogen cyanide and moisture (Table 5.6); this is because, in the case of Fumba Chai variety, the moisture loss is slower thus allowing for linamarase to breakdown the cyanogenic glucosides. Famurewa and Emuekele (2014) concluded that the higher the moisture, the greater the loss in the cyanide content during drying. This however does not explain the increase in the loss of HCN with the increase in the chips size in the varieties 1 and 2. Chipping and drying reduced the hydrogen cyanide and moisture content by high percentages.

Table 5.7 shows the colour parameters for the dried cassava chips of three different thicknesses. There was no significant difference (p>0.05) in L*, a* and b* values between the chip thicknesses.

Table 5.7: Colour variation of dried cassava chips as affected by chip thickness

Variety	Size	Colour Parameters		
		L*	a*	b*
Fumba Chai	1 mm	82.8 ± 6.2^{a}	1.1 ± 0.2^{a}	7.8 ± 0.6^{a}
	3 mm	81.1 ± 8.9^{a}	1.0 ± 0.3^{a}	7.3 ± 1.2^{a}
	5 mm	91.6 ± 5.5^{a}	2.0 ± 1.2^{a}	9.5 ± 1.5^{a}
MH95/0183	1 mm	93.7 ± 1.2^{a}	0.1 ± 0.1^{a}	7.5 ± 0.8^{a}
	3 mm	88.9 ± 2.4^{a}	0.9 ± 0.5^{a}	9.5 ± 1.4^{a}
	5 mm	89.7 ± 7.9^{a}	0.7 ± 0.8^{a}	8.0 ± 1.7^{a}
MM96/2480	1 mm	88.7 ± 3.1^{a}	0.3 ± 0.5^{a}	6.0 ± 1.2^{a}
	3 mm	94.8 ± 3.4^{a}	0.2 ± 0.1^{a}	6.7 ± 0.1^{a}
	5 mm	88.4 ± 7.2^{a}	0.9 ± 1.0^{a}	7.8 ± 2.3^{a}

Values=Means ± Standard deviation, means in the same column with different superscripts are significantly different (P≤ 0.05)

The L* a* b*values ranged between 81.1and 94.8, from+0.1 to +2.0 and from +6.0 to +9.0 respectively; high L* values indicated whiteness of the cassava chips thus indicating that no fermentation and microbial contamination took place while drying (Eriksson et al., 2014). Results indicate that thickness of cassava chips had no effect on the colour of the chips dried using the tent solar drier; this is in agreement with a report by Tunde-Akintunde (2009) that concluded that varieties of cassava may have a bigger role in variations of colour than the drying methods.

According to Olowoyeye (2014) who compared drying of cassava chips in a cabinet dryer and sun drying, cabinet drying resulted in little or no change in the colour of the cassava chips, but it was obvious that in the sun drying method, the chips were decolourized, thus underscoring the importance of improved drying methods. From this study, it can therefore be concluded that chips dried in the solar tent drier are of better quality in terms of colour, which corresponds to consumer preferences for cassava products such cassava chips and cassava flour.

In the present study, the tent solar dried products were found to have cyanide levels that were above the maximum acceptable levels set by the standards, with the range being similar to the

HCN levels observed in the cassava chips surveyed in the market; this indicates that in both cases the cassava chips are unsafe. The moisture content of the tent solar dried cassava chips and the cassava chips surveyed from the markets were in the similar range, this shows the importance of low moisture content to avoid post-harvest losses. The L* colour parameter of the cassava chips surveyed in the market ranged from 69.0 to 92.0, and the tent solar dried cassava chips had an L* value that ranged from 81.0 to 94.8 indicating that in the present study the tent solar dried cassava chips were whiter that what was available in the markets.

5.3   Conclusion and Recommendations

The tent solar drier, contributes to reduction in the hydrogen cyanide content of the cassava roots by approximately 50% and in the moisture levels to acceptable values while maintaining white colour; hence good quality of dried products; however, the residual HCN content in the tent solar dried cassava chips was high and so compared to the chips surveyed in the markets it is concluded that in both cases they are unsafe but of good aesthetic quality.

Farm based processing should adopt the solar tent drier, as it is affordable, less laborious, hygienic and efficient in reduction of cyanogenic content as well as moisture content; thus improving on the safety and quality of final cassava products. Processing prior to drying should be enhanced and adopted by the processors to ensure residual HCN is within safe acceptable levels. The processing intervention recommended should be washing of the raw cassava roots after peeling and chipping, before drying.

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CHAPTER 6

6.0 General Conclusions and Recommendations

6.1 General Conclusions

The present study concludes that:

I. The cassava chips and cassava flour in the markets are highly contaminated, indicating poor hygiene measures during post-harvest processing and handling,

II. The moisture content levels of the dried cassava chips and cassava flour in the market are optimum (below 12% moisture content) for long post-harvest storage.

III. Aflatoxin levels in the cassava chips and cassava flours in the markets are below the maximum acceptable levels by the Codex Alimentarius Commission standards.

IV. The HCN levels in the dried cassava chips and flours surveyed in the markets are in amounts that exceed the maximum acceptable levels.

V. Majority of the dried cassava chips and flour surveyed in the market have high L* values that indicate they are of good quality.

VI. The tent solar dried cassava chips have low moisture content but are high in residual HCN.

VII. The loss of HCN as a result of tent solar drying of cassava chips increases with increase in chips thickness.

6.2 General Recommendations

It is recommended that:

I. Farmers and processors should be trained on good practices especially good hygiene practices and good storage practices; so as to prevent hazards in food or reduce them to acceptable levels hence maintain safe products

II.   Cassava breeders come up with cultivars that have lower cyanogenic glucosides content and the information be disseminated to the farmers, as well as encourage adoption of such cultivars to ensure low residual HCN after processing.

III. The farm based processing should adopt simple technologies like the tent solar drier, to reduce post-harvest losses of cassava produce as well as reduce the probability of contamination during drying process.

IV.   Washing and squeezing excess water from raw cassava tubers after harvesting should be added as an important step in post-harvest processing to reduce the cyanide levels, prior to chipping and drying to ensure the final dried cassava chips will have acceptable levels of HCN. Washing should after chipping the roots and be done using clean potable water to avoid cross contamination.

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