# COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH-FOOD RESEARCH INSTITUTE

**CSIR-FRI/CASSAVA G-MARKETS PROJECT**

# CYANOGENIC GLYCOSIDES AND CASSAVA PROCESSING: A REVIEW AND A COMPARATIVE ANALYSIS OF DIFFERENT PROCESSING APPROACHES ON THE SAFETY AND QUALITY OF HIGH QUALITY CASSAVA FLOUR

**Technical Report**

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**Executive summary**

Cassava is one of the most important root and tuber crops, providing nourishment for more than half a billion people the world over. It derives its importance from the fact that it is a valuable source of less costly calories, widespread and an integral contributor to food security in developing countries. The crop has received attention as a raw material for a wide range of industrial applications including the production of bioethanol, adhesives, pharmaceuticals, plastics as well as pelletized animal feed.

One of the drawbacks of the root crop for use as food is its potential toxicity, a phenomenon which stems from the cyanogenic glycoside content of the crop. These compounds undergo enzymatic degradation to produce HCN which is lethal at 35 - 150 µmol/kg. Sub-fatal doses over a long period affect the nervous system and thyroid glands. Cyanogenic compounds also account for bitterness in certain cassava varieties. Detoxifying cassava presents an avenue for expanding its domestic and industrial potential as a raw material.

These techniques involve a combination of unit operations that trigger the by endogenous enzymes into HCN, which is subsequently evaporated (by heating) or dissolved in water (depending on the processing method under consideration). Processing breaks down cyanogens markedly and reduces their potency. This, however, depends on the starting material and the method and extent of processing.

Recent attempts at making cassava a more useful as a raw material for industrial applications has been to process into unfermented High Quality Cassava Flour (HQCF). This flour is useful for bakery products, production of glucose syrup and starch but its safety and quality are not streamlined because of the different approaches adopted in its processing. In this study, the effect of different processing techniques on some safety and quality parameters were evaluated. Two size reduction methods (grating and slicing) and two drying methods (mechanical and solar drying) used to process cassava into flour were compared.

# CHAPTER ONE

## Chapter synopsis

This chapter presents review of previous research on cassava cyanogenic glycosides, their structure, toxicity and its relationship with bitterness as well as interventions and previous attempts made at detoxifying cassava. It begins with a general overview of cassava, its socio-economic and nutritional significance to the cassava producing regions. The chapter focuses on detoxifying these cyanogens during processing, the mechanisms and the unit operations involved in these processes. Both the roots and leaves of cassava are covered in this chapter.

## 1.0 Introduction

## 1.1 GENERAL OVERVIEW OF CASSAVA AND ITS IMPORTANCE

Cassava (*Manihot esculenta* Crantz) is arguably the most important staple in most tropical regions of the world. With a somewhat ambiguous origin (Allem, 2002), the plant is widely grown in areas with different geographical conditions. It has been identified as a potentially valuable source of food for addressing food security in developing countries (Montagnac *et al*., 2009). The crop is hardy and can survive adverse conditions such as infertile soil, drought, pests and diseases (Bokanga, 1999; El-Sharkawy, 2003) and plays several important roles in Africa such as serving as a rural staple food, famine-reserve crop, cash crop for households and as a raw material for feed and industrial manufacturing (Nweke *et al*., 2002).

Primarily, cassava is cultivated on small-scale farmers on small plots of land. African produces more cassava than the rest of the world put together (FAO, 2012), with production hitting 230 million tonnes in 2010. Although African countries present the lowest yields, Nigeria, DR Congo, Angola and Ghana are among the 10 in the league of world cassava production. In 2010, Angola was highest in terms of production per capita (726 kg/person), followed by Ghana (563 kg/person) and Thailand (314 kg/person) (FAO 2012). While it is used predominantly for food in Africa, in South America, Asia and Europe, the crop mainly serves industries (mostly starch and ethanol) and some used for the production of animal feed.

The leaves and roots are which make up 50% and 6% of the mature plant respectively (Tewe and Lutaladio, 2004) are considered important in terms of its use for food and animal feed. The edible part of the root accounts for 80 – 90 % of the total weight of the root (Alves, 2002; Wheatley and Chuzel, 1993) and is rich in digestible carbohydrate, mainly starch (Charles *et al*., 2005). It's mineral content is comparable to that of several legumes but is low in fat and protein (of low quality) and should be eaten with other foods that may supplement the deficiency. Conversely, the leaves are richer in proteins, minerals and vitamins and lower in carbohydrates compared to the roots (Adewusi and Bradbury, 1993). Much of the protein in the leaves is made

up of linamarase, the enzyme that detoxifies the cyanogenic glycosides in cassava (Bokanga, 1995).

If the contribution of cassava to the livelihood of producers, processers and traders are to be realized fully, there is the need to counter the three major limitations to its use; i.e., poor shelf-life, low protein content and cyanogenic potential (Westby, 2002). The cyanogenic potential of cassava is by far the single factor that adversely constraints the use of cassava as food and feed for animals. This is as a result of the toxic effect of cyanide on humans and animal who rely on cassava as food.

### 1.1.1 Nutritional and anti-nutritional properties

Cassava is cultivated in areas with limited soil fertility by farmers with restricted economic resources and used as food and as raw material for certain industrial products. As presented in Table 1, both leaves and roots are nutritionally valuable (Tewe and Lutaladio, 2004). The roots are a rich source of energy, appreciable in mineral content but marginal in vitamins. The leaves, which are also used for food in certain areas, are rich in vitamins, proteins, minerals (Lebot, 2009) and carbohydrate, which is mainly starch (Gil and Buitrago, 2002). A lot of programmes and strategies have been put in place to prop up cassava's zinc, iron, protein and vitamin A content (Montagnac *et al*., 2009). Generally, however, the leaves present valuable nutritional potential compared to the root which is widely utilized.

**Table 1.1: Nutritional composition of cassava roots and leaves**

| | Cassava roots | Cassava leaves |
|---|---|---|
| ***Proximate composition*** | | |
| Food energy (kcal) | 100.0 – 149.0 | 91.0 |
| Moisture (g) | 45.9 – 85.3 | 64.8 – 88.6 |
| Dry weight g) | 29.8 – 39.3 | 19.0 – 28.3 |
| Protein (g) | 0.3 – 3.5 | 1.0 – 10.0 |
| Lipid (g) | 0.03 – 0.5 | 0.2 – 2.9 |
| Total carbohydrate (g) | 25.3 – 35.7 | 7.0 – 18.3 |
| Dietary fiber(g) | 0.1 – 3.7 | 0.5 – 10.0 |
| Ash(g) | 0.4 – 1.7 | 0.7 – 4.5 |
| ***Vitamins*** | | |
| Thiamin (mg) | 0.03 – 0.28 | 0.06 – 0.31 |
| Riboflavin (mg) | 0.03 – 0.06 | 0.21 – 0.74 |
| Niacin (mg) | 0.60 – 1.09 | 1.3 – 2.8 |
| Ascorbic acid (mg) | 14.9 – 50.0 | 60 – 370 |
| Vitamin A (µg) | 5.0 – 35.0 | 8300 - 11800 |
| ***Minerals*** | | |
| Calcium (mg) | 19 – 176 | 34 – 708 |
| Phosphorus (mg) | 6 – 152 | 27 – 211 |
| Iron (mg) | 0.3 – 14.0 | 0.4 – 8.3 |
| Potassium (%) | 0.25 (0.72) | 0.35 (1.23) |

| | | |
|---|---|---|
| Magnesium (%) | 0.03 (0.08) | 0.12 (0.42) |
| Copper (ppm) | 2.00 (6.00) | 3.00 (12.0) |
| Zinc (ppm) | 14.00 (41.00) | 71.0 (249.0) |
| Sodium (ppm) | 76.00 (213.00) | 51.0 (177.0) |
| Manganese (ppm) | 3.00 (10.00) | 72.0 (252.0) |

Bradbury and Holloway, 1988

In spite of the impressive nutritional value (roots and leaves), cassava contains toxic substances and anti-nutrients which restricts the digestibility and absorption of some nutrients. Phytates and oxalates abound in cassava, with contents of 624mg/100g (Marfo *et al*., 1990) and 1.35 – 2.88 g/100g (Correa, 2000; Wobeto *et al*., 2007) respectively. Phytic acid binds calcium, magnesium, iron and zinc (Hambidge, 2008) while oxalate complexes with calcium and magnesium and makes them bio-unavailable (Massey, 2007). They may also complex with protein and inhibit peptic digestion. Other antinutritional factors in cassava including saponins, tannins (Wobeto *et al*., 2007), trypsin inhibitors in the leaves (Correa *et al*., 2004) and the cyanogens have also been reported.

## 1.2 CYANOGENIC GLYCOSIDES

Cyanogenic glycosides are derivatives of α-hydroxynitriles from aliphatic and aromatic protein amino acids and aliphatic non-protein amino acids, found in plants and some animals belonging to the phylum arthropoda (Zagrobelny *et al*., 2004). They are secondary metabolites that are widespread in plants and act as defense compounds to fight against herbivore and pathogen attack (Heldt and Piechulla, 2011; Vetter, 2000). Several forms of these compounds abound and have been reported in a number of edible plants.

Bound forms of cyanogenic glycosides occur as Linamarin, Lotaustralin (Acetonehydrin), Amygdalin, and Dhurrin. These compounds are generally stable at neutral pH. Linamarin and Lotaustralin have a wide distribution and have been found in cassava and lima beans (Jorgensen *et al*., 2011; Vetter, 2000) while Amygdalin has been reported in apples, peaches and cherries and Dhurrin in sorghum leaves (Haque and Bradbury, 2002). Other forms of cyanogenic glycosides have also been reported in other plant species (Bak *et al*., 2006). Chemical structures of some common cyanogenic glycosides are shown in Figure 1.1

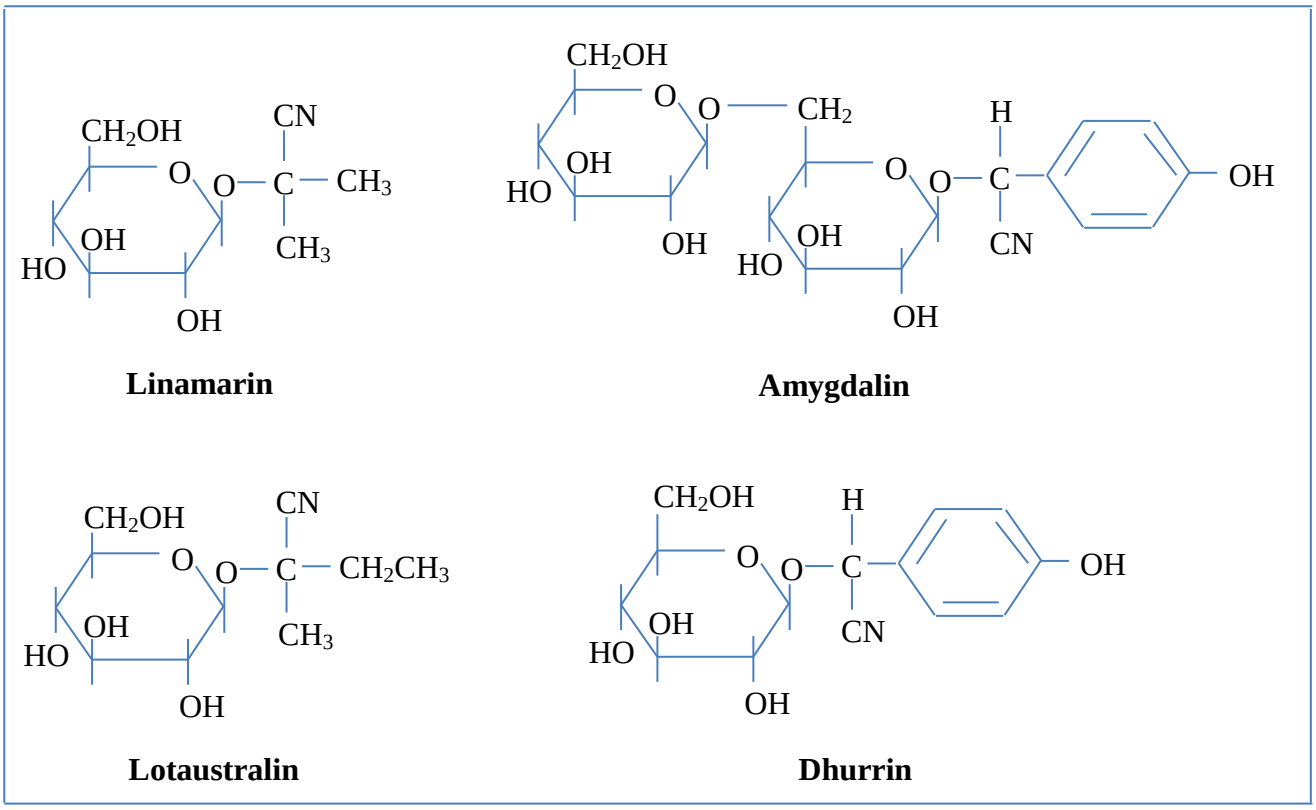


**Figure 1.1: Chemical Structures of some cyanogenic glycosides**

Upon hydrolysis, cyanogenic glycosides breakdown into a sugar and a cyanohydrin which rapidly decomposes to hydrogen cyanide (HCN), a compound that has a long-term damaging effect on the central nervous system and the thyroid glands (Anhwange *et al*., 2011). The production of HCN from cyanogenic glycosides is an enzymatic process, commonly called cyanogenesis which occurs when a cyanogenic plant tissue is pulped. This may occur during processing of the plant tissue or when it is directly chewed by animals.

In order not to poison themselves, cyanogenic glycosides (which are themselves non-toxic) and the enzyme that catalyzes its hydrolysis are stored in different compartments in plants tissues (Figure 1.2). Glycosides are stored in the vacuoles while the enzyme, glycosidase is stored in the cytosol (Heldt and Piechulla, 2011) and only come into contact when the partition is broken. When cell wall structures are raptured and the bound form of the glycosides is brought into contact with the glucosidase, hydrogen cyanide is released through a two-reaction process (Shibamoto and Bjeldanes, 2009). The first reaction involves the breakdown to yield a cyanohydrin and a sugar, while the second one involves the decomposition of the highly unstable cyanohydrin into an aldehyde or ketone and hydrogen cyanide (HCN) and is catalyzed by hydroxynitrile lyase. The degradation of cyanogens to produce HCN by this two-step process is referred to as cyanogenesis (Deshpande, 2002).

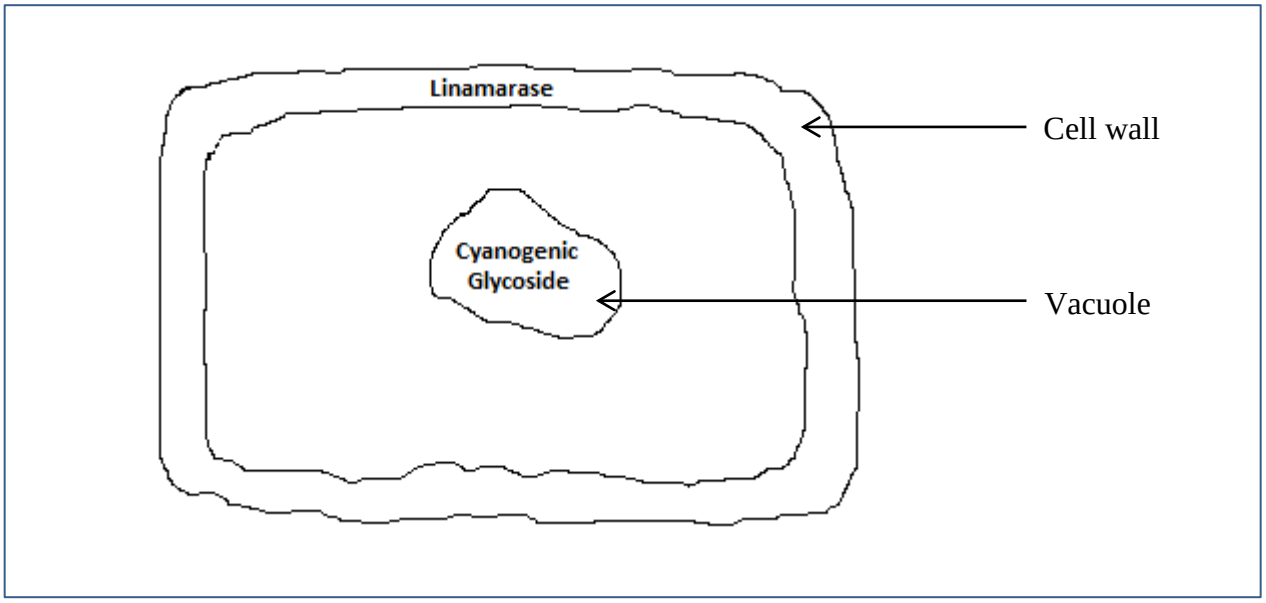


**Figure 1.2: Location of cyanogenic glycoside and linamarase in the plant cell, adapted from Conn (1994)**

### 1.2.1 Toxicity of cyanogens

The toxicity of cyanogenic glycosides results from the production of HCN, resulting in cyanide poisoning. Cyanide is a highly toxic compound with both acute and chronic effects (Shibamoto and Bjeldanes, 2009) stemming from ability to inhibit respiration and the action of some metallo-enzymes (Deshpande, 2002). The lethal dose of HCN for humans, according to Deshpande (2002), has been estimated as ranging between 0.5 – 3.5 mg/kg body weight. Indeed, Jansz and Uluwaduge (1997) reported damage to the central nervous system in people who have been exposed to low levels of cyanide through their food over a long period of time. Thyroid glands may also be affected when exposed to sub-lethal doses because at these levels, HCN is converted to goitrogens such as thiocyanate (Deshpande, 2002; Abuye *et al*., 1998). Other reports have implicated HCN in cases of neuropathy (Harris and Koomson, 2011; Madhusudanan *et al*., 2008), diabetes mellitus (Morrison *et al*., 2006) and growth retardation in children (Banea-Mayambu *et al*., 2000) while consumption of up to 100 mg in adults has resulted in death (Yeoh and Sun, 2001).

Detoxification of CN in humans is by conversion to thiocyanate, which is excreted in urine, in a process catalyzed by rhodanese. The process expends methionine and cysteine which are obtained through diets, and as such depletion of these amino acids without replacement may lead to protein malnutrition and stunting (Banea *et al*., 2012). A lack of these essential amino to detoxify ingested cyanide, leads to an increase in blood cyanide concentration, an occurrence that manifests in certain neurological disorders (Cardoso *et al*., 2004; Harris and Koomson,

2011). Certain pancreatic disorders have been reported among cassava consumers who lack the right levels of proteins in their diets.

Many edible plants have been found to contain significant amounts of cyanogens which place a restriction on their use to a very large extent. Substantial concentrations have been reported in cassava (Manihot esculenta), a staple food of economic importance in Africa, South America and South Eastern parts of Asia that feeds more than half a billion people (Anhwage *et al*., 2011; Nhassico *et al*., 2008; Nweke, 2004; Nweke *et al*., 2002). All parts of the cassava plant contain cyanogenic glycosides in the form of linamarin and lotaustralin, in a ratio of 97:3 (Lykkesfeldt and Moller, 1994). The concentration of cyanogens in roots and leaves differ from the same plant (Riis *et al*., 2003) and is known to be more intense in the leaves than the stem and roots (Nambisan, 2011). The leaves and the roots have cyanide contents ranging from 53 – 1300 and 10 – 500 mg cyanide equivalents/kg of dry matter respectively (Siritunga and Sayre, 2003; Wobeto *et al*., 2007). The cyanogen principles are produced at the apex of the shoot (Andersen *et al*., 2000) and transported to the roots and leaves.

The use of cassava tuber for food and other industrial products is greatly hampered by its short shelf life (Zidenga *et al*., 2012) and cyanogenic potential (Falade and Akingbala, 2010), even though it is known to be a good source of energy (Jisha *et al*., 2010; Montagnac *et al*., 2009). Many industrial and food products processed from cassava have been found to contain significant levels of degradation products of cyanogenic glycosides. Yeoh and Sun (2001) reported 15 – 61 mg of HCN/kg in various foods containing cassava flour, while Cumbana *et al*., (2007) reported 8 - 85 mg for cassava flour. Other reports by Adindu *et al*., (2003), Djazuli and Bradbury (1999) and Sopade (2000) showed significantly higher amounts of cyanide containing compounds than recommended by FAO/WHO (1991).

Processing plays an effective role in the reduction/removal of cyanogens and their degradation products. This is accomplished by two separate treatments; that is, one that raptures the cellular compartments and brings the degradation enzymes into contact with the bound and inactive forms of the cyanogens and another that destroys the products formed from this reaction and favours the evaporation of HCN (Bainbridge *et al*., 1998; ).The efficiency of cyanogen removal depends largely on the kinds of unit operations involved in the processing method (Nambisan, 1994) as well as the initial cyanogen load (Cardoso *et al*., 2005). In order to attain levels within the recommended safe limits set by WHO, initial root cyanide load not exceeding 250 ug/g has been proposed for efficient processing (Cardoso *et al*., 2005).

### 1.2.2 Relationship between bitterness and toxicity of cassava

Depending on the cyanogenic glycoside content and taste, cassava is categorized into three classes namely; sweet, average toxic and bitter, with <50, 50 – 100 and > 100 ppm of linamarin calculated as mg CN/kg of edible portions (fresh weigh basis) respectively (Jansz and

Uluwaduge, 1997; Nhassico *et al*., 2008). Bitterness in cassava has been associated with linamarin because this cyanogen is bitter (King and Bradbury, 1995). This relationship, not clear cut, though, may not be a good indicator of toxicity as was previously thought (Jansz and Uluwaduge, 1997) because other compounds in the parenchyma and cortex also impart bitterness. That notwithstanding, local farmers classify cassava as being bitter or not bitter (Chiwona-Karltun, 2004; Kebede *et al*., 2012) and use this grouping as an indicator of toxicity (Chiwona-Karltun, 2004). Bitter cassava has been observed to be less prone to theft and predation (Chinowa-Kartun *et al*., 1998).

## 1.3 DETOXIFICATION OF CASSAVA CYANOGENS

The presence of toxic cyanogenic glycosides in cassava constitutes a critical limiting factor to its use, together with other considerations such as deficiency in some essential nutrients and high deterioration rate. Detoxification through breeding/genetic engineering and processing offers an opening to scaling this debacle that confronts economic and social prospects of the plant. This reduces the exposure to cyanogenic compounds and thus lowers or eliminates the risk of cyanide intoxication (Onabolu *et al*., 2002). Autolysis of linamarin is extensively relied on in detoxifying cassava (especially during processing) for human consumption. This is triggered by maceration or cell disruption, which results in bringing linamarase into contact with the glycosides and hydrolyses them. The activity of linamarase, however decreases a few days after harvest (Iwatsuki *et al*., 1984). The reasons responsible for this lowered activity is not certain, but has been related to the formation of enzyme inhibiting compounds such as polyphenols (Essers *et al*.,., 1996).

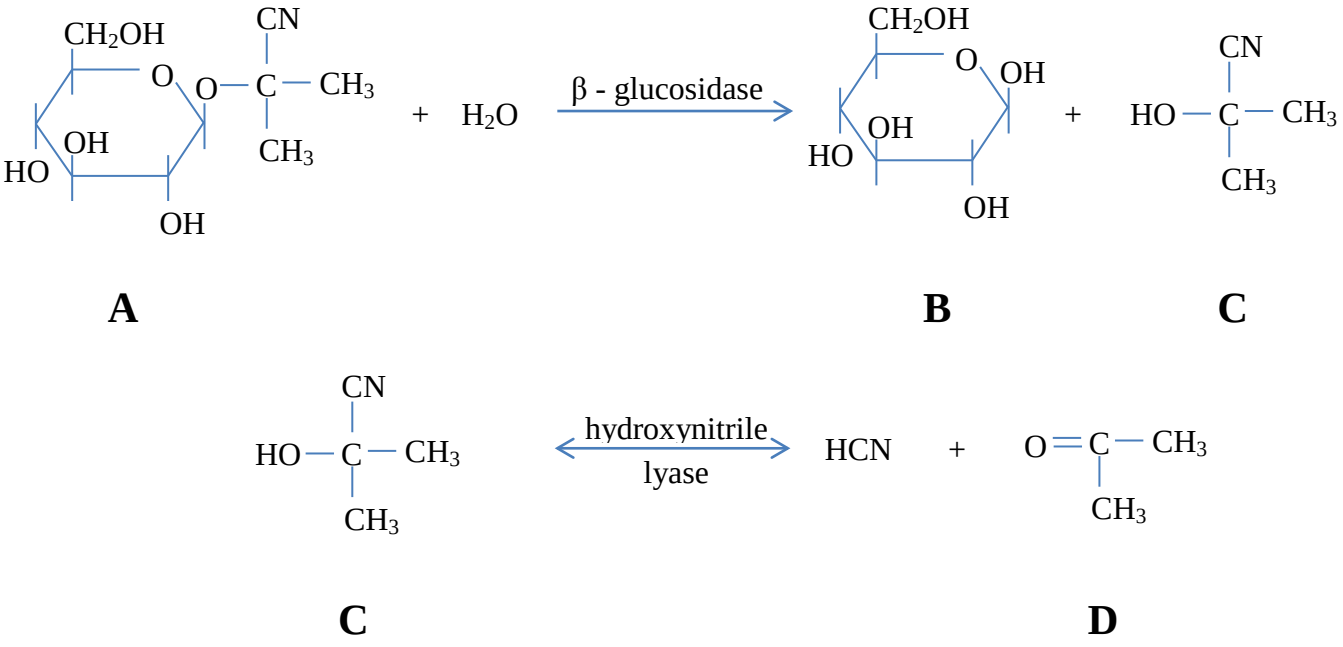


**Figure 1.3: Enzymatic breakdown of Linamarin (McMahon *et al*., 1995)**

Figure 1.3 shows the breakdown of linamarin into HCN and acetone. Linamarin (A) hydrolyses into glucose (B) and acetone cyanohydrin (C), and further into hydrogen cyanide and acetone (D). The breakdown of acetone cyanohydrin is influenced by pH and temperature (occurs spontaneously at pH > 4 and temperatures > 30 C) McMahon *et al*., (1995).

### 1.3.1 Biotechnology and conventional breeding

The hindrance to attaining optimal use of cassava can best be achieved when cyanide-free strains are obtained from breeding programmes because they do not occur naturally (Bradbury and Holloway, 1988). Cyanide-free strains would make cassava reliably safe, more acceptable and marketable and reduce cyanide effluent from cassava processing plants (Siritunga and Sayre, 2003). Genetic engineering, using antisense technology, has been used to block the synthesis of linamarin, resulting in cyanide-free cassava. Dramatically reduced linamarin content in leaves and roots of wild-types has also been achieved by genetic manipulation (Anderson *et al*., 2000; Siritunga and Sayre, 2003; Siritunga and Sayre, 2004). The downside to this development, however, is the likelihood of having reduced plant yield as a result of stalling the synthesis of linamarin (Taylor *et al*., 2004). The resulting transgenic plant could not produce roots because of a lack of ammonia, which is produced by the roots using linamarin as its source. Obstructing the synthesis of linamarin also leaves the plant vulnerable to animal and insect attack since linamarin is used in a defensive mechanism (Vetter, 2000). Besides these technical and research issues, controversy and skepticism surrounding genetically modified organisms (Falkner, 2004) may pose a challenge to the introduction and use of transgenic “strains” in part of the world. Genetic transformation and molecular biology techniques have not made any commercially remarkable impact even though they present great potential.

Conventional methods of breeding, which involves selection and crossing varieties to yield desirable traits, have also been applied in a bid to reduce the cyanogen content in cassava. Previous studies by Iglesias *et al*., (2002) showed reduced cyanogen content in some clones compared to their parental variety. The low vegetative multiplication rate and the fact that several factors affect the quality of planting material (Ceballos *et al*., 2010), however, complicates and makes this method quite difficult to implement.

### 1.3.2 Processing

Aside of genetic/breeding interventions embarked upon to obtain significantly reduced cyanogen content in cassava, biological detoxification methods such as enzyme and bacteria action and physical methods such as processing present suitable options to attaining a similar goal. These methods have resulted in tremendous and significant economic gains as far as the use of cassava is concerned. Detoxification essentially involves two separate treatments; first is one that enhances the contact between linamarase and its substrates (cyanohydrins) followed by a second

that volatilizes the HCN produced as a result of contact between the enzyme and its substrates. Processing largely promotes these conditions that are required for adequate detoxification. Cassava processing improves shelf-life, detoxifies the roots, facilitates transport and enhances consumer acceptability (Westby, 2002; Nyirenda *et al*., 2011). The shortcoming of processing as a detoxification method, conversely, is that a lot of them result in loss of nutrients (Murugan *et al*., 2012).

Enzymatic removal of cyanogens is commonly accomplished by treating samples with enzymes isolated from bacteria to breakdown cyanogenic compounds into acetone cyanohydrins, which decomposes spontaneously to HCN or by treating with plant cell wall-degrading enzymes such as cellulolytic and pectolytic enzymes to enhance the release of linamarin and allow for more contact time with linamarinase (Yeoh and Sun, 2001). The latter principle has been exploited in the production of cassava starch (Sornyotha *et al*., 2010). The HCN produced is subsequently dissolves readily in water or is released into the air (Rolle, 1998; Murugan *et al*., 2012). The enzyme hydrolyses of the cyanogens is sensitive to changes in pH (Cumbana *et al*., 2007), with pH > 5 favouring the breakdown. Certain species of Bacillus, pseudomonas and klebsiella oxytoca have been reported to utilize cyanide as the only source of nitrogen under aerobic and anaerobic conditions thus breaking it down into non-toxic compounds (Kaewkannetra *et al*., 2009). Bacillus subtilis KM05 isolated from cassava peels has been used to detoxify cassava flour (Murugan *et al*., 2012) by degrading linamarin into HCN and subsequently releasing ammonia. In another study by Nwokoro and Anya (2011), cassava flour samples treated with linamarinase enzyme isolated from L.delbrueckii resulted in an 89.5% reduction in cyanide content.

#### *1.3.2.1 Fermentation*

Fermentation as a method of processing primarily enhances nutritional properties through biosynthesis of vitamins, essential amino acids and proteins, by improving protein quality and fibre digestibility as well as the enhancement of micronutrient bioavailability and degradation of anti-nutritional factors (Achinewhu *et al*., 1998; Motarjemi, 2002). Fermentation of cassava, both aerobic and anaerobic, favors the hydrolysis of linamarin into HCN. Even though details of the mechanism involved are unclear (Vasconcelos *et al*., 1990), fermentation softens the cells of the roots and favours contact of the enzymes with its substrate (Errers, 1995). In the case of submerged fermentation, this process synergises with leaching of cyanogen to detoxify the cassava roots (Westby and Choo, 1994).

Fermentation has been applied in the production of gari (Onabolu *et al*., 2002), akyeke/atioke (Tetchi *et al*., 2012), bikedi and ntoba mbodi (Kobawila *et al*., 2005), cassava dough (Amoa-Awua *et al*., 1997), farinha puba (Aidoo, 1992) and several other foods customary to cassava production areas worldwide (Westby, 2002). Three major types of fermentation are widely

practiced in different parts of Africa; these are the grated root fermentation, mould fermentation of roots in heaps and fermentation of roots under water (Westby, 2002). Fermentation of cassava roots is largely acidic (pH 3.8) while that for leaves is alkaline (pH 8.5) with lactic acid bacteria dominating the microbiota (Ngaba and Lee, 1979; Oyewole and Odunfa, 1988). Some lactic acid bacteria and yeast possess linamarase activity and are recognized for significantly contributing to cyanogenic glycoside breakdown during fermentation of cassava (Amoa-Awua *et al*., 1996, Kimaryo *et al*., 2000; Lei *et al*., 1999). These microorganisms are capable of utilizing the cyanogens and their degradation products (Akindahunsi *et al*., 1999) thereby ridding their substrate of these noxious substances and rendering the substrate safe.

Previous reports have shown a remarkable reduction in cyanogenic potential of cassava following fermentation. More than 50 % and 35 % reduction in cyanogen levels has previously been achieved in the production of gari and fermented cassava flour respectively (Kemdirim *et al*., 1995). Iyayi and Dosel (2000) and Enidiok *et al*., (2008) have also reported up to 80 % and 41% reduction in cyanide levels respectively during fermentation. Other researchers have also reported varying levels of decline in cyanogen potential after fermentation (Cardoso *et al*., 2005; Bradbury, 2004; Djoulde *et al*., 2007; Oyewole and Ogundele, 2001; Zvauya and Muzondo, 1995). Indeed reduction in cyanide level in all cases depends on the initial cyanide levels of the raw material.

#### *1.3.2.2 Soaking*

Soaking cassava roots usually precedes fermentation, cooking or drying. Retting, followed by sun drying is exploited as a method of processing cassava roots in some parts of Africa. This technique of long soaking cassava roots in stagnant or slow running ponds and causes the breakdown of tissues and extraction of the starchy mass (Ayernor, 1985). The water softens the cells of the cassava roots, provides a larger medium for fermentation and facilitates leaching of cyanogenic glycosides. The method removes a substantial amount of free cyanide but has little effect on bound cyanide. Soaking peeled or unpeeled cassava roots is practiced in the northern and central regions of Malawi (Nyirenda, 2003) to produce ‘waluwa’ and ‘kanyakaska’ which are dried and pounded into flour and used to prepare a local delicacy called ‘kodowole’. The cassava roots come out of the process having lost between 31.0% and 49.9% (for unpeeled and peeled roots respectively) of their cyanogenic potential. Other studies have resulted in remarkably significant reduction in cyanogenic glycosides after soaking (Ampe and Brauman, 1995)

#### *1.3.2.3 Cooking*

Boiling cassava roots, which is often for direct consumption with accompaniments such as soups and stews, is commonplace in most areas where cassava is produced for culinary purposes.

Cooking is Processing cassava roots by this method is preceded by peeling, cutting into chunks/dicing and washing. Disruption of cell membrane during cooking largely occurs between 60 and 70 °C and not long after that linamarase is destroyed, making contact with its substrate inadequate for thorough detoxification. This causes a possible retention of cyanogenic glycoside levels (Jansz and Uluwaduge, 1997). Cyanohydrins from aldehydes, may also exist even after cooking because they are thermo-stable (Onabolu *et al*., 2002). As a result, boiling is often criticized and an ineffective standalone method of detoxifying cassava roots and hence is preferred as a method of processing sweet cassava (), although the heat favours rapid evaporation of HCN produced (Bokanga, 1994). Indeed, the extent of reduction of cyanogenic glycosides has been related to the cooking time (Hidayat *et al*., 2002). Jansz and Uluwaduge (1997) have reported cooking to reduce cyanogen potential by 50 -70% in Southern Asia. Fukuba *et al*., (1982) introduced a soaking and squeezing stage prior to cooking and achieved a remarkable reduction in cyanogenic potential of up to 70%. Boiling/cooking has also been applied to process cassava leaves and resulted in 75 % reduction (Hidayat *et al*., 2002) and in some cases more than 90% reduction in cyanide level (Ngudi *et al*., 2003).

#### *1.3.2.4 Roasting Drying*

Cassava roots have been processed into a lot of dried products. Drying is widely accepted as an efficient processing method for cassava roots as it results in products that are shelf-stable with relatively reduced cyanide content. In as much as advanced systems of drying exist, sun drying is the most adopted method in cassava processing regions of Africa and as such sun-dried cassava products are the most common (Westby, 2002). Dried cassava pieces can be processed further into other preferred forms. Drying or roasting cassava is usually preceded by peeling, chipping, chunking or grating before spreading out in the sun to dry.
Detoxification is achieved by

The drying mechanism in itself does not play any significant role in the detoxification process but the tissue disruption that precedes drying (Essers *et al*., 1996). The efficiency of cyanide removal during drying is dependent on moisture content of the roots, rate of moisture loss (which relates to drying conditions), and the extent of tissue disruption (Essers *et al*., 1996; Tivana, 2012). The influence of moisture content on detoxification is crucial, as glucoside degradation has been observed to stop between 13% and 18% moisture. This is because diffusion of linamarin during drying continually decreases and at a point where bulk water for transport is lacking, it becomes immobilized thus preventing its interaction with linamarase in the drying medium (Essers *et al*., 1996, Mlingi *et al*., 1995). Extending the period of drying with higher moisture levels have been observed to result in enhanced linamarin breakdown, thus explaining the fact that fast drying rates result in lower detoxification while slower rates result in higher cyanogen removal (Essers *et al*., 1996).

Cyanohydrin levels remain high in the product during drying because of the enzyme hydrolysis that takes place, especially when root pieces are humid. Their levels could be reduced further by thorough drying well below 12 or 13% moisture (Mlingi *et al*., 1995). HCN levels conversely remain low during drying because it volatilizes as a result of its exposure to heat.

#### *1.3.2.5 Other unit operations*

Several other unit operations or a combination of unit operations employed during cassava processing also contribute to the reduction in cyanide potential. These include size reduce operations such as cutting, pulping (grating/chipping and crushing), washing/soaking. Size reduction precedes a lot of processing operations. In cassava processing, cells break open during size reduction and bring endogenous enzymes into contact with their substrates, consequently initiating the hydrolysis of cyanogens into hydrogen cyanide and acetone. Processes that begin with pulping result in the greatest detoxification of the final products (Bokanga, 1999). Other size reduction operations such as mincing and rasping have been reported to result in a loss of more than 70% of cyanogenic glycosides (Jansz and Uluwaduge, 1997).

# CHAPTER TWO

## Chapter synopsis

This chapter presents the role of processing on the quality indices of HQCF. It begins with a brief a brief background and the approach involved in assessing the influence of processing on the quality indices. Different techniques in size reduction (chipping and grating) and drying (mechanical and solar) are compared for their effect on key chemical (cyanide, aflatoxins, ash, starch, etc) and microbiological (yeast and molds, coliforms, etc) indicators of HQCF quality. Results from the study show that

## 2.1 BACKGROUND

In recent times attempts have been made to add more value to cassava and also make it more useful as a raw material for industrial applications. One of the approaches has been to process the roots into unfermented flour for domestic and industrial uses. This flour, also called High Quality Cassava Flour (HQCF) is useful for bakery products, production of glucose syrup and starch as well as glue for the plywood industry. HQCF can also serve as a source of starch for the textile industry. That notwithstanding, some drawbacks to optimum utilization of HQCF for food purposes include its cyanogenic potential and somewhat irregular or unpredictable quality characteristics. HQCF obtained from different sources have shown very wide variation in some chemical properties and microbiological makeup.

As the popularity of domestic and industrial applications of HQCF continues to rise, there is the need to establish the role of unit operations in cyanide detoxification and how these processing steps combine to affect the quality of HQCF. This would form a basis of standardizing protocols for processing cassava into HQCF and contribute to assured quality of the finished product. The study was therefore designed to compare the effects of different techniques employed in two major processing steps (size reduction and drying) on cyanide detoxification, during the production of HQCF.

### 2.1.1 Main objective

- To assess the impact of different unit operations on safety and quality of HQCF

### 2.1.2 Specific objectives

1. Produce HQCF with different size reduction and drying approaches
2. Evaluate some key chemical and microbiological indicators and compare the effect of processing operations on these quality indices.

## 2.2 MATERIALS AND METHODS

### 2.2.1 Raw materials

Matured cassava (10 months old) procured from experimental farms of CSIR-Crops Research Institute was processed into High Quality Cassava Flour (HQCF) at the CSIR-FRI Root and Tuber Products Development Unit.

### 2.2.2 Processing HQCF

*HQCF produced by grating*

Cassava roots were processed into HQCF following the method described by Dziedzoave *et al*., (2006). The roots were washed with potable water and hand-peeled with stainless steel knives and washed twice in potable water before further processing. Peeled cassava roots were then grated in a motorized grater. The grated mash was immediately loaded into polypropylene woven sacks and dewatered in a manual single screw press. The pressed cake was disintegrated manually and spread thinly on trays for drying in either a solar tent dryer or a mechanical dryer. Solar drying took place over a period of 14 hours during which the thinly spread granules were turned several times. Mechanical drying also took place for 8 hrs at 60 °C in a diesel-operated walk-in cabinet dryer. The dried granules were ground in a hammer mill and sieved (250 µm) to obtain a smooth and free-flowing flour.

*HQCF produced by slicing/chipping*

Cassava roots were washed and peeled as describe in the previous section. Peeled cassava roots were quickly chipped (< 5 mm thickness) in a motorized slicer. The freshly chipped roots were immediately spread thinly on drying trays and dried either in a solar tent dryer or a mechanical dryer. Solar drying took place over a period of 14 hours during which the thinly spread chips were turned several times. Mechanical drying also took place for 8 hrs at 60 °C in a diesel-operated walk-in cabinet dryer. The dried chips were ground in a disc attrition mill and sieved (250 µm) to obtain a smooth and free-flowing flour. All the equipment used to process the HQCF were fabricated by the CSIR-FRI, Accra

### 2.2.3 Microbial Assessment

The microbiological analyses carried out were counts of Aerobes, Yeast and Molds, Coliforms, *E. coli*, *Staph. aureus* and *Salmonella spp*. These counts were determined using accredited methods according to the Nordic Committee on Food Analysis (2006) and ISO 17025.

### 2.2.4 Chemical Analyses

#### *2.2.4.1 Cyanide*

Cyanide content was determined using the alkaline titration method (ISO 2164). Twenty grams of sample was transferred into a 1 L distillation flask and 200ml distilled water added for steam

distillation. The distillate (150 ml) was collected in 20 ml of 1 N NaOH. The apparatus was adjusted in order for the tip of the condenser to dip below the surface of the NaOH solution in the receiver. The distillate in NaOH solution was transferred into a 250 ml volumetric flask made up to the mark and 100ml of this solution titrated against 0.02 N $AgNO_3$ solution to a permanently turbid end point. The results were calculated using the relation 1 ml 0.02 N $AgNO_3$ = 1.08 mg HCN, and reported as mean ± standard deviation.

#### *2.4.4.2 pH and Total Titratable Acidity (TTA)*

Ten grams of flour sample was weighed into a 250 ml beaker. 90 ml of distilled water was added and mixed well. The mixture was left for 1 hour at room temperature. The pH was measured in triplicate using a pH meter (Jenway 3330, UK).

#### *2.2.4.3 Starch*

Lintner's

#### *2.2.4.4 Crude fiber, total ash and acid insoluble ash*

Crude fiber and total ash were analyzed in triplicates by standards methods 963.09 and 920.87 of the Association of Official Analytical Chemists (AOAC, 1990), whilst acid insoluble ash was determined by Kirk and Sawyer (1991)

#### *2.2.4.4 Heavy metals*

The dry ashing method was used for Atomic Absorption Spectrophotometer (AAS) analysis AOAC, 2005). Three grams (3 g) each sample was ashed in a Muffle furnace at 550°C for 8 h. Five milliliters of nitric acid was added and the resultant solution heated until the ash dissolved. The solution was topped up with 10 ml of nitric acid (0.1 mol/L), filtered into a 50 ml volumetric flask and made up to the mark with nitric acid. Blank solution was treated the same way as the sample. The absorbance of metals in sample solution was read using an AAS (Buck Scientific 210VGP Flame, Buck Scientific East-Norwalk, USA). Using air/acetylene gas, metals analyzed were Pb, Cu, Fe, As, Hg, Sn and Zn. The metal content were derived from calibration curves made up of minimum of three standards.

#### *2.2.4.5 Aflatoxins*

Samples were analyzed quantitatively for aflatoxins according to Stroka and Anklam (1991)

### 2.2.5 Sampling and data analysis

Samples were randomly taken from each unit operation along the processing line and analyzed for key chemical and microbial indicators of HQCF safety and quality. The data obtained were analyzed for differences using one way ANOVA (SPSS 17) and means considered significantly

different at p≤0.05. Significantly different means were separated by Duncan's Multiple Range Test.


**Figure 1a: Processing HQCF by grating and mechanical/solar drying**


**Figure 1b: Processing HQCF by chipping and mechanical/solar drying**

## 2.3 RESULTS

### 2.5.1 Microbial Load

Microbial status of cassava through the various stages of processing into HQCF is presented in Tables 1 – 6. At the start of processing the yeast and molds, aerobic plate and coliform counts were 4.70 x $10^3$, 1.00 x $10^2$ and 0.09 x $10^2$, correspondingly for the freshly peeled cassava. Washing reduced the coliform and total plate count of peeled cassava and rather resulted in an increase in yeast and mold count (Table 1). *E. coli* and *Staphylococcus aureus* counts throughout

the processing steps were less than 10 while *Salmonella* was "not detected" in any of the cassava samples tested.

Table 1: Microbial Characteristics of raw and washed cassava at the beginning of processing

| *Micro-organism* | *Peeled cassava* | *After washing* |
|---|---|---|
| Yeast and Molds | $4.70 \times 10^3$ | $2.20 \times 10^4$ |
| Aerobic plate count | $1.00 \times 10^2$ | 190 |
| Coliform count | 9 | 42 |
| *E. coli* count | <10 | <10 |
| *Staph aureus* count | <10 | <10 |
| *Salmonella spp.* | ND* | ND* |

*ND – Not Detected

Tables 2 – 4 presents the effect of grating and slicing as methods of size reduction on microbial load during HQCF processing. As shown, unit operations covered here are size reduction with or without pressing, and spreading. For yeast and mold, coliform and total place counts, a general trend of an increase in microbial load was observed using both slicing and grating as methods of size reduction. Contrary to this trend however, yeast and mold count reduced from slicing through spreading. Slicing generally proved to result in lower counts of yeast and mold, coliforms and aerobic plate count compared to grating as indicated in Tables 2-4.

Table 2: Yeast and mold count after size reduction

| Processing step | Size reduction | |
|---|---|---|
| | Grating | Slicing |
| After size reduction | 2.60E+03 | 3.30E+03 |
| After pressing | 3.20E+03 | N/A |
| After spreading | 3.20E+03 | 1.90E+03 |

Table 3: Aerobic plate count after size reduction

| Processing step | Size reduction | |
|---|---|---|
| | Grating | Slicing |
| After size reduction | 570 | <10 |
| After pressing | 600 | N/A |
| After spreading | 1.20E+03 | 180 |

Table 4: Coliform count after size reduction

| Processing step | Size reduction | |
|---|---|---|
| | Grating | Slicing |
| After size reduction | 174 | <10 |
| After pressing | 192 | N/A |
| After spreading | 192 | 140 |

#### *2.5.1.1 Microbial characteristics of HQCF under different drying conditions*

Tables 5 and 6 show the microbial characteristics of HQCF from the two size reduction lines (grating and slicing). Compared to mechanical drying, solar drying generally had much influence

on reducing microbial load of intermediary products along the HQCF processing line, except in the case of aerobic plate count where mechanical drying caused a greater reduction in counts, than solar drying (Tables 5 and 6).

Table 5: Microbial characteristics of HQCF (produced by grating) after drying

| | Mechanical | Solar |
|---|---|---|
| Yeast and Molds | $3.60 \times 10^4$ | $1.90 \times 10^3$ |
| Aerobic plate count | $4.50 \times 10^7$ | $9.00 \times 10^7$ |
| Coliform count | $4.10 \times 10^6$ | $3.50 \times 10^6$ |
| *E. coli* count | <10 | <10 |
| *Staph aureus* count | <10 | <10 |
| *Salmonella spp.* | ND | ND |

Table 6: Microbial characteristics of HQCF (produced by slicing) after drying

| | Mechanical | Solar |
|---|---|---|
| Yeast and Molds | <10 | $5.25 \times 10^2$ |
| Aerobic plate count | $7.70 \times 10^4$ | $1.10 \times 10^9$ |
| Coliform count | $2.20 \times 10^3$ | $2.30 \times 10^7$ |
| *E. coli* count | <10 | <10 |
| *Staph aureus* count | <10 | <10 |
| *Salmonella spp* | ND | ND |

### 2.5.2 Chemical Analysis

#### *2.5.2.1 Cyanide analysis of cassava through processing*

Total cyanide content of cassava through processing into HQCF is presented in Tables 7a-b. Cyanide in the raw cassava tuber was about 39 mg HCN/kg, which is more than three times the recommended level of <10 mg HCN/kg (FAO/WHO, 1991). A reduction of more than 70% in cyanide content was established using the two approaches of processing HQCF. Throughout the production process, a gradual reduction in cyanide was observed. In accordance with previous reports (Ayernor, 1995; Bainbridge *et al*., 1998), size reduction (chipping or grating) and drying caused a decrease in cyanogen content during processing. Among these unit operations, drying caused the greatest reduction followed size reduction (grating or chipping) and washing.

Size reduction during processing disrupts tissues and cells thereby bringing cyanogenic glycosides and hydrolytic enzymes together. The process leads to the production of HCN, which evaporates in the presence of heat (Essers *et al*., 1996). Among the two approaches to size reduction, cyanide removal was greater in grating (followed by pressing) compared to chipping (Table 7a). Grating, followed by pressing caused a reduction in cyanogens potential of more than 60% as opposed to about 34% by slicing. This observation was expected since the extent of cell disruption in grated cassava roots creates a more intimate contact between enzyme and substrate compared to the case of slicing (Ayernor, 1995; Cardoso, 2005).

Table 7a Total cyanide (mg HCN/kg) content of cassava during processing

| Processing Step | Cyanide content (mg HCN/kg) | |
|---|---|---|
| After peeling | 39.13±0.31[a] | |
| After washing | 35.11±0.21[b] | |
| | Grating | Slicing |
| After size reduction | 26.01±0.09[b] | 28.16±0.27[c] |
| After pressing | 14.01±0.05[a] | |

The two methods of drying resulted in different levels of cyanide in HQCF produced with the solar-dried samples recording lower cyanide levels than those dried using the mechanical dryer (Table 7b). Under mechanical drying, grated samples had significantly lower ($p<0.05$) cyanide content than sliced ones but the same cannot be said for the solar dried flour in which sliced samples compared well with grated samples. Slower moisture removal and drying rates, as in the case of solar drying are known (Essers *et al*., 1996) to be more efficient in cyanide removal because this method presents a longer period of exposure of cyanide compounds to hydrolytic enzymes. The result of this prolonged exposure is a greater breakdown of these glycosides into a cyanohydrin, which readily decomposes into HCN and is evaporated by heating.

Table 7b: Total cyanide (mg HCN/kg) of cassava flour

| | Mechanical | Solar |
|---|---|---|
| Grated | 8.32±0.10[a] | 6.14±0.03[a] |
| Sliced | 11.06±0.03[b] | 10.23±0.21[b] |

The efficacy of cyanide removal during mechanical drying is reduced because of the fact that the internal temperature of the product is likely to exceed 55ºC. Temperatures in excess of 55ºC prevent linamarase from acting at its optimal capacity or completely inactivate it, leaving the cyanogens to accumulate in the flour (Perera, 2009; Cooke and Maduagwu, 1978).

### *2.5.2.2 Other chemical analysis*

Analyses on other chemical constituents which serve as quality indicators for HQCF are presented in Table 8.

Table 8: Chemical composition of fresh cassava and HQCF

| Processing step | Chemical property | | | | | |
|---|---|---|---|---|---|---|
| | Ash | AIA* | Starch | Fiber | TTA* | pH |
| *Raw cassava* | *2.86±0.01[a]* | *0.01* | *133.3* | *1.95±0.01[ab]* | *0.22±0.01[d]* | |
| After grating | 2.80±0.03[a] | 0.01 | 132.4 | 1.75±0.03[a] | 0.52±0.03[c] | - |
| After pressing | 1.41±0.02[b] | 0.01 | 71.3 | 1.86±0.03[b] | 0.22±0.01[d] | - |
| After slicing | 3.01±0.01[a] | 0.05 | 121.8 | 1.72±0.32[ab] | 0.56±0.01[c] | - |
| SS | 2.93±0.04[c] | 0.03 | 63.2 | 1.81±0.02[c] | 0.13±0.01[a] | 6.4±0.02[a] |
| SG | 1.60±0.00[e] | 0.01 | 45.1 | 1.67±0.03[c] | 0.13±0.01[a] | 6.7±0.01[a] |
| MS | 3.11±0.02[d] | 0.01 | 56.2 | 1.85±0.01[c] | 0.33±0.01[b] | 5.1±0.03[b] |
| MG | 1.70±0.01[f] | 0.01 | 47.6 | 1.81±0.03[c] | 0.34±0.01[b] | 5.1±0.05[b] |

*AIA – Acid insoluble ash, TTA – Total titratable acidity

Chemical properties of raw material used affect the quality of HQCF produced and therefore good quality starting materials should be used if the desired quality standard is to be achieved. The chemical composition of the raw cassava used for processing the HQCF is illustrated in Table 8. Total ash reflects the mineral content of food products (Marshall, 2010) while acid insoluble ash is often indicative environmental contamination with siliceous materials such as sand (Rao and Xiang, 2009). Differences between acid insoluble ash for flours from the various production lines were not significant ($p>0.05$). The total ash content of the HQCF from the two lines of size reduction and drying ranged between 1.7 – 3.1% and compared well with the established standard of 3%, while the acid insoluble ash was well within the acceptable quality level (0.15% max). The starch content of HQCF processed by the various methods was less than the range of 65-70% recommended by Dziedzoave *et al*., (2006).

As shown (Table 8) however, flours from sliced cassava had higher starch content compared to that from grated cassava. Reduced starch content in flour from grated cassava could be due to pressing which follows grating. This unit operation expels more than 40% of water from the grated cassava mass (Dziedzoave *et al*., 2006). Fiber content of the flours, as well as that of the intermediary products were comparable and did not differ markedly from one another. The flours had fibre ranging from 1.67 to 1.85%, a range which is less than the amount of fibre permissible in HQCF. Total titratable acidy was considerably higher in HQCF dried by mechanical compared to solar means and exceeded the standard (<0.25%) set for HQCF. The pH of the flour ranged between 5.1 and 6.7 for HQCF dried mechanically and grated-solar dried HQCF. Samples produced by mechanical drying were considerably lower in pH compared to that dried in the solar dryer and therefore suggests that some level of fermentation must have occurred in mechanically dried samples. This occurrence could explain why TTA in these samples were higher. Good quality HQCF must be unfermented and have a pH > 5.5 (Bechoff *et al*., 2011).

#### *2.5.2.3 Trace metal analysis of cassava flour*

Availability of trace metals in food is dependent on their inclusion in cell structures and on treatment and processing conditions (Hurrel, 1999; Steadman *et al*., 2001). The heavy metal composition of the HQCF is presented in Table 9. These metals are non-biodegradable, may be taken up by plants through their roots and accumulated. The main concern of its contamination of crops is its effect as a carcinogen. As shown, although the Zn content of the flour from the slicing/chipping line is found to be significantly higher ($p<0.05$) than that from the grating line, it does not exceed the maximum limit of 22mg/kg (Dziedzoave *et al*., 2006) set for HQCF. The content of the other metals were not significantly different for the two different size reduction lines (grated and chipped). Fe was also found to be higher in sliced samples compared to those that were grated, but the case of Cu was quite different as HQCF from the various lined had similar concentrations. The content of these trace metals in the final flour are well within their recommended ranges and do not exceed their maximum limits. Therefore, as far as heavy metals

are concerned, the HQCF can reliably be classified as safe for use in the manufacture of food products.

Table 9: Trace metal concentration of raw, intermediary and HQCF

| Processing Step | Trace metal concentration (mg/kg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pb | Cu | Fe | As | Hg | Sn | Zn |
| Raw cassava | ND* | $2.05\pm0.26^{d}$ | $14.59\pm0.23^{bc}$ | ND | <0.01 | ND | $6.49\pm0.06^{cd}$ |
| After grating | ND | $1.57\pm0.31^{bcd}$ | $16.64\pm0.35^{d}$ | ND | <0.01 | ND | $9.02\pm0.58^{e}$ |
| After pressing | ND | $1.39\pm0.15^{abc}$ | $13.16\pm0.05^{b}$ | ND | <0.01 | ND | $5.05\pm0.27^{b}$ |
| After slicing | ND | $1.74\pm0.18^{cd}$ | $16.37\pm0.33^{d}$ | ND | <0.01 | ND | $7.44\pm0.06^{d}$ |
| SS | ND | $1.36\pm0.11^{abc}$ | $14.75\pm0.65^{c}$ | ND | <0.01 | ND | $9.28\pm0.12^{e}$ |
| SG | ND | $1.15\pm0.21^{abc}$ | $11.32\pm0.01^{a}$ | ND | <0.01 | ND | $5.50\pm0.55^{bc}$ |
| MS | ND | $0.79\pm0.09^{a}$ | $13.30\pm0.71^{bc}$ | ND | <0.01 | ND | $10.79\pm0.16^{f}$ |
| MG | ND | $1.02\pm0.08^{ab}$ | $10.91\pm0.44^{a}$ | ND | <0.01 | ND | $3.92\pm0.03^{a}$ |

*ND – Not Detected. Means bearing different superscripts are significantly different at p=0.05

### *2.5.2.4 Aflatoxin Analysis*

As presented in Table 10, aflatoxin analysis conducted on raw material, intermediary and finished products revealed that none of them contained mycotoxins since these toxins were "not detected" in the all the samples.

Table 10: Aflatoxins in intermediary and final HQCF

| *Sample* | *Aflatoxins (ug/kg)* | | | | *Total Aflatoxins* |
|---|---|---|---|---|---|
| | *B1* | *B2* | *G1* | *G2* | *(µg/kg)* |
| Raw cassava | ND | ND | ND | ND | ND |
| After Grating | ND | ND | ND | ND | ND |
| After Pressing | ND | ND | ND | ND | ND |
| After slicing | ND | ND | ND | ND | ND |
| ADSS | ND | ND | ND | ND | ND |
| ADSG | ND | ND | ND | ND | ND |
| ADMS | ND | ND | ND | ND | ND |
| ADMG | ND | ND | ND | ND | ND |

ND – None detected

This observation suggests that there was no contamination of raw material, intermediary and finished products by organisms such as *Aspergillus and Fusarium spp*. during processing of cassava into HQCF. These organisms usually inhabit the food product and synthesise the toxins, as metabolites, in the presence of high levels of carbohydrates and low levels of protein (Essono *et al*., 2009). Consumption of food contaminated with mycotoxins is reported to have adverse effect on human health (James, 2005; Lewis *et al*., 2005). Mycotoxins content of the flour was observed to conform to the limits set for HQCF (Dziedzoave *et al*., 2006).

# CHAPTER THREE

## Chapter synopsis

This chapter wraps up the report and presents the conclusions and recommendations from the study.

## 3.0 CONCLUSION

Cassava is by far the most important tuber crop in the lives of many people the world over and in recent times serves as a less costly source of raw material for industrial applications. Its uses, however, is hampered because of its potential toxicity which is due to the presence of cyanogenic glycosides. Processing successfully detoxifies cassava and reduces the risk of intoxication by consuming cassava. The efficiency of cyanide removal however, depends on the processing technique employed and the extent of processing.

The two methods of size reduction and drying had different effects on the safety and quality indicators of high quality cassava flour. In the case of cyanogenic potential, grating and solar drying resulted in better reduction of HCN than slicing/chipping and mechanical drying. These observations further emphasize the need for finer cell disruption and prolonged drying in order in order to allow for extensive degradation and efficient detoxification of cassava during HQCF processing.

## 3.1 RECOMMENDATIONS

With HQCF fast gaining popularity as a raw material with several industrial prospects, its production must be standardized and streamlined in order to ensure consistent safety and quality characteristics. Approaches to its production must that ensure a higher degradation of cyanogens and therefore grating is suggested as a good size reduction method in this respect. As well, faster and hygienic drying methods such as mechanical or solar drying must be used so that consistency is assured.

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