CSIR-FRI/NRI CASSAVA GMARKET PROJECT

Work Package 4: Ensuring the safety and quality of processed cassava products in market-oriented production.

Report on the Review of previous experiences and works on cyanogenic glycosides in cassava processing

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Contents

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 can grow and produce significant harvests even in environmental conditions which are inclement for most crops. World production quantity of the produce increased by more than 30 % over the period between year 2000 and 2010, with more than half of the total amount produced in Africa. Cassava is primarily grown for use as food and has over the years played an inimitable role in providing valuable calories for people of diverse socio-cultural standings. That notwithstanding, 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, which naturally serve wards off insect and herbivore attack, undergo enzymatic degradation to produce HCN which is lethal at 35 - 150 μmol/kg, administered in a single dose. Sub-fatal doses over a long period have been reported to affect the nervous system and thyroid glands. HCN has also accounted for cases of reduced blood pressure, diabetes mellitus and growth retardation in children. Cyanogenic compounds have also been identified as contributing to bitterness in certain cassava varieties. Reduction of cyanogen content reduces the risk of intoxication associated with cassava consumption.

Detoxifying cassava of cyanide presents an avenue for expanding both domestic and industrial applications. Even though contemporary interventions such as genetic engineering and breeding have been applied to generate cyanide-free varieties, traditionally, detoxification is achieved by processing. Methods such as fermentation, cooking, drying and roasting have resulted in significant reduction of cyanide content of cassava. These techniques involve a combination of unit operations that trigger the breakdown of cyanogens by endogenous enzymes into HCN, which is subsequently evaporated (by heating) or dissolved in water (depending on the processing method under consideration). Processing has resulted in markedly lessened potency of cyanogenic glycosides in cassava, even though the reduction in toxicity depends on the starting material, and the method used and the extent of processing.

1.0 INTRODUCTION

This report presents review of previous works 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 write-up focuses on detoxifying these cyanogenic glycosides during processing, the mechanisms and the unit operations involved in these processes. Both the roots and leaves of cassava are covered in this review.

1.1 Objectives

To review various unit operations involved in cassava processing and their effect on the degradation of cyanogenic glycosides.

2.0 GENERAL OVERVIEW OF CASSAVA AND ITS IMPORTANCE

Cassava (*Manihotesculenta*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.

2.1 Nutritional and anti-nutritional properties

Cassava is cultivated primarily 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. Nutritional composition of cassava roots and leaves

	Cassava roots	Cassava leaves
Proximate composition		
Food energy (kcal)	100 – 149	91
Moisture (g)	45.9 – 85.3	64.8 – 88.6
Dry weight g)	29.8 – 39.3	19 – 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 – 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)	0.6 – 1.09	1.3 – 2.8
Ascorbic acid (mg)	14.9 – 50	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.

3.0 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 aresecondary 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 Fig. 1

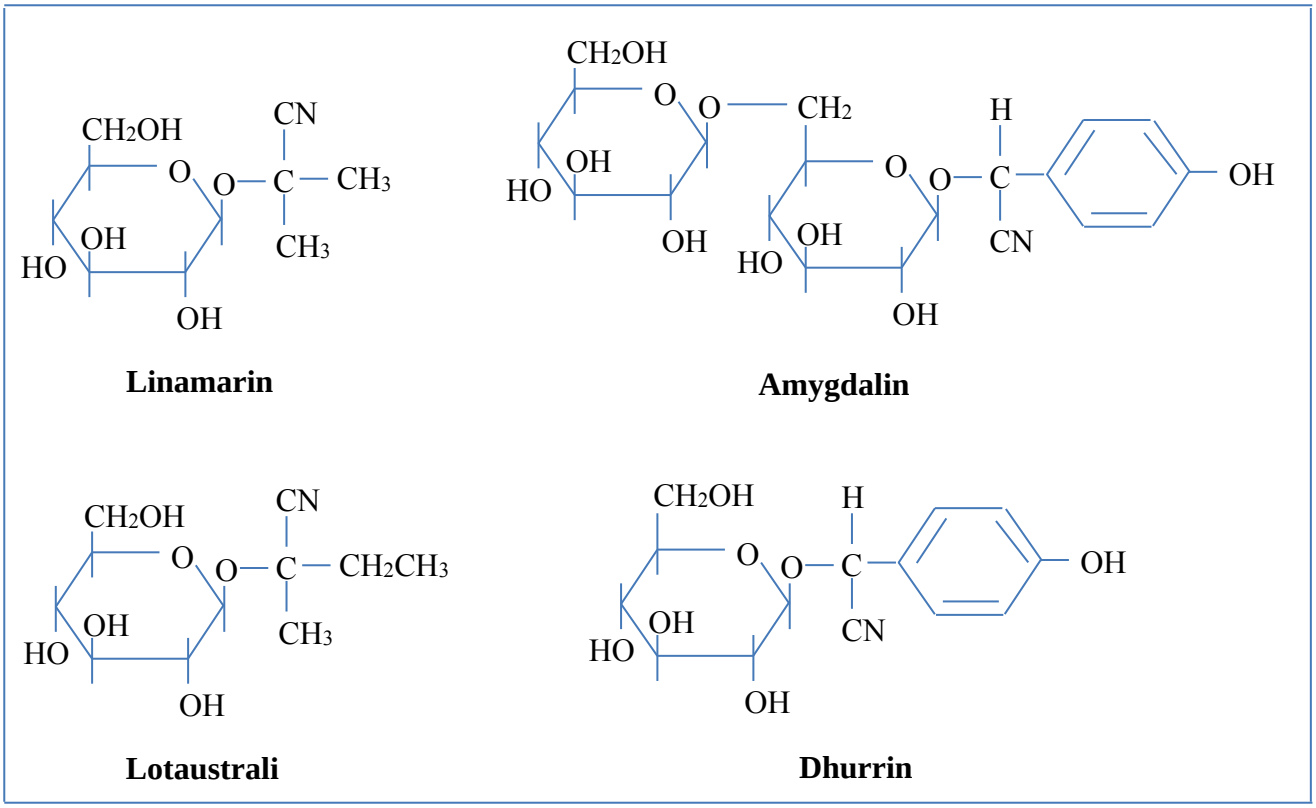

Fig. 1. Chemical Structures of some cyanogenic glycosides

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 (Fig 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 andthe 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 hydroxynitrilelyase. The degradation of cyanogens to produce HCNby this two-step process is referred to as cyanogenesis (Deshpande, 2002).

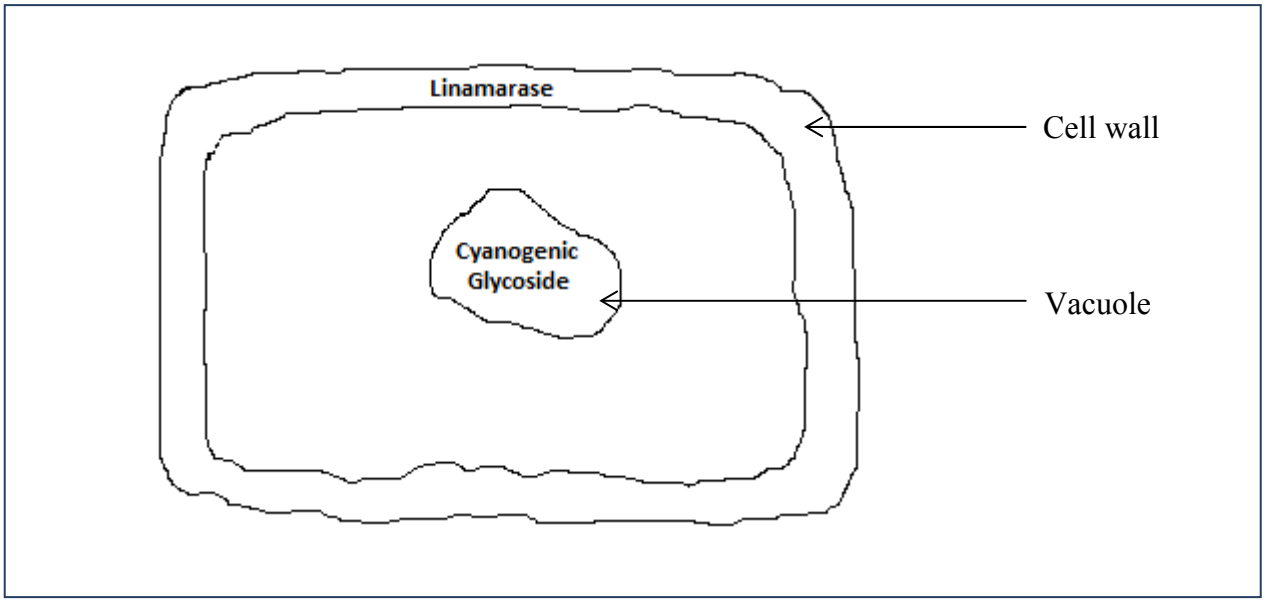

Fig 2. Location of cyanogenic glycoside and linamarase in the plant cell, adapted from Conn (1994)

3.1 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) andgrowth 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 whichplace a restriction on their use to a very large extent. Substantial concentrations have been reported in cassava (Manihotesculenta), 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, whileCumbana*et al*., (2007) reported 8 - 85 mg for cassava flour. Other reports by Adindu*et al*., (2003), Djazuli and Bradbury (1999) andSopade (2000) showed significantly higher amounts of cyanide containing compoundsthan 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 250ug/g has been proposed for efficient processing(Cardoso *et al*., 2005).

3.2 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).

4.0 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 (Esser*et al*.,., 1996).

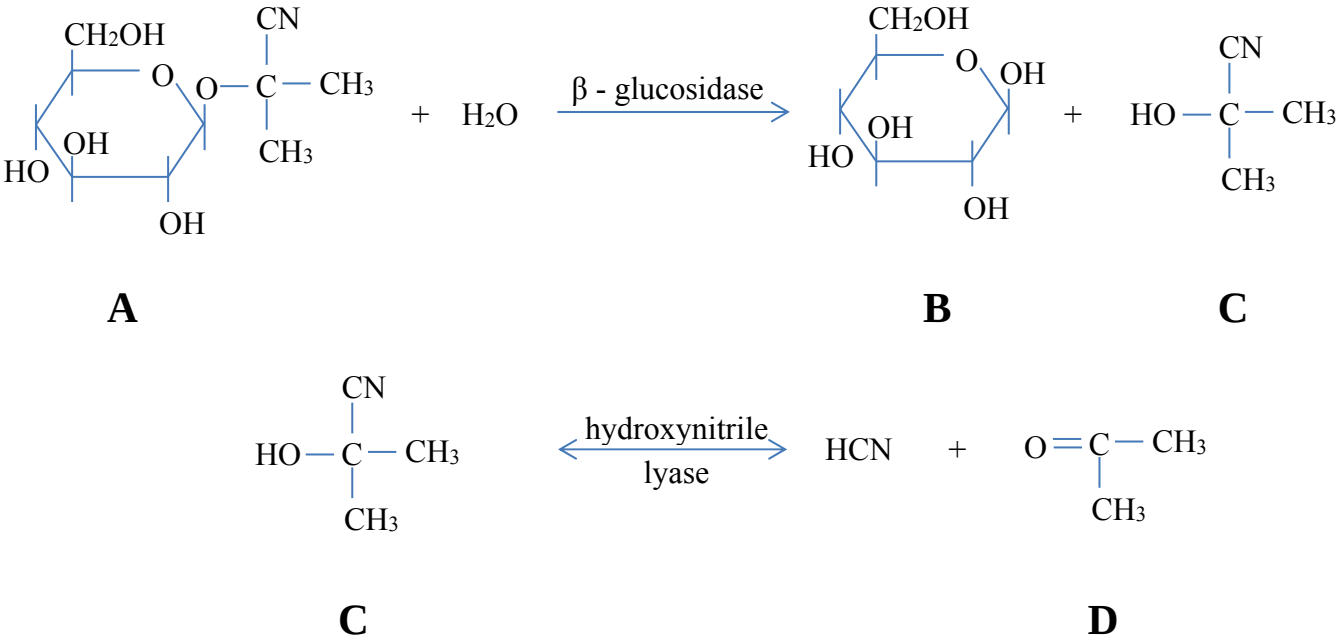

Figure 3: Enzymatic breakdown of Linamarin (McMahon *et al*.,., 1995)

Fig. 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).

4.1 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 theypresent 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.

4.2 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 klebsiellaoxytoca 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.delbrueckiiresulted in an 89.5% reduction in cyanide content.

4.2.1 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 synergiseswith 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 ntobambodi (Kobawila*et al*., 2005), cassava dough (Amoa-Awua*et al*., 1997), farinhapuba (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.

4.2.2 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)

4.2.3 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).

4.2.4 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 Africaand 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 (Esser*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 (Esser*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(Esser*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 (Esser*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.

4.2.5 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).

5.0 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 efficiencyof cyanide removal however, depends on the processing technique employed and the extent of processing. Processing operations such as fermentation, boiling/cooking, roasting and drying, applied to process cassava have been able to reduce cyanide content to acceptably safe levels.

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