

Food safety and quality considerations for cassava, a major staple containing a natural toxicant

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Introduction

Cassava (*Manihot esculenta* Crantz) is native to South America and southern and western Mexico. It was one of the first crops to be domesticated, is thought to have originated in Brazil (Phillips, 1974) and is known to have also been grown in Columbia, Guatemala,



FIGURE 8.1 Cassava peeled and prepared for further processing.

Venezuela and southern Mexico (Lokko et al., 2007). Also known as manioc, yucca, or tapioca, it is one of the most important staple food crops grown in developing countries. The native peoples of the Caribbean and northern South America were probably some of the earliest cultivators of cassava (Henry and Hershey, 2002), and many of their customs of cultivation and processing remain virtually unchanged today. Practices from ancestral times also have been conserved throughout the Amazon basin. Most tropical countries, including eastern countries such as Indonesia and Thailand produce cassava, but its cultivation is most highly concentrated in four areas: northern and eastern coastal Brazil, southern Brazil and eastern Paraguay, northwestern South America (especially the Caribbean coast of Columbia), and the Greater Antilles in the Caribbean, which includes Haiti, the Dominican Republic, Cuba (Henry and Hershey, 2002) and Jamaica.

Cassava (Fig. 8.1) spread from Central and South America to other parts of the world in the post-Columbian period, having been introduced into Western Africa and Zaire in the late 1500s, probably by slave ships. It was introduced into Madagascar and Zanzibar (East Africa) via Réunion by the end of the 1700s, and by 1800 it had reached India. By the 1850s, it was widely cultivated in Southeast Asia and Africa. Cassava is now the third most important source of calories in the tropics after rice and maize, is now grown in over 90 countries and is a staple for half a billion people in Africa, Asia, Latin America and the Caribbean (Jackson and Chiwona-Karltun, 2018). Global cassava production encompasses most of the developing world) which collectively accounts for 47% t of the world's population and 46% of its arable land.

Cassava production and consumption trends

The plant has become a staple in developing countries since its introduction to major growing areas, largely because of its adaptability to conditions that are often inimical to

the growth of other crops. Cassava is adapted to growing in the zone that falls between latitudes 30 degrees north and south of the equator, at elevations of not more than 2,000 m above sea level. It grows well at temperatures ranging from 18 to 25°C, with rainfall of 50 to 5,000 mm annually, and in poor soils with a pH range from 4 to 9.0 (Ezumah and Okibo, 1980). Typically, it is grown by poor farmers, often on marginal land. Many of these farmers are women. Since it can withstand drought and because of its efficient production of food energy, year-round availability, tolerance to extreme stress conditions, and suitability to present farming and food systems in Africa and the Caribbean, it is sometimes a nutritionally strategic famine reserve crop in areas of unreliable rainfall (Ezumah and Okibo, 1980; Hahn et al., 1987). Cassava is also a source of commercial animal feed, fiber for paper and textile manufacturers, and starch for the food and pharmaceutical industries, with the world's largest importer of cassava and cassava derivatives being China (Prakash, 2018).

It is estimated that 70% of the world production of cassava comes from five countries: Nigeria, Brazil, Indonesia, Thailand and the Democratic Republic of the Congo, with Africa and Asia now producing more than Latin America and the Caribbean. Nigeria, Thailand and Indonesia with 47.4, 30.2 and 23.9 million tonnes in 2013, respectively, are the world's largest producers, with a total of 268 million metric tons produced in 2014 (International Fund for Agricultural Development (IFAD) & Food and Agricultural Organization of the United Nations (FAO), 2000; Worldatlas.com, 2019). Fifty six percent (56%) of the world's cassava is grown in Africa, thirty two percent (32%) in Asia and 12% in the Americas (Jackson and Chiwona-Karltun, 2018). Cassava production on the African continent has continued to increase with the annual average growth rate over the last 10 years outpacing population growth, with the exception of 2017 and 2018. The current outlook for cassava production in Asia is uncertain with China, the largest regional and global market for the product, cutting back imports as it works through its domestic surplus of maize (Prakash, 2018). There is much lower production in the Americas than other regions, with Brazil, Paraguay and Colombia producing a projected 20.9, 3.3 and 2.3 million metric tonnes respectively and all other Latin American producers, 4.2 million metric tonnes combined. Haiti (415,000 metric tonnes) and the Dominican Republic (500,000 metric tonnes) are the other major producers in the Caribbean (FAOSTAT, 2015). Still, most countries in the Americas, except for those in North America, continue production of cassava, which plays an important cultural and dietary role throughout the region. A traditional processing centre where cassava is collected and processed to make cassava flour, cassava bread and other products is shown in Fig. 8.2.

There have been consistent gains in productivity and yields for all cassava producing regions as the importance of the crop increases. In 2015, the five countries with the highest yields were India (300 Hg/Ha*), Cook Islands (250 Hg/Ha), Suriname (200 Hg/Ha), China (200 Hg/Ha) and Barbados (200 Hg/Ha) (FAOSTAT, 2015). As Asian countries like Thailand, Indonesia, Vietnam and Cambodia have increased their production, gains in productivity have also begun to rise, largely fueled by what had been a consistent increase in demand from China for more cassava chips and pellets (Prakash, 2018). This has paralleled an explosion in the growth of the area under cultivation as some Asian countries

* Hg/Ha means hectagram (100g) per hectare, the standard measurement used by FAO for crop yields.



FIGURE 8.2 Cassava at a traditional processing centre in Central America.

such as Lao Peoples Democratic Republic and Vietnam have seen the area under cultivation increase from almost nothing to 100,000 ha and three-fold to 600,000 ha, respectively.

While this current change in the fortunes of the crop in Asia is clearly driven by economic prospects, most farmers have traditionally grown cassava for food security and as a response to famine, hunger and drought. This is particularly so in Africa, a fact supported by surveys in selected African countries (Food and Agricultural Organization of the United Nations (FAO), 2005). Another important reason is that cassava is a hardy crop that has significant resistance to pests and diseases, hence the reason it plays such an important role in developing country diets (Food and Agricultural Organization of the United Nations (FAO), 2005). As a result, the whole plant provides a nutritious basic staple during periods of drought or reduced rainfall and is important in the mitigation of famine and hunger, particularly in Africa (Jackson and Chiwona-Karlton, 2018). With the crop enjoying increased popularity as a result of greater domestic demand in producing countries, increased production yields and generally higher prices, the increased interest in, and access to, export markets has also helped to transition cassava from a crop planted for food security purposes to one that is rising in economic importance for developing countries (Food and Agricultural Organization of the United Nations (FAO), 2005; Prakash, 2018; Jackson and Chiwona-Karlton, 2018).

In Africa, cassava is almost exclusively used for consumption as food or used in foods (Food and Agricultural Organization of the United Nations (FAO), 2005; Prakash, 2018) with about 95% of the total cassava production, after accounting for waste, being used as food. Total cassava consumption in Africa has more than doubled, due largely to a significant increase in per capita consumption in countries such as Ghana and Nigeria where cassava was produced as a cash crop for urban consumption. It is likely that the importance of cassava in some countries, for example the Congo, is underestimated due to under-reporting, as many families eat cassava for breakfast, lunch and dinner and cassava is known to contribute over 1000 calories per person per day, i.e., 55% of the average daily caloric intake (Food and Agricultural Organization of the United Nations (FAO), 2005). In

addition to the roots, cassava leaves are also widely consumed as a vegetable in several places where cassava is grown such as in the Congo and Tanzania. The availability of cassava in a convenient food form, such as *gari*, has played a major role in the increase in the per capita cassava consumption in Ghana and Nigeria. Future increases in cassava consumption in other African countries will depend on how well cassava is prepared into food forms to create an easy-to-use alternative to wheat, rice, maize and sorghum for urban consumers.

Cassava was found to be the cheapest source of calories among all food crops in each of the six countries reported in a study conducted by the Food and Agricultural Organization of the United Nations (FAO) (2005). As family incomes increased and lifestyles changed, the consumption of cassava as dried root flour declined while consumption in convenient food forms such as *gari* increased. This was despite the fact that dried cassava root flour was cheaper than *gari* because of the high cost of processing *gari* (Food and Agricultural Organization of the United Nations (FAO), 2005). Medium and high-income families were found to consume *gari* because it was cheaper and more convenient to cook than grains. Consequently, the future of cassava as a rural and urban food staple will depend on its ability to compete with wheat, rice, maize, sorghum and other grains in terms of cost, convenience and availability in urban markets. The role of convenience, labor-saving production, harvesting and processing technologies in this regard will be important.

Cassava toxicology and safety

Cassava cultivars grown on all continents contain naturally toxic compounds known as cyanogenic glycosides (Conn, 1969; Jackson-Malete et al., 2015). Cyanogenic glycosides (CGs), like other cyanogenic compounds, produce hydrogen cyanide (HCN) when the cells in which they reside become damaged or are being degraded, as during digestion (Nahrstedt, 1988; Kashala-Abotnes et al., 2019), through enzymatic hydrolysis by beta-glucosidase. While the cyanogenic glycosides themselves are relatively non-toxic in their native form, their ability to produce HCN upon maceration and its high level of toxicity make them very dangerous. Clinical signs of acute cyanide intoxication include a rapid pulse, rapid respiration, stomach pain, vomiting, diarrhea, a drop in blood pressure, dizziness, headache, mental confusion, twitching and convulsions. When the cyanide levels exceed the acute lethal dose of 0.5–3.5 mg per kilogram of body weight, exceeding the bodies ability to detoxify it, death due to cyanide poisoning can occur (Kwok, 2008; Kashala-Abotnes et al., 2019). Consequently, care must be taken in the handling, preparation and consumption of this important staple to avoid undesirable health outcomes due to HCN poisoning.

There are two varieties of cassava: “sweet” cassava, which has a low toxin content, and “bitter” cassava with a characteristically high toxin content. The toxins of concern, cyanogenic glycosides (CGs), are a group of chemicals that occur naturally in over 2,000 plants which are highly toxic when consumed (Kwok, 2008). CGs are found in cassava in the form of linamarin and lotaustralin or a combination thereof, as free hydrocyanic acid (HCN) and cyanohydrin (Chikezie and Ojiako, 2013). All cassava varieties can be classified into these

two groups, with the roots of “bitter” cassava cultivars containing higher levels of CGs than those of “sweet” cassava cultivars (Bolhuis, 1954). Generally, the sweet varieties of cassava, because of their lower content of cyanogenic glycosides (Carmody, 1900), can be eaten without pre-preparation (i.e. “raw”). The bitter varieties require pre-processing to make the final product safe for consumption because of the much higher toxin levels (von Hagen, 1949; Chiwona-Karlun et al., 2004).

The cyanide released by the breakdown of the cyanogenic glycosides during preparation, post-ingestion or even after absorption into the body (Brimer, 2000), is toxic and can cause severe acute poisoning. Typically, however, it is more frequent that chronic poisoning is observed. This may be characterized by slower growth and development, and neurological symptoms resulting from central nervous system (CNS) tissue damage (Tylleskär et al., 1992). Ruminants, in which the fore-stomach flora contributes to the hydrolysis of cyanogenic glycosides, are considered to be more vulnerable to such compounds than monogastric animals (Brimer, 2001) and this, therefore, has implications for the use of the crop in the making of animal feed.

The main cyanogenic glycoside in cassava is linamarin (Dunstan et al., 1906) and there are smaller amounts of lotaustralin (Brimer, 2000) also typically present. They occur in the proportions of about 10:1. Linamarin and lotaustralin are synthesized from the amino-acids valine and isoleucine. These cyanogenic glycosides (Seigler, 1991) can be found throughout the whole cassava plant with the highest concentrations in the young leaf shoots (Joachim and Pandittsekere, 1944), followed by the petioles, stems and roots (de Bruijn, 1973). Synthesis of the glycosides mainly occurs in the leaves and they are transported to the roots, although there is some synthesis in the root as well (Bokanga 1995). Within the root, the peel contains more cyanogenic glycosides than the edible flesh (Bokanga, 1994). Genetic and environmental factors concurrently determine the glycoside levels in the roots (Mahungu, 1994). Nowhere in the world has a cassava cultivar without any cyanogenic glycosides been identified, despite anecdotal statements to the contrary.

All cyanogenic glycoside-containing plants also contain enzymes for the decomposition of the glycosides. In cassava, this endogenous enzyme is called linamarase (Kereztesy et al., 1994). The glycosides and the enzymes are stored in separate compartments within the plant cell, the former being stored in the cell wall and the latter in the cell vacuoles (Mkpong et al., 1990). In order for cassava tissues to liberate hydrogen cyanide (HCN) contact has to be made between the substrate linamarin and the enzyme linamarase. This is done by bruising the tissues or by any other process that ruptures the cell structure such as grinding, grating, soaking and fermentation, freezing, drying or the addition of chemical agents (McMahon et al., 1995).

The hydrolysis of the glycosides yields glucose and cyanohydrins that remain stable at a pH <5 and at low temperatures. An increase in temperature or pH results in spontaneous breakdown of the cyanohydrins to acetone and HCN (McMahon et al., 1995). The breakdown may also be facilitated by the enzyme hydroxynitrile lyase that is expressed in the leaves but not in the roots. This process of releasing HCN is referred to as cyanogenesis (Conn, 1969). The glycosides, cyanohydrins and HCN are collectively referred to as cyanogens because they are all capable of forming the cyanide ion CN⁻ that is the toxin. There are other factors that affect the levels of cyanogenic glycosides such as the age of the plant, growing conditions and genetic factors.

Cassava safety

There are a number of studies from different parts of Africa that show the consequences of very small changes in processing on the amounts and types of cyanogens that remain in the final product and hence on the chemical food safety of these products. A study from Zaire was one of the first studies to reveal the consequences of shortcuts in the processing of cassava flour (Banea et al., 1992). This was later followed up with a comparative study from Tanzania of two processes named makopa and chinyanya, both resulting in flour (Mlingi et al., 1995). Similarly, a study in Nigeria showed the effects of two different methods of dewatering, continuous dewatering during fermentation versus dewatering at the end of the fermentation, on the residual level of cyanohydrins in *gari* (Onabolu et al., 2002a).

In the study from Nigeria, the authors observed a very different development of the pH of the product during the processing and of the final product pH when comparing the two different methods of dewatering. The difference may very well account, at least in part, for the observed significant difference in the level of residual cyanohydrin in the *gari*, or may stem from differences in the flora of microorganisms produced by the two dewatering processes as concluded by Onabolu et al. (2002b). There are studies that have focused on the fermentation process and how different strains of *Lactobacillus plantarum* influence the final residual total cyanogens (Lei et al., 1999). The processing of all cassava roots and leaves increases the shelf-life of these products.

Pinto-Zevallos et al., (2016) detailed the role that the CGs found in cassava play in defending the plant from pests, a side effect of which is the risk to human health from consumption of improperly processed bitter cassava. Falade and Akingbala (2010) reviewed the approaches required for the consistent safe use of cassava as a food, discussing the importance of processing such as grinding and fermentation, as well as storage and packaging. The review discussed traditional African foods such as fermented products, including cassava bread, fermented cassava flour, fermented starch, fufu, lafun, akyeke (or attieke), agbelima, and *gari*, and unfermented products including tapioca, cassava chips and pellets, unfermented cassava flour and starch. They also evaluated new uses of cassava as a food, including as flour in gluten-free or gluten-reduced products (e.g., bread, biscuits, etc.). Frediansyah (2017) described the making of a range of traditional Indonesian products including peyeum, tape singkong, gaplek, tiwul, gathot, timus, getuk, gemblong, opak/keripik singkong, tepung singkong/cassava flour, tepung tapioca/tapioca and mocaf from cassava. Of these, peyeum, tape singkong and mocaf are fermented, with mocaf, a fermented gluten-free flour being the most recent trend in the industry. Dórea (2004) reported that despite what may be regarded as high concentrations of naturally occurring neurotoxins (the CG linamarin) in the cassava which was typically consumed daily with fish, the consumption of the staple in large amounts over the course of a lifetime posed no health risk for native Amazonians in South America. In 2015 when MacDonald's in Venezuela could not get enough potato to offer traditional fries, they put *cassava fries* on their menu, extending the product into a non-traditional area as a food (Harkup, 2017).

Cassava has been shown to be at risk of aflatoxin (AFT) contamination should its processing, handling and storage not conform with best practices. Aflatoxins contribute to liver cancer, affect maternal and infant health, and cause stunting in young children.

Consequently, care must be taken to preclude its formation during the processing and handling of cassava and cassava products. Vasconcelos et al. (1990) discussed the detoxification of cassava during the making of *gari*. Fermentation for 48 hours significantly reduced the cyanide content of *gari* ($P < 0.05$) but did not eliminate it. It also promoted elevated levels of aflatoxin (Chikezie and Ojiako, 2013), indicating that while AFT is not seen as a major risk in cassava products, care should be taken to prepare, handle and store them under conditions which prevent the growth of AFT-producing fungi such as *Aspergillus* spp. Muzanila et al. (2000), in a comparison of wet and solid state fermentation and sun drying of bitter and sweet cassava, respectively, in Tanzania found no mycotoxin (AFT) production at the end of the period of processing. This is in keeping with the findings of Gnonlonfin et al. (2012) for *cassava chips* in Benin vs maize samples.

Manjula et al. (2009) found that while there was negligible presence of fumonisins in dried cassava and maize, relatively high levels of AFT (up to 13.0ppb) were found in *cassava chips and flour* samples collected from villages in Tanzania and the Congo and stored for four (4) months. Maize kernels had much higher levels of both toxins and very high (up to 39.5% and 70.5%) presence of *Aspergillus* and *Fusarium* spp., respectively on the kernels, indicating a potential food safety risk. In a study of *lafun*, a traditional fermented and dried product from Nigeria, as well as the water and fermentation broth, Lateef and Ojo (2016) found a range of potentially pathogenic organisms, including *Staphylococcus aureus*, *Escherichia coli*, *Salmonella typhimurium*, *Bacillus cereus*, *Klebsiella oxytoca*, *Aspergillus fumigatus*, *Aspergillus flavus* and *Aspergillus niger*, among others. The aspergilli were capable of producing aflatoxins up to a level of 1,600 ppb.

Effects of cassava-mediated cyanide exposure

The human toxicity of cyanides from cassava is well established and these have been identified as the cause of the tropical myeloneuropathies tropical ataxic neuropathy (TAN) and Konzo (Kashala-Abotnes et al., 2019). First described in Nigeria, TAN is a progressive myeloneuropathy that is characterized by the progressive loss of control of bodily movements (ataxia) while Konzo is a permanent upper motor neurone disease that is clinically distinct and was first described in the Democratic Republic of Congo (DRC) at the end of the 1800s (Kashala-Abotnes et al., 2019). Studies from Zaire and Mozambique showed a strong association between Konzo and dietary cyanide exposure (Tylleskär et al., 1992; Cliff et al., 2011). Konzo outbreaks have been reported in other African countries including Tanzania, Cameroon, Angola, Central African Republic (CAR) and Zambia (Chabwine et al., 2011; Cliff et al., 2011; Mlingi et al., 2011; Kashala-Abotnes et al., 2019). Outbreaks are usually occasioned by disasters such as famine, war or drought during which people resort to the consumption of inadequately processed “bitter” cassava.

Experimental studies show that cyanide can pass the placental barrier of rodents, but no information is available on humans or species with a similar placental structure. Developmental neurotoxicity is often non-specific, and the adverse effects may depend on the timing of exposure. While the etiology of Konzo has not yet been fully clarified, a toxic/nutritional etiology is strongly suggested (Tylleskär et al., 1992). Kashala-Abotnes et al. (2019) have noted that evidence suggests that the disruption of thiol-redox and protein-folding mechanisms may be the cause of the illness, potentiated by poor nutrition,

dietary cyanogen exposure, poverty and pre-disposition due to genetics. Evidence from other neurotoxic substances suggests that exposures during the third trimester are most likely to cause functional deficits, e.g. decreased IQ scores (Grandjean and Landrigan, 2014). Unless they are severe, the deficits may be inconspicuous during infancy but later become apparent when the child has difficulties in school. This pattern has been widely documented in regard to such neuro-toxicants as lead, methylmercury, and polychlorinated biphenyls. Such deficits may hamper educational achievement and economic success (Grandjean and Landrigan, 2014). A useful review of the konzo and its related neuropathies is presented in Kashala-Abotnes et al. (2019).

Processing and utilization of cassava tubers (roots) and leaves

Cassava, unlike other tuberous crops, is highly perishable, being comprised of 70% moisture and requires processing as soon as the roots are harvested to increase the shelf-life. If not processed within three to four days, cassava roots will begin to discolor and rot. Consequently, quick processing of cassava roots is imperative to avoid spoilage but also because it improves the palatability of the prepared dishes (Lancaster et al., 1982; Hahn et al., 1987; Onabolu et al, 2002a). It is suggested that cassava processing in Africa has been adapted from processing methods used for other crops that have traditionally been grown and utilized in Africa (Nweke et al., 2001). To get an understanding of the development of cassava processing in Africa, one needs to look at practices related to indigenous African food crops such as yams, sorghum and millet and review Jones (1959) and Berry and Petty (1992). It has also been suggested that the processing methods for cassava in West Africa may stem from the techniques of processing toxic yams combined with the knowledge of the returnee slaves.

In order to render cassava safe for consumption for populations that depend on or consume cassava, cassava toxicity can be minimized in two ways: a conscious effort to select cassava varieties that have low cyanogenic potential or the application of scientific knowledge in the processing and removal of the cyanogenic glycosides from the plant. For processing, the objective is reduction of the cyanogens to safe levels for consumption. This is the preferred approach taken by native Amazonians who have been eating cassava for centuries (Dufour, 1994) and appear to have opted for processing as a sure way of eliminating the risk of toxicity from cassava consumption. However, processing of cassava roots and leaves is not only conducted for detoxification purposes but also to prepare the cassava products desired. Processing also improves shelf-life, reduces bulk during transportation and improves palatability of the prepared dishes.

Processing of the leaves

A summary will be presented here on the processing of cassava leaves as a vegetable. A more detailed treatment of the processing of cassava roots will be covered later on and is captured in excellent discussions by Lancaster and Brooks (1983), Lancaster et al. (1982) and Nweke and Bokanga (1994).

Cassava leaves have been imperfectly understood as a vegetable especially by the scientific community. Due to a lack of data, we cannot at this point state just how much cassava leaves are consumed or how much of the cassava that is grown is actually grown for the leaves. There is a need for such studies to ascertain the production and consumption of cassava leaves in Africa. In 1959, according to Jones (1959), the absence of such studies had been attributed to the fact that cassava was viewed as an inferior crop in relation to cereal crops, particularly maize that has received much attention politically in the African context (McCann, 2001). For example, in the report from the Harvard Africa Expedition 1926–1927, it was reported that the leaves of portulaca and sweet potato were very important leaves as vegetable greens. However, although there was the observation of high cassava root consumption, the report made no mention of cassava leaf consumption. Jones (1959) postulates that this could be due to two factors: one, that there is an abundance of edible green vegetables in Africa and thus cassava leaves are not that important, or two, that cassava leaf consumption is discouraged so people are reluctant to admit or report their consumption due to the negative labeling and connotation of being economically backwards if reporting the consumption of cassava leaves.

Interestingly, green leaves are an integral and accepted part of the diet of many African societies. This is because leaves comprise part of the production system of root crops, cereals, legumes as well as other plants. In French West Africa cassava leaves have formed part of the diet for quite some time. The most preferred variety of cassava leaves the “tree manioc” also referred to as “thunder manioc” because it is perceived to have magical properties (Jones, 1959). The roots from the “tree manioc” are not consumed as they contain a lot of water and fibers. The stalks of the cassava are burned and the ashes are used as a seasoning salt. In some cases, the ashes can be used as dye, snuff or for soap-making. Similarly cassava leaves play an important role in the diets of many Eastern and Southern African countries (Lancaster and Brooks, 1983). In a study carried out across Africa, 81% of cassava growing communities reported consuming cassava leaves (Nweke, 1994).

For the most part, cassava is primarily grown for the roots while the leaves just happen to be a by-product. However, early observations which were later confirmed revealed that there are varieties such as those mentioned above that are grown and preferred for the leaves. Bokanga (1994) argues that harvesting the leaves may have detrimental effects on the root yield but that with controlled harvesting this would not be the case. On the other hand, not much research has been done on understanding the multi-functionality of the roots and leaves or trade-offs that farmers make when utilizing cassava roots and leaves (Chiwona-Karltun et al., 2015).

Unlike the roots, cassava leaves contain very high levels of CG approximately 5–20 times more than that of the edible root (Bokanga, 1994). Fortunately, there is little cause to be wary of eating cassava leaves. Cassava leaves also contain the enzyme, linamarase, a β -glucosidase that can breakdown the glycosides linamarin and lotaustralin. In order for the two to meet, there has to be a breakdown of the leaves’ cell walls as they are stored in separate sections. This can happen through grinding, pounding or chopping. This reaction leads to a breakdown of the cyanohydrins to hydrogen cyanide.

Studies have shown that pounding the leaves for about 15 minutes, followed by boiling them in twice their weight of water for 15–20 minutes, even with levels of cyanogen potential of over 1,000 mg HCN equivalents kg^{-1} , can reduce these levels between 4 and

11 mg HCN equivalents kg^{-1} . As much as 30% of the cyanogenic glycosides are reduced by pounding alone and after boiling for less than 15 minutes, they are reduced to less than 1% of the initial levels (Bokanga, 1994). This is the reason why consumption of cassava leaves, if done properly, does not lead to cyanide poisoning. The high enzyme content and activity in the leaves, coupled with the pounding that brings together the linamarase and the linamarin induces hydrolysis of the cyanogenic glycoside, which is then easily removed by traditional methods.

More recently, there have been more studies on cassava leaves, mapping preparation and potential use in canning. The highest per capita consumption of cassava leaves is in what was formerly Zaire (now the Democratic Republic of the Congo) with as much as 500 g/day (Lancaster and Brooks, 1983). A study in Central Africa describes how “saka-saka” or “mpondou” is prepared with cassava leaves, palm oil, chillies, salt, onions and baking soda. Sometimes, dried fish is added to the dish along with other vegetables, depending on availability. Another cross-country study from six African countries confirmed the importance of cassava leaves as a vegetable in the African diet (Ufuan Achidi et al., 2005). The younger the leaves, the more preferred they are as a vegetable and young leaves have been reported to have a higher protein concentration and less fibers.

There does not seem to be much variation in the processing and preparation of the leaves apart from the time taken to complete the process. These differences would appear to be due to cultural practices, the age of the leaves, variety, genetics, and environmental or geographical location (El-Sharkawy, 2003). In East and Southern Africa, cassava leaves are more often cooked together with bicarbonate soda, mixed with ground peanut flour or with coconut milk (Chiwona-Karlton et al., 1998).

While processing safely reduces the amounts of cyanogenic glycosides, there is the concern that the nutritional quality is compromised with regard to the protein, vitamins and sulfur-containing essential amino acids. Studies by Bradbury and Denton (2014) and Bradbury et al. (2011) showed that slightly modifying the process and pounding the leaves for at least 10 minutes, followed by washing them with twice their weight of water at ambient temperature and changing water between washing reduces the cyanogens by 99%. Repeated washing reduces these levels even more and retains nearly all the protein, the amino acids and vitamins of the original leaves.

Agricultural studies have emphasized the role that women play as food producers and providers particularly in Africa, with as high as 80% of all food for household consumption being produced by women. Apart from providing the macro-calories in the form of staple crops, women are also largely responsible for ensuring dietary variation as they use their knowledge to gather wild crops, process and prepare the food. This is particularly the case in rural areas where socio-cultural norms and traditions has food production and preparation clearly divided between males and females. Already in the 1970s Boserup (1970) described the different roles and domains that women and men played in agricultural societies and referred to them as female and male farming systems.

With the well-documented transformation of cassava in West Africa and Southern Africa, changes in the way that men and women participate in the various phases of production are evident. Early studies in Zaire described cassava farming within a shifting cultivation system where it was necessary to clear and make available new fields every seven to ten years (Fresco, 1986). The clearing of new fields required the felling of big trees and

rough bush, such activities requiring the engagement of men. In such a system, women would be more responsible for planting, harvesting and processing. The situation is clearly illustrated by [Ohadike \(1981\)](#), during a pandemic influenza attack when men were incapacitated or had died, and women were left to do all the chores by themselves. There was a shift from yam production to crops like cassava as women could easily grow cassava ([Ohadike, 1981](#)). Similarly, in the Barotse floods bordering Zaire and Zambia, cassava was readily adopted as there was a huge male migration to work in the mines and millet production required intensive labor ([Vickery, 1989](#)).

As technologies, both in terms of improved planting materials and processing technologies have become readily available, income from cassava has been realized by both men and women. According to [Nweke et al. \(2001\)](#), while cassava has been termed in some literature as a woman's crop, this is no longer the case as men participate in the production, processing and marketing. While small-scale machinery has made it possible in West Africa for women to also use machinery for processing, such is not the case in East and Southern Africa. The International Institute of Tropical Agriculture (IITA) has been promoting the use of these technologies ([IITA, 1990](#)), but the cost remains relatively high for most rural households to acquire them. Ultimately, what one observes are women continuing to be engaged at the lower end of the cassava value chain of processing, such as peeling, grating, pounding, frying, roasting and drying. Because cassava is vegetatively propagated, much of this work is done by hand with no machinery involved. In countries where the sweet varieties are readily sold in urban areas, this production is largely controlled by men, from production to marketing, as has been observed in Malawi ([Moyo et al., 1998](#); [Akoroda and Mwabumba, 2000](#)). On the other hand, women and destitute households prefer to grow bitter cassava varieties because the processing required prior to consumption confers protection from theft ([Chiwona-Karltun et al., 1998](#)). Based on evidence from Congo, Ghana and Nigeria, as cassava becomes commercialized, men begin to participate at all levels of the production, processing and marketing making cassava predominately a male crop ([Nweke et al., 2001](#)). This has implications for women and if not carefully studied may lead to some undesirable nutritional outcomes.

Processing of the roots

Cassava has an abundance of digestible carbohydrates in the form of starch that are a major source of food energy. Raw cassava roots have more carbohydrate than potatoes but less carbohydrate than wheat, rice, yellow corn, and sorghum on a 100 g basis ([Afoakwa et al., 2012](#)). The carbohydrate content in cassava roots is reported to range from 32% to 35% on a fresh weight (FW) basis, and from 80% to 90% on a dry matter (DM) basis ([Montagnac et al., 2009](#)). Eighty percent of the carbohydrates in cassava roots is starch ([Buitrago et al., 2002](#)), with 83% in the form of amylopectin and 17% being amylose. Cassava roots contain small quantities of sucrose, glucose, fructose, and maltose ([Tewe and Lutaladio, 2004](#)). These sugars are only present in minute quantities, ranging between 1.57 and 2.89% on a dry weight basis ([Aryee et al., 2006](#)). However, it has been reported that in sweet varieties, the sucrose content can be as high as 17% and also that the fiber content is dependent on the age, variety and environment ([Charles et al., 2005](#)). In terms of vitamins, only vitamin C is present in relatively high amounts of 15 – 45 mg/100 g.

With regards to minerals, there have been reports of zinc ranging from 3 to 140 ppm and iron levels of 8–24 mg/kg (Burns et al., 2012). Cassava roots are often referred to as being mostly white in color, but it should not be forgotten that there is a spectrum of colors ranging from white to yellow. Yellow tubers contain much more β -carotene than white tubers and cassava is a good source of pro-vitamin A carotenoids compared with other root crops.

Depending on the variety, the protein content of cassava roots ranges from less than 1% and to 5% on a dry weight basis. The protein has low levels of the essential amino acids lysine and leucine as well as of the sulfur-containing methionine and cysteine (Yeoh and Chew, 1976; Gomez and Noma, 1986; Diasolua Ngudi et al., 2002). In contrast, the total protein content in leaves may reach up to 35% of the dry weight. The leaves are low in lysine and leucine as well as in histidine as compared to human nutritional needs (Lancaster and Brooks, 1983; Nassar and Marques, 2006). Currently, improving the protein content of cassava in the tubers by genetic modification is discussed as a possibility in the scientific literature, although not yet implemented at scale (Stupak et al., 2006).

The varieties of roots that are preferred for the making of starch-based foods are those with high levels of mealiness that appear to be associated with high dry matter and starch content (Safo-Kantanka and Owusu-Nipah, 1992). Therefore, knowing the proximate composition of the roots before cooking is important in the preference and selection of the tuber for cooking (Chiwona-Karltun et al., 2015). Studies by Charoenkul et al. (2006) of several varieties, showed that flours contain almost the same components as are present in the raw materials, except the moisture content. The gelatinization qualities of cassava starch are very different from the flour in terms of viscosity levels as well as other properties. This has been attributed to the varying activities of amylase activity in the flours (Charoenkul et al., 2011). Low-cyanogen varieties ("sweet" cassava) are readily eaten fresh, boiled or roasted and so these cassava roots are regarded as a vegetable. According to Jones (1959) in the first book published on cassava, fresh cassava roots of the "sweet varieties" were consumed as vegetables. Most processing techniques for cassava roots entail a sequence of peeling, washing, grating, fermenting, drying, frying or baking. While roots from sweet varieties are processed to achieve the desired product, mostly flour, the bitter varieties must always be thoroughly processed. The main methods for processing bitter cassava roots are: soaking without peeling, peeling then soaking and fermenting, grating and fermenting, grating and sun drying, sun-drying, particularly the sweet or low cyanogen varieties, heap fermentation, leaching, roasting and steaming (Lancaster et al., 1982; Essers et al., 1995).

Cassava bread: traditional production in Belize, Central America

As indicated in the introduction, cassava is made into various traditional products that form the base of the diets in many developing countries. Countries in the Central American region of the Americas are no exception, with the Garifuna people of Belize, Central America, as well as other peoples throughout the Americas consuming cassava as a staple. Cassava Products Limited of Dangriga, Belize is one of the firms in that country that has sought to capitalize on this traditional food and further develop the industry and the sector by upgrading their operations to expand production and extend the range of products they can supply. They have sought to further capitalize on the extensive research



FIGURE 8.3 Steps in the making of cassava flour in Belize: (A) peeled cassava (B) inspection of the cassava flour. *Source: André Gordon (2015).*

financed by international agencies that has been done on the cassava tuber and its commercialization, particularly in Colombia in South America and in Nigeria.

In Belize, the traditional use of cassava is in the production of cassava bread. The cassava bread has an extended shelf life because of the way it is traditionally made. Cassava tuber can also be converted into flour, which can be used alone or mixed with other types of flour to be used in a variety of applications, particularly in the baking industry in developing countries. There is an attractive market for cassava products, as well as combination flour products in Belize and other Central American countries, Southern America, Jamaica in the Caribbean where a major bakery has launched a range of cassava-based bakery products, and also in the United States of America.

The traditional way of making cassava flour and cassava bread by the Garifuna people in Belize is shown in [Figs. 8.3 and 8.4](#) respectively. The tuber is peeled ([Fig. 8.3A](#)) and then grated to produce ground cassava. The ground cassava is then gathered together, soaked to remove the toxin, formed into a “cake” by initial pressing, and then pressed to extract the liquid ([Fig. 8.4A](#)), mainly cassava starch and water, which contains the remaining cyanogenic glycosides. The dried cassava cakes which result ([Fig. 8.4B](#)) are then separated, spread and dried to form cassava flour ([Fig. 8.3B](#)) or formed into cassava bread which is then dusted with cassava flour ([Fig. 8.4C](#)) to prevent sticking/adhesion, and then stacked in preparation for packaging ([Fig. 8.4D](#)).

Nutritional value of cassava

The tubers (roots)

Cassava consumption is a significant part of diets in the Americas and Sub-Saharan Africa where consumption was estimated to be 20 and 80 kg/capita, respectively ([Aerni, 2006](#)). Being one of the most efficient converters of solar energy into soluble carbohydrate per unit area with 1 kg of moisture-free cassava meal yielding up to approximately 3,750 kcal



FIGURE 8.4 The making of cassava bread in Belize. Source: *André Gordon (2015)*.

(Okezie and Kosikowski, 1982), the cassava tuber is an excellent source of energy. The tuber (root) is an excellent source of starch, the second most energy dense food of those commonly consumed in developing countries (Table 8.2) and provides an average of 286 calories/person/day in Sub-Saharan Africa (Jackson and Chiwona-Karltun, 2018). However, because the tuber contains very little protein (up to 2%) by comparison to maize, sorghum, rice and all the other major staple foods (Table 8.1), it has been identified as a cause of protein-energy malnutrition in Sub-Saharan Africa where the poor consume high quantities of this energy-dense but nutrient-poor staple. Despite this concern, cassava roots contain other nutrients such as thiamine, riboflavin, niacin and ascorbic acid, all at similar levels to those found in rice. Nevertheless, its nutrient composition requires it to be combined with other more protein and nutrient rich foods if long term nutrient deficiencies are to be avoided.

The leaves

Farmers that grow and consume cassava consider it a versatile crop as the roots provide energy while the leaves provide the basis for making a stew that can augment the

TABLE 8.1 Calories and protein provided from major staple crops consumed in Sub-Saharan Africa.

Crop	Calories/person/day	Protein/person/day (g)
Maize	337	8.6
Cassava Root	286	2.0
Sorghum	202	6.0
Rice milled	175	3.6
Millet	137	3.3
Wheat	121	3.6
Yams	78	1.2
Plantains	61	0.5
Sweet potato	33	0.4
Potatoes	10	0.2

Source: [FAO statistical database 2015](#) (adapted from [Jackson and Chiwona-Karlton, 2018](#)).

TABLE 8.2 Mineral and vitamin content (per 100 g) of cassava and spinach leaf, soybean and yellow maize.

	Ca (mg)	Fe (mg)	Vitamin A (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Vitamin C (mg)
Cassava leaves	300	7.6	3000	0.25	0.60	2.4	310
Amaranth leaves	410	8.9	2300	0.05	0.42	1.2	50
Soyabean	185	6.1	28	0.71	0.25	2.0	0
Maize (yellow)	13	4.9	125	0.32	0.12	1.7	4

Source: West et al. (1988) (adapted from [Jackson and Chiwona-Karlton, 2018](#)).

consumption of the roots when cooked together. Cassava leaves are consumed in the Congo, Tanzania and 60% of the countries in Sub-Saharan Africa, but are not consumed in West Africa, with the exception of Sierra Leone, and, compared to other vegetables, are a very good source of major nutrients. Unlike the tubers, cassava leaves contain more Calcium, Vitamin A, Riboflavin, Niacin and Vitamin C than other major staples such as *Amaranthus* leaves, soybean and maize (Table 8.2). The major carotenoids in the leaves are the non-vitamin A carotenoid lutein 86–290 mg/kg fresh weight (FW) and the pro-vitamin A carotenoid β -carotene at 13–78 mg/kg FW ([Adewusi and Bradbury, 1993](#)). The leaves contain between 8% and 9% crude protein, inclusive of the essential amino acid lysine, although they tend to be deficient in methionine and tryptophan. It has been suggested that combining the leaves with a source of protein such as cod or other fish could counter-balance any deficiency in the protein quality that may exist and the leaves also contain minerals including ferric oxide and calcium as shown in Table 8.2 which help to improve their overall contribution to dietary needs.

A major negative for the leaves is that they contain antinutritional factors, including tannins, polyphenols, oxalates, nitrates, saponins and phytates. Like the tubers, they also contain cyanogenic glycosides that should be removed by cooking for at least 10 minutes prior to consumption. It has also been shown that processing of the leaves by pounding or grinding, and processing of the tubers by oven drying and fermentation can reduce the presence of these antinutrients by 50–85%, respectively (Achidi et al., 2008; Montagnac et al., 2009). Nevertheless, these considerations, as well as the negative view of the consumption of cassava leaves in parts of Uganda and other parts of Africa, have depressed their use as a food and also resulted in underreporting of their consumption where they are routinely used (Jackson and Chiwona-Karltun, 2018).

Cassava's critical role in global food security

As is evident from the growing trend towards using tapioca, cassava flour, cassava itself directly and other forms of the tuber in foods and various food applications, the crop will continue to play an important role in helping to assure food security of the world's most at risk in Sub-Saharan Africa, Asia and the Americas. In Africa, about 85% of all cassava utilization is for consumption, with roughly 80% prepared as *gari* and other processed foods. With the fast rate of population growth and urbanization in West Africa, demand for cassava as food remains very high especially as a relatively cheaper source of energy. The remaining 20% is used for fresh household consumption. Haggblade et al. (2012) traces five definitive steps that have led to a cassava transformation in Southern Africa. They use the case of cassava in Malawi, Mozambique and Zambia, including improved yields and drought tolerance, its promotion as a famine reserve crop by the colonial masters, and now the rapidly increasing demand for cassava as it transitions to multiple uses in different parts of the world. This has resulted in renewed focus on the crop by private, government and non-governmental organizations (Haggblade and Hazell, 2010). Challenges with maize in Africa resulted in governments, NGOs and other development agencies more aggressively promoting cassava as a food security crop as well as for its commercial benefits.

In Southern Africa, the production of sweet cassava for chewing as a snack, chips or boiling is equally as important as the production of bitter varieties that are used for making flour. The transformation is, however, slower than in Western Africa. Nevertheless, the high productivity of modern cassava varieties has resulted in lower production costs per kilogram of carbohydrate, thereby opening up profitable commercial opportunities for cassava-based foods, starches and feeds (Jackson and Chiwona-Karltun, 2018). From a food security perspective, cassava's high productivity, coupled with drought tolerance, low input costs and a flexible harvesting calendar, enable even households of modest means to ensure food supplies seasonally and over extended periods of time (Alene et al., 2013). Farmers have responded to productivity gains and growing markets by increasing cassava production and sales (Haggblade et al., 2012).

While most of the cassava produced in Asia and Latin America is for non-human consumption, in Africa cassava still remains a major food crop, second only to maize. According to Nweke (2004), cassava has been Africa's best kept secret and that is why the

transformation of cassava in Africa has taken a long time. Nweke (2004) shows five stages of cassava transformation in Nigeria: 1) cassava as a food staple 1910–1945; 2) cassava as a cash crop 1946–1977; 3) the mealybug disease invasion 1978–1983; 4) the cassava surge changing policy incentives 1984–1994 and 5) new markets and new challenges 1995 to present. To accelerate the production and utilization of cassava for food security as well as to capture markets and industry, Nigeria implemented a presidential cassava initiative. This enabled persons working with the government and the private sector to travel to Asia and Latin America to learn about how to add value to cassava. As an incentive, former President Obasanjo in Nigeria mandated a 10% mixture of cassava with wheat flour. There was also major investment in improved varieties, increasing yields with the same amounts of labor. This meant that provision of food calories became much cheaper and low-income households could benefit nutritionally. The involvement of the private sector in promoting production, processing and diversifying the utilization of cassava has enabled Nigeria to be a pace-setter in Africa. As the importance of the crop to global food security, particularly in food insecure regions continues to increase, more attention will need to be paid to ensuring its safe preparation and use. Food safety concerns will therefore remain a major focus of private, national and multilateral efforts to expand the use and consumption of cassava.

The impact of urbanization on the role of cassava in developing countries

Urbanization creates demand for cheaper sources of calories. More and more research on cassava processing and fortification for use in confectionery, bread and other industries are being explored in some developing countries, with examples being Mozambique (Tivana, 2012), Indonesia (Frediansyah, 2017) and Jamaica where cassava is being prized for its role in producing gluten-free baked products (The Gleaner, 2019), as well as its expanding role as a replacement for hops in the making of Red Stripe Beer (Serju, 2018). In Indonesia as well, the role of cassava in the expanded production of gluten-free flour is of great significance for the future growth of domestic consumption. Since 2011/2012, South African Breweries (SAB) has been brewing and bottling cassava-based Impala Beer in South Africa and Mozambique while targeting the lower income group (Maritz, 2013; France Presse, 2017). Cassava is also being used in Nigeria for making beer. It has been used in parts of the Americas for this purpose for centuries, native peoples in South America such as the Jivaro, the Yuida and the Tupinamba producing a beer-like drink called masato, caouin, and nihamanchi (depending on the region) from boiled cassava (manioc) root for thousands of years, for both daily and sacramental use (Buhner, 1998).

As urban centers in the developing world transform, so do diets. People are looking not only for cheaper sources of energy, but also foods that are easy and quick to prepare. Much of the cassava value chain studies have been about producing high quality cassava flour that can be integrated into confectionery, noodles and sweet substitutes. There is increasing demand, however, for easy-to-prepare, convenient, tasty and authentic cassava products, particularly in the Americas where an expanding diaspora in North America is looking for familiar foods in a convenient form. This has fueled demand for traditional products such as the cassava breads shown in Fig. 8.4, bammies, a Jamaican/Caribbean

tortilla-like cassava product and even *attieke* and *gari* among the increasing numbers of African diaspora in the US and Canada. Studies have also shown that it is cheaper, further up the food chain, to substitute cereal grains like maize with cassava in the formulation of feed for livestock and poultry (Tewe and Lutaladio, 2004). These trends are slowly resulting in the transformation of cassava from solely a food reserve into a commercial crop, the most impactful example of which is its application in brewing, as discussed above.

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