Chapter 8
Improving Safety of Cassava Products

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Abstract Cassava was domesticated in the Amazon Basin, where Native Americans selected many bitter varieties, and devised methods for detoxifying them. Cassava reached Africa in the sixteenth century, where rural people soon learned to remove the cyanogenic toxins, e.g., by drying and fermenting the roots. Processing cassava to remove the cyanogenic toxins including the cyanide formed during the processing is time consuming. The work is often done by women, while women and men often prefer bitter cassava varieties for social reasons and superior taste and color. In spite of deep, local knowledge of safe processing, traditional foods made with contaminated water may contain bacterial and fungal pathogens. Improper storage may encourage mycotoxins, such as aflatoxin. Recent advances in industrial processing are developing foods that are free of toxins and microbial contamination. Processing and selling cassava leaves is an emerging but fast-growing sector. Cassava leaves also contain cyanogenic toxins normally in higher concentrations than the cassava roots. In the future, more attention must be paid to the safe processing of cassava leaves and roots, especially as food processing becomes increasingly industrialized worldwide.

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8.1 Improving Safety of Cassava Products in Regional Cassava Production and Processing

The safety of a raw material or a processed food product can be classed into physical, microbiological, and chemical safety. Physical safety, such as sharp particles or contaminants in food, is not discussed here; the focus is on microbiological and chemical threats. The last decade has witnessed a rise in the quality of research and development on the management of pathogenic bacteria and mycotoxin-producing fungi in cassava products. Several research-funding agencies, at times in partnership with the CGIAR programs, have supported much of this development, discussed in this chapter, particularly regarding cassava food safety and human health.

A persistent challenge is how research and education integrate traditional indigenous knowledge on food toxicity, processing, preparation, and food safety into modern research on food technology. Many curricula fail to teach the role of traditional indigenous knowledge, science and technology, and their implications for Africa's food systems. Historically, cassava food safety evolved in the context of practices originating from cassava's region of origin in lowland South America, and elsewhere where the crop was taken since the sixteenth century often linked to slavery and trade. These interactions have laid the foundations for the repertoire of skills in processing, preparation, preferences for taste, cassava products, potential for modification, and consumer preferences.

The chemical safety of a plant-derived food may be affected by the environmental occurrence of toxic anthropogenic compounds. Furthermore, chemical safety is affected by toxic elements concentrated by the plant, e.g., selenium and cadmium, toxic secondary organic metabolites formed by the plant, and toxic organic compounds formed during food processing such as acrylamide.

This chapter focuses on the safety of foods derived from cassava roots and leaves, progress in research and recent consumer legislation worldwide. The chapter also addresses the toxic compounds the plant forms, cyanogenic toxins in the form of cyanogenic glycosides and their products of degradation, as well on aflatoxins that are carcinogenic mycotoxins. The chapter ends with a section on future needs and policy recommendations with emphasis on the opportunities emerging with the African Continental Free Trade Area, particularly for women.

8.2 Introduction

8.2.1 Traditional Indigenous Knowledge in Cassava

According to the World Intellectual Property Organization, "Traditional knowledge (TK) is knowledge, know-how, skills and practices that are developed, sustained and passed on from generation to generation within a community, often forming part of its cultural or spiritual identity" (WIPO 2021). Nowhere is this passing of traditional knowledge so closely interlinked as in the domestication and utilization of cassava as a food in the diet. Cassava is one of about 100 species of the genus *Manihot* that also includes several rubber-producing plants (Schery 1947). This genus is a member of the Euphorbiaceae family, and *Manihot esculenta* is the only plant in that family that produces tuberous roots that have led to its domestication (Schery 1947). Cassava was domesticated in the Amazon region purposively selected for its fleshy roots and wide range in color (white to yellow), starch and taste, particularly based on sugar content (Schaal et al. 2006). Amazonian communities have long interacted with cassava as evidenced by their diverse uses of its roots and leaves (Schwerin 1971). Unlike most other places that have adopted cassava, the whole cassava plant is used, not just the roots (Schaal et al. 2006). During domestication, cassava landraces with high and low levels of cyanogenic glycosides appeared. Toxic types were associated with lower population density and shifting agriculture with more isolated gardens where cyanogens provided protection against damage by animals. The Amazonian peoples developed sophisticated technology to detoxify the bitter types for consumption (McKey et al. 2010). Amazonian peoples have a deep understanding of cassava and of its uses (Carvalho et al. 2004). For example, sugary landraces were used for making natural sweetened drinks; amylose-free starch varieties were fed to young children as this was easier on the stomach; deep yellow colored cassava roots were used for making the traditional drink *tucupi*. Native Amazonian Tukanoan and Jivaroan peoples used cassava leaves as a vegetable, grated and boiled (Dufour 1994). Scientific publications, especially earlier ones, depict cassava as a food that is poor in nutrients, which should be discouraged as food for children. Scientists have learned and still can learn from indigenous communities with deep knowledge of the preparation and consumption of cassava. Such studies demand innovative methods, interdisciplinary teams combining scientists, practitioners, feminist food scholars, and those with a long history of farming and using cassava in Africa as well as worldwide.

As cassava became more and more domesticated and populations moved in search of more land or better opportunities, these agrarian-based families often carried the local and favorite cassava cuttings with them. The Carib- and Arawak-speaking peoples who migrated from South America took cassava with them to the Caribbean (Cousins 1903). For cassava to be readily adopted in Africa, there may have been some existing knowledge of processing toxic plants, such as of processing toxic yams on the west coast of Africa (Ohadike 1981). Because the slave ships often carried cassava as a provision during their travels between the New World and Africa, some processing methods like that of *gari* were brought over to Africa and adapted locally (Northrup and McCammon 1980). In her book on eating wild plants safely, Williams provides ten basic rules about how to enjoy the edible ones without endangering oneself with the poisonous ones. Rule #6 and rule #10 are particularly useful and remain relevant in light of the ensuing section on the chemical food safety of cassava products.

Box 8.1 Basic Rules for Eating Wild Plants Safely

Rule #6

"Know what part of the plant is edible and when it is edible."

Rule #10

"Know the common poisonous plants of the area." A good question to ask when learning any new plant is, "Is there anything poisonous that looks like this?"

Source: Kim Williams 1977. Eating Wild Plants. P 3–5.

8.3 Chemical Safety of Cassava Food Products – The Story About Cyanogens

Of the approximately 374,000 plant species currently described (Christenhusz and Byng 2016), at least 2500 contain cyanogenic glycosides (Zagrobelny et al. 2008). These compounds have important roles in plant defense due to their bitter taste and to their release of the highly toxic compound hydrogen cyanide (HCN) upon plant tissue disruption. Recent research points to additional roles as storage compounds of reduced nitrogen and sugar (Zagrobelny et al. 2008).

Cassava is one of a few plants that contain potentially toxic cyanogenic glycosides, yet are still used as food. Adolf Nahrstedt (1993) reviewed cyanogenesis and food plants, including cassava, lima bean, sorghum, bamboo, flax, bitter almond, apricot, cherry, and laurel cherry. An evaluation of the health risks of cyanogenic glycosides in foods (EFSA 2019) includes the seven mentioned on the Nahrstedt's list and no additional species. The roots and leaves of fresh cassava release hydrogen cyanide (HCN) during chewing and processing and storage. More than 291 million tons of cassava were produced worldwide in 2017, of which Africa accounted for over 60%. In 2017, Nigeria produced 59 million tons, making it the world's largest producer (about 20% of global production) with a 37% increase in the last decade (FAO 2017). The present status concerning production of safe food from cassava worldwide is discussed below.

8.4 Microbial Safety of Cassava Products (Bacteria, Fungi, and Mycotoxins)

Interest in the microflora associated with cassava roots and foods made from them started around the mid-1980s. Many of the root-derived foods are fermented, such as the sun-dried sour starch, which is mainly produced in Colombia and in Brazil.

Table 8.1 Microflora of cassava flour processed by domestic heap fermentation

Microflora	Mean ^{10}LogN/g (6 samples)
Total aerobic mesophiles	8.45
Lactobacillus spp.	7.50
Micrococcaceae	7.30
Pseudomonas spp.	6.60
Enterobacteriaceae	6.53
Bacterial endospores	6.30
Coliform bacteria	6.28
Escherichia coli	4.00
Bacillus cereus	<2.7
Clostridium perfringens	<1.7
Staphylococcus aureus	<1.7
Salmonella	Absent in 25 g
Yeasts	6.62
Filamentous fungi	5.00

Source: Based on Essers et al. (1995a)

The production of this and other fermented cassava root products involves a lactic acid fermentation and a decrease in pH down to around 3.5. However, the quality varies widely (Morlon-Guyot et al. 1998).

Studies of the fungal flora show that the mucoraceous fungus *Rhizopus oryzae*, associated with the postharvest spoilage of the roots, effectively degrades linamarin (a type of cyanogenic glucoside) (Padmaja and Balagopal 1985). By the end of the 1980s, certain cassava root products, such as flours, were included in Brazilian studies on the occurrence of mycotoxins in foods (Soarez and Rodrigues-Amaya 1989).

During the 1990s, studies began to report on the total microflora, i.e., species of bacteria, yeasts, and filamentous fungi (Essers et al. 1995a, b, c). In the study entitled "Reducing Cassava Toxicity by Heap-Fermentation in Uganda," Essers et al. (1995a) identified and quantified (10LogN/g flour) a number of species of bacteria, some bacterial groups, total yeasts, and total filamentous fungi in flour made from cassava roots that had undergone domestic heap fermentation (Table 8.1).

Fourteen filamentous fungi were identified to species (Table 8.2). Extracts of 25 flours and one sample of dried scraped-off molds were analyzed for mutagenicity and cytotoxicity using the Ames test with the tester strains *Salmonella typhimurium* TA100 and TA98, with and without the addition of S9 liver homogenate, and also for the presence of any aflatoxins. The aflatoxins were analyzed by High Performance Thin Layer Chromatography (HPTLC) with a detection limit of 2 microgram per kilogram (Essers et al. 1995a).

The authors of the above study concluded that except for *Neurospora sitophila* and *Geotrichum candidum*, all other fungi identified (Table 8.2) were able to produce mycotoxins under cultured conditions. The high number of *Escherichia coli* in

Table 8.2 Filamentous fungi occurring in cassava flour processed by domestic heap-fermentation

Fungi	Number of samples in which detected (*n* = 6)
Aspergillus fumigatus	3
Aspergillus niger	1
Aspergillus oryzae	4
Aspergillus parasiticus	1
Fusarium sporotrichioides	1
Geotrichum candidum	6+
Mucor circinelloides	2
Mucor racemosus	3
Neurospora sitophila	6+
Neurospora crassa	1
Penicillium frequentans	1
Penicillium waksmanii	1
Rhizopus oryzae	5+
Rhizopus stolonifer	4

Note: + Numerous in each positive sample
Source: Based on Essers et al. (1995a)

one sample was linked to unhygienic processing, while the spore-forming *Clostridium perfringens* and *Bacillus cereus*, found sporadically, might produce toxins after cooking ugali, a maize dish popular in Tanzania and Kenya, if the grain had been stored for a long time. However, finding no cytotoxicity, mutagenicity, nor any aflatoxins, it was concluded that such mycotoxins were not formed in quantities that are detrimental to public health (Essers et al. 1995a).

The study by Essers et al. (1995a) points to the threat of pathogenic bacteria from contaminated water. A study in Nigeria found that the bacterial and coliform counts of fermented cassava flour (kpor umilin) were reduced considerably if the product was made with potable water and additional washing (Tsav-wua et al. 2004; Inyang et al. 2006).

8.4.1 The Development After Essers et al.

From 2007 to 2019, research on the safety of cassava food products suddenly increased. Thirteen articles are summarized in Table 8.3.

Table 8.3 Summary of articles on microbiological food safety for cassava products (2007–2019)

Year	Country	Cassava product(s)	Potentially hazardous microorganism identified (y/n/NA)	+Mycotoxin(s) identified (y/n/NA)	Recommendations/ conclusions given (y/n)	++ Ref. number
2007	Nigeria	Gari, lafun, ogiri	Y	NA	N	1
2008	Benin	Casava chips	Y	N	N	2
2008	Nigeria	Fufu	Y	NA	Y (HACCP strategy recommended)	3
2009	Nigeria	Lafun, fufu, gari	N	NA	N	4
2010	Uganda	Casava chips	Y	Y (aflatoxins)	Y (drying methods recommended)	5
2010	Nigeria	Wet fufu	Y	NA	Y (GMP recommended)	6
2012	Nigeria	Gari	NA (only total counts analyzed)	NA	Y (type of packaging material recommended)	7
2012	Benin	Cassava chips	Y	N	Y (maize and groundnuts are higher in aflatoxins)	8
2013	Nigeria	Fermented cassava flour "lafun"	Y	NA	Y (improved water quality and health inspections during production)	9
2014	Nigeria	Gari	NA (only total counts analyzed)	NA	Y (keep moisture low by proper packaging)	10
2016	Kenya	Cassava chips, flour	Y (heavy contamination with coliforms and for one sample with *E. coli*)	NA	Y (proper training of producers)	11
2017	Nigeria	9 products ++	NA	Y (aflatoxins and fumonisins)	Y (mycotoxin levels are low)	12
2019	Nigeria	Cassava root (white and yellow) fermented 4 days	Y/N (*E. coli* found after 48 hours of fermentation, but not after 72 and 96 hours)	NA	N	13

(continued)

Table 8.3 (continued)

+NA (not analyzed for)

++References by numbers: 1, Ljabadeniyi (2007); 2, Gnonlonfin et al. (2008); 3, Obadina et al. (2008); 4, Obadina et al. (2009); 5, Kaaya and Eboku (2010); 6, Obabina et al. (2010); 7, Adejumo and Raji (2012); 8, Gnonlonfin et al. (2012a, b); 9, Adebayo-Oyetoro et al. (2013); 10, Olopade et al. (2014); 11, Gacheru et al. (2016); 12, Abass et al. (2017); 13, Obi and Ugwu (2019); 14, Odu and Maduka (2019)

+++Cassava starch, HQCF, lafun, fufu flour, tapioca, fine yellow gari, fine white gari, yellow kpo-kpo gari, white kpo-kpo gari

Note: This microbiological research dealt with the most analyzed commercialized products bought at selected markets or supermarkets, while a few of the studies included products produced by the scientists themselves in the laboratory. The analytical methods may have different limits of detection or of quantification for mycotoxins

8.4.2 The Developments Made Possible

One pleasant surprise from this research was the absence or exceptionally low level of aflatoxins in some of the studies, some of which even failed to find the fungus *Aspergillus flavus*, which causes aflatoxins (Abass et al. 2017; Kaaya and Eboku 2010; Gnonlonfin et al. 2012a, b), especially considering that these studies did use advanced analytical methods. During this period, several manuals were published, such as *Potential for Commercial Production and Marketing of Cassava: Experiences from the Small-Scale Cassava Processing Project in East and Southern Africa* (Abass et al. 2013), *Quality Management Manual for Production of High Quality Cassava Flour* (Dziedzoave et al. 2006), and *Quality Management Manual for the Production of Gari* (Abass et al. 2012), suggesting improving conditions for developing commercial cassava food products on a larger scale. Such more advanced business developments even can find further support by the fact that an expert group with representatives from (1) University of Natural Resources and Life Sciences in Vienna, Austria, (2) Kwara State University in Nigeria, (3) International Fund for Agricultural Development, and (4) IITA in 2017 published the extremely important paper “Assessment of the Potential Industrial Applications of Commercial Dried Cassava Products in Nigeria” (Awoyale et al. 2017). In this paper, they summarized seven functional properties and seven pasting properties for 13 cassava product groups, based on samples collected from cassava processors and marketers.

8.4.3 The Cyanogenesis of Cassava

The major cyanogenic compound in cassava is linamarin. As it degrades, it releases the toxic HCN, through a two step process. That is the reactions with a glucosidase (linamarase) followed by a reaction with a second enzyme (hydroxynitrile lyase). Further in-depth details are shown in the risk assessment by the European Food Safety Authority (EFSA 2019, p. 11). The reactions start when the cyanogenic glucoside and the enzymes are brought in contact through rupture of the plant tissues, in which the three components have been stored separately (Behera and Ray 2016). Intact cassava roots may release less than 10 mg HCN/kg fresh tissue or as much as 1100 (EFSA 2019).

In 2003, Codex Alimentarius Commission released the Codex Standard for Sweet Cassava (CODEX STAN 238-2003), which has been amended three times, i.e., 2005, 2011, and 2013. This standard among others regulates the maximum content of cyanogenic glucosides.

Box 8.2 Codex Standard for Sweet Cassava (CODEX STAN 238-2003)
"Sweet varieties of cassava are those that contain less than 50 mg/kg hydrogen cyanide (fresh weight basis). In any case, cassava must be peeled and fully cooked before being consumed."

In 2010, the 238-standard was followed by another standard, this time for bitter cassava root.

Box 8.3 CODEX STANDARD FOR BITTER CASSAVA1 (CODEX STAN 300-2010)
"This Standard applies to commercial bitter varieties of cassava roots grown from *Manihot esculenta* Crantz, of the Euphorbiaceae family, to be supplied fresh to the consumer, after preparation and packaging. Cassava for industrial processing is excluded. Bitter varieties of cassava are those containing more than 50 mg/kg of cyanides expressed as hydrogen cyanide (fresh weight basis). In addition to the requirements of the General Standard for the Labelling of Prepackaged Foods (CODEX STAN 1-1985), the following specific provisions apply: Each package shall be labelled as to the name of the produce and type (bitter) and may be labelled as to the name of the variety. A statement indicating the following is required: cassava must not be eaten raw; cassava shall be peeled, de-pithed, cut into pieces, rinsed and fully cooked before consumption; and cooking or rinsing water must not be consumed or used for other food preparation purposes."

While the commercial marketing of bitter cassava according to the CAC standard (CODEX STAN 300-2010) is limited, studies in Denmark (Kolind-Hansen and Brimer 2010), Ireland (O'Brien et al. 2013), and Australia (Burns et al. 2012) demonstrated many cassava roots sold as sweet were in fact bitter. Cassava safety becomes important as African migrants, 22 million in Europe alone, seek to consume foods from their home continent.

The toxicity of a cyanogenic food plant such as cassava has to do with the amount of HCN and cyanohydrins formed before or while eating. This is because the intact glycosides (e.g., linamarin) are stable in the digestive tract, but the cyanohydrins will split into HCN and its constituent aldehyde/ketone. The non-hydrolyzed part of the linamarin is absorbed and excreted unchanged in the urine (Brimer and Rosling 1993). The primary mode of action for acute toxicity of HCN is the inhibition of the cell's oxidative phosphorylation. This leads to anaerobic energy production. Due to their high oxygen and energy demand, the brain and heart are among the most sensitive organs. Thus, cyanide can result in hypoxia, metabolic acidosis, and impairment of several vital functions. The CONTAM Panel of EFSA in 2019 concluded that there are no data indicating what the acute reference dose (ARfD) for cyanide of 20 μg/kg bw, established in 2016, should be (EFSA 2019). Certain neurological disorders, e.g., spastic paraparesis (konzo) and tropical ataxic neuropathy, have been associated with chronic dietary exposure to cyanide. However, this has always been in populations where cassava was the main food source. In areas with low iodine intake, chronic cyanide exposure from cassava has also been associated with hypothyroidism and goiter. In 2012, the JECFA concluded that the epidemiological association between cassava consumption and konzo was consistent, even though the etiological mechanism of konzo is still unknown (cited in EFSA 2019).

Clearly, the content of cyanogenic glycosides in raw cassava roots and the effects of food processing on these toxins are of major importance. Below, we will take a further look.

8.4.4 Traditional Processing: Reasons and the Products

According to Olsen and Schaal (1999), wild populations of *M. esculenta* occur primarily in west central Brazil and eastern Peru. This region is also the home for Native Americans, including the Tukanoans, where Dufour studied 14 cassava varieties and their cyanogenic potentials (Dufour 1988). The mean potentials varied from around 310–561 mg HCN equivalents/kg f.w. for the *Kii* (= toxic cultivars) and down to around 170 for *Makasera* (nontoxic/safe), the only nontoxic cultivar grown. The toxic varieties were preferred for growing (Dufour 1988). These values can be compared with the accepted highest content of cyanogenic glycosides in sweet cassava roots as accepted by the CAC standard, i.e., 50.

Ten years later after Dufour's publication, a study by Chiwona-Karltun et al. (1998) found similar results in Malawi, where cassava had been brought by the Portuguese starting in the 1500s (Leestma 2015). The study found that bitter cultivars were often preferred, because of experience and traditional indigenous knowledge in processing, managing theft, and most of all ensuring food security (Chiwona-Karltun 2001; Chiwona-Karltun et al. 2000). Toxicity was not seen as a problem, although such roots needed processing for detoxification (Chiwona-Karltun et al. 2000) and the women were extremely adept at correlating bitter taste with toxicity (Chiwona-Karltun et al. 2004). In 1986, Fresco wrote: "throughout Africa, bitter varieties are much more common than sweet ones, notwithstanding the fact that sweet varieties have been promoted by some colonial administrations out of concern with the toxicity of bitter varieties. There is no satisfactory explanation in the literature for the predominance of bitter varieties" (Fresco 1986, p. 153). From the work in Malawi and studies elsewhere, it is clear that bitter varieties where they constitute a major part of the diet are socially preferred, notwithstanding the amount of work that is required and mostly undertaken by women, to process and render them safe for consumption.

8.5 Gender-Preferred Traits and Traditional Indigenous Foods

Now we understand that a considerable part of cassava roots grown worldwide needs to be processed in order to remove a major part of the cyanogenic glycosides present, thereby making a safe product, and in addition obtain one of several kinds of foods. Long processing times leave women with little time for other activities (Nweke 1999). This could have profound effects on the dietary diversity of a household as observed in the Amazon Basin (Dufour 1994) where women spent much time processing cassava. Processing is essential to reduce the water content and preserve the very perishable roots in a way they can be more easily transported.

Processing is also related to gendered variety and trait preference. In the works published by Chiwona et al. in (1998), the reasons for the preferences for bitter varieties were linked with experience and possession of traditional indigenous knowledge in processing, managing social changes in the society such as theft, and most of all ensuring food security. The studies also revealed that bitter cassava cultivars had certain traits that provided products that were deemed to be of superior quality, e.g., processed cassava flour is perceived to be finer and whiter in the making of the staple dish *kondowole* (Chiwona-Karltun et al. 1998). Cassava leaf foods from bitter varieties are regarded as tastier, also verified in Zambia (Chiwona-Karltun et al. 2015). Most importantly, bitter cassava reduced the fear of being without food, especially for women that were "vulnerable in society." These women were usually in female-headed households, and they needed to protect their food sources based on the deep knowledge of food processing and preparation. Incorporating gender-preferred traits continues to be a challenge in breeding programs (Weltzien et al. 2019) especially when these priorities compete with urban demand for food, changing diets and preferences for processed foods (Raheem & Chukwuma 2001).

It is worthwhile reflecting on how to preserve traditional food knowledge while understanding these preferred cassava traits from a gendered perspective. For example, in Jamaica, the popularity of *bammy bread* (Fig. 8.1), a preferred traditional food has been preserved largely through the women to women transfer of knowledge and expertise. By way of the kitchen and cuisine identity, bammy bread has successfully been incorporated in modern bakeries and extended to beyond export markets (Canevari-Luzardo et al. 2020). As climate change dampened the production and availability of cassava, Jamaica stopped exporting bammy and only served the national market. This calls for paying closer attention to the roles that women and men play in cassava value chains (Andersson et al. 2016), including how specific products impact women and men and their well-being. As traditional foods are

Fig. 8.1 Traditional fried bammy bread. Photo credit Sam Biehl

Fig. 8.2 Mortar used for pounding cassava leaves (left) (Photo credit Brian LeniKanjeri Msukwa, Malawi). Preferred locally pounded cassava leaves being cooked (right). (Photo credit D. Dufour (CIRAD))

increasingly appreciated for their contribution to health and well-being, demand for locally made and processed foods will gain more traction.

Cassava leaves also play important roles. Fresh or dried cassava leaves are rarely sold on the market, largely due to the focus on cassava roots as an energy provider. But now cassava leaf production and marketing are well established in the Democratic Republic of the Congo, Rwanda, Angola, and Malawi to mention a few examples and have even reached, e.g., European markets in frozen form as sold in special shops. The technology for processing, packaging, and marketing remains a challenge. To render cassava leaves safe to eat, they must be disintegrated in order for the endogenous enzyme to initiate the breakdown of the cyanogenic glucosides (Bokanga 1994). Pounding for at least 15–20 minutes is crucial. Few affordable leaf-processing machines are available (Fig. 8.2).

8.5.1 The Traditional Processing Reasons and the Products

Several cassava root products were developed in the center or origin of the crop. The manual *Cassava Products of Brazil* lists starch, sour starch, *puba* flour (similar to African *fufu*), fermented roasted flour (similar to gari), *tucupi* (fermented savory syrup), tiquira, unfermented gari (*farinha de mandioca*), and cassava crisps (Crenn 2019). Various scientific articles and book chapters published after 2010 have described the different unit processes and their impact on the composition of cassava root-based food products (Gnonlonfin and Brimer 2013; Gnonlonfin et al. 2012a, b). Important processes include drying, soaking, cooking (baking, frying, steaming), size reduction (grating), fermentation (dry in heap or wet), and smoking (to make the smoked balls called *kumkum*).

Fermentation can be used to make cassava products that are free of cyanogenic toxins, as discussed in the following section.

8.5.2 The Progress in Knowledge and Technology

Gari is the most well-known fermented cassava food product found throughout much of West Africa. Today, it comes in several professional and internationally marketed brands. Yet in many places, gari is still produced locally to eat at home or to sell. The CGIAR organizations have been involved in training and research on gari.

Starting with the manual *Quality Management Manual for the Production of Gari* (Abbas 2012) and following up with workshops like "Nigeria's Gari Revolution: Improving Efficiency and Equity of a Staple Food" (organized by Global Cassava Partnership for the 21st Century in 2016), this important fermented product is becoming professionalized. However, depending on the naturally occurring microorganisms for its fermentation, gari and other fermented cassava products still have room for improvement. The possibilities include (1) the selection and characterization of microorganisms found in safe products and (2) microorganisms which upon testing may be candidates for more complete degradation of the cyanogenic glycosides in cassava roots.

Penido et al. (2018) selected and characterized microorganisms (lactic acid bacteria and yeasts) originating from the production of Brazilian sour cassava starch, while Kostinek et al. (2007) isolated 375 predominantly lactic acid bacteria from fermenting cassava in different African countries. *Lactobacillus plantarum* isolated from fermenting cassava can hydrolyze (degrade) cyanogenic glycosides (e.g., linamarin), as can different *Bacillus subtilis* isolates collected from low pH starters used to produce *gergoush* (a Sudanese fermented snack) (Lei et al. 1999; Abban et al. 2013). See also the chapter by Behera and Ray (2016) on "Microbial Linamarase in Cassava Fermentation."

Fig. 8.3 Grating sweet cassava by hand (left), (Photo credit Joyce NaMtawali Mwagomba, Malawi) and sun drying the grated cassava on mats to produce high-quality cassava flour (HQCF, right). (Photo credit D. Dufour (CIRAD))

8.6 Conclusions and Looking Forward

Traditional indigenous cassava-based food products have been developing greater food safety. Worldwide, more and more popular drinks like *bubble* or *boba* tea with tapioca "pearls" have been developed with very low levels of cyanogens (Bulathgama et al. 2020). New food products based on cassava must focus on these toxins to develop safe products.

As more women venture into value addition especially at local scale and hoping to capitalize from the African Continental Free Trade Area and the opportunity it may accord women, we need to enable women's participation. However, there are some immediate challenges for women and men, such as lack of access and skills to resources to scale-up production. For example, large-scale processing of high-quality cassava flour or cassava flour and cassava leaves is still rudimentary. Packaging and meeting standards for export requires training and investments that often are beyond the reach of women or small-scale farmers (Fig. 8.3).

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