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Short Communication

Processing of cassava roots to remove cyanogens

A. Paula Cardoso[a], Estevao Mirione[b], Mario Ernesto[b], Fernando Massaza[b], Julie Cliff[c,d], M. Rezaul Haque[e], J. Howard Bradbury[e,*]

[a] *Ministerio da Saude, Laboratorio Nacional de Higiene de Alimentos e Aguas, CP 264, Maputo, Mozambique*
[b] *Direccao Provincial da Saude, Laboratorio Regional de Higiene de Alimentos e Aguas CP 14, Nampula, Mozambique*
[c] *Faculdade de Medicina, Universidade Eduardo Mondlane, CP 257, Maputo, Mozambique*
[d] *Monash University, Clayton, Victoria 3800, Australia*
[e] *School of Botany and Zoology, Australian National University, Canberra, ACT 0200, Australia*

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Abstract

A simple equation is developed between the total cyanide contents of cassava root parenchyma and the processed product with the % retention of cyanide on processing. This equation is applied to different methods of processing used worldwide. Thus to produce cassava flour of 10 mg HCN equivalents/kg flour (ppm), the WHO safe level, by sun drying or heap fermentation requires starting with sweet cassava containing 12–32 ppm total cyanide. In an average year only 14% of flour samples in our study areas in Nampula Province of Mozambique had total cyanide contents of <10 ppm. Distribution curves of flour total cyanide show that the percentage of samples exceeding 100 ppm total cyanide increased from 6% in an average year to 43–65% in a low rainfall year, when cases of konzo also occurred.

Processing methods used to produce farinha in Brazil and gari in West Africa reduce the total cyanide content to less than one eighth of that using heap fermentation and less than one sixteenth of that using sun drying. Heap fermentation and sun drying, commonly used in eastern and southern Africa, do not adequately remove cyanide in a normal year and are hopelessly inadequate when used on cassava grown during drought. New and greatly improved processing methods are urgently needed. The high levels of cyanide intake in central, eastern and southern Africa from high cyanide flour are the most likely cause of konzo in young people and the very long term consumption of gari of lower cyanide content in West Africa is the most likely cause of TAN in older people.
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Keywords: Cassava processing; Sun drying; Heap fermentation; Cyanide; Linamarin; Safe levels of cyanogens; Flour; Gari

*Corresponding author. Tel.: +61-2-6125-0775; fax: +61-2-6125-5573.
E-mail address: howard.bradbury@anu.edu.au (J.H. Bradbury).

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1. Introduction

Cassava is the third most important food source in the tropics after rice and maize and is the staple food of at least 500 million people (Cock, 1985). Cassava is easy to grow, yields well in good conditions and even in poor soils subject to dry conditions it still produces edible roots. The roots are very starchy and the young leaves are a good source of protein (Bradbury and Holloway, 1988). Because of the perceived agricultural advantages of growing cassava and increasing population pressures its usage is being extended to regions in Africa and elsewhere in which it was not formerly used.

As a defence mechanism against attack by predators, cassava produces two cyanogenic glucosides; linamarin and a small amount of lotaustralin (methyl linamarin). These cyanogens are distributed widely throughout the plant, with large amounts in the leaves and the root cortex (skin layer), and generally smaller amounts in the root parenchyma (interior). In so-called sweet cassava the parenchyma contains only a small amount of cyanogens, so that after peeling, these roots can be safely boiled and eaten, as occurs in the South Pacific (Bradbury and Holloway, 1988). The bitter taste of bitter cassava is very largely due to linamarin (King and Bradbury, 1995) and high cyanide parenchyma roots must be processed before consumption to reduce the amount of toxic cyanogens to a safe level. The World Health Organisation (WHO) has set the safe level of cyanogens in cassava flour at 10 ppm (FAO/WHO, 1991), and the acceptable limit in Indonesia is 40 ppm (Damardjati et al., 1993; Djazuli and Bradbury, 1999).

Consumption of cassava and its products that contain large amounts of cyanogens may cause cyanide poisoning with symptoms of vomiting, nausea, dizziness, stomach pains, weakness, headache and diarrhoea and occasionally death (Mlingi et al., 1992; Akintonwa et al., 1994). Cyanide intake from cassava exacerbates goitre and cretinism in iodine deficient areas (Delange et al., 1994) and is almost certainly the cause of konzo in eastern, central and southern Africa. Konzo is an irreversible paralysis of the legs of sudden onset, which occurs particularly in children and women of child bearing age (Ministry of Health Mozambique, 1984; Howlett et al., 1990; Cliff et al., 1997). Tropical ataxic neuropathy (TAN) is a chronic condition of gradual onset that occurs in older people who consume a monotonous cassava diet. It causes loss of vision, ataxia of gait, deafness and weakness (Osuntokun, 1994; Howlett, 1994; Onabolu et al., 2001). These medical conditions caused by cyanide overload could be prevented by a considerable reduction in the per capita cyanide intake.

At a workshop in Nampula City (Ernesto et al., 2002a), a strategy was developed to reduce daily cyanide intake as follows:

1. Introduce other staples, vegetables, pulses and fruits to decrease the daily cyanide intake and broaden the diet.
2. Improve processing of cassava roots giving products with less residual cyanide.
3. Introduce low cyanide, high yielding and well-adapted varieties of cassava.
4. Improve early warning systems using picrate kits (Egan et al., 1998; Bradbury et al., 1999) to monitor cyanide levels in cassava products and urinary thiocyanate concentrations in the population (Haque and Bradbury, 1999).

Focussing attention on the second point of the strategy, viz. processing, we note that many different methods have been developed over hundreds of years (Padmaja, 1995). These methods give products that (1) are a good food source, (2) have reduced amounts of toxic cyanogens and (3) may be stored or transported; once harvested the cassava root deteriorates rapidly (Bradbury and Holloway, 1988). Some methods remove nearly all residual cyanogens (Nambisan and Sundaresan, 1985; Dufour, 1994) but many leave appreciable amounts behind (Mlingi and Bainbridge, 1994; Cardoso et al., 1998). In this paper, a simple equation is developed that relates the total cyanide contents of roots before processing and products after processing with the % retention of cyanogens after processing. This equation is used to gain an understanding of cyanide retention due to processing.

2. Methods

2.1. Development of an equation relating cyanide contents of peeled roots and products and the % retention of cyanide in products

Let total cyanide content of peeled roots = R mg HCN equivalents/kg fresh root (ppm)

Let total cyanide content of product = P mg HCN equivalents/kg fresh product (ppm)

Since the mean moisture content of cassava roots is 62.8% (Bradbury and Holloway, 1988), the amount of dry matter in 100 g root = 100−62.8 = 37.2 g.

Thus cyanide content of dry root before processing = $R \times 100/37.2 = 2.69\ R$

The percentage of the original cyanide in the peeled root that is retained in the product is the "% retention". Cardoso et al. (2003) obtained a moisture content of cassava flour of 7.2%, which is dependent on the relative humidity.

Cyanide content of dry product after processing = $2.69\ R \times$ % retention/100.

Cyanide content of air equilibrated product $P = 2.69\ R \times \%\ \text{retention} \times 100/(100 \times 107.2)$.

$$P = 0.025\ R \times \%\ \text{retention}. \qquad (1)$$

If the large loss of moisture during processing occurred without any loss of cyanide, (i.e. % retention = 100) then the cyanide content of the processed product (P) would be 2.5 times that of the root (R). The numerical value of 0.025 is dependent on the moisture contents of both roots and products, e.g. if moisture content of product were 10% then the value would be 0.024 or if the moisture content of roots were 65% then the value would be 0.027.

It is useful to rearrange Eq. (1) to calculate the maximum root cyanide content (R_{max}), for a particular % retention, that will give a product with the safe limit of WHO ($P = 10$ ppm) or the Indonesian standard ($P = 40$ ppm). Substituting R_{max} for R in Eq. (1) and rearranging gives

$$R_{max} = P/(0.025 \times \%\ \text{retention}) \qquad (2)$$

3. Results and discussion

3.1. Total cyanide contents in roots and leaves of cassava

The total cyanide content of cassava parenchyma is dependent on the cultivar, the environment and various other factors. For >1500 accessions there was a continuous distribution of cyanide content from 1 to >500 ppm which peaked in the region of 30–50 ppm (Bokanga, 1994a).

Although acyanogenic roots were reported prior to 1940, this has never been confirmed (de Bruijn, 1983; Bradbury and Holloway, 1988), but roots containing only 1–2 ppm have been reported (Bradbury et al., 1991; Bourdoux et al., 1982). At the other extreme there are reports of total cyanide levels of 1090 and 1550 ppm in Tanzania (Mlingi and Bainbridge, 1994), mean values of 1100 ppm in India (Nambisan, 1994) and 454 ppm in the Amazon (Dufour, 1994). The range of total cyanide contents of root parenchyma is therefore 1–1550 ppm.

Although there is a continuous distribution of total cyanide levels in cassava parenchyma, traditionally cassava roots have been categorised as either sweet or bitter based on taste, with sometimes a third category 'bland' included. The bitterness is largely due to linamarin, but other bitter and sour components present may confuse the taste buds (King and Bradbury, 1995), hence this taste test is not always an effective warning system against the use of poisonous roots. A useful guide based on total root cyanide content used by Bourdoux et al. (1982) and others is: innocuous <50 ppm, moderately poisonous 50–100 ppm and dangerously poisonous >100 ppm. The dangerous nature of very high cyanide varieties is underlined by the name of one variety in Nigeria that is called 'chop and die'.

The root cortex (peel) and mature leaves generally have larger amounts of total cyanide than parenchyma ranging from 900 to 2000 ppm (Nambisan and Sundaresan, 1994; Bokanga, 1994b). Nevertheless, because of the high linamarase activity in leaves as compared with root and the traditional method of processing leaves that involves pounding followed by boiling, the residual cyanide is quite low (Bokanga, 1994b; Diasolua Ngudi et al., 2003).

3.2. Safe levels of total cyanide content in roots

We may well ask with Dixon et al. (1994), what is the safe level of total cyanide content in cassava roots? To answer this question for roots processed to flour or gari, Eq. (2) is used to calculate the maximum root total cyanide content for a particular processing method to obtain products with the WHO safe level of 10 ppm and the Indonesian standard of 40 ppm. As shown in Table 1, the maximum total root cyanide levels that can be used to get 10 ppm total cyanide flour are 16 ppm for sun drying and 32 ppm for heap fermentation. These low maximum root cyanide levels can only be achieved using innocuous sweet cassava, which explains why even in average rainfall years in Mozambique, such as 1996 and 1999, only 13–14% of flour samples contained <10 ppm total cyanide (Cardoso et al., 1998 and Fig. 1a).

The Indonesian standard of 40 ppm for flour allows maximum root cyanide levels of 64 and 128 ppm for sun drying and heap fermentation respectively (Table 1). In 1996, 51% of samples gave flour of <40 ppm (Cardoso et al., 1998) and 67% in October 1999 (Fig. 1a). We conclude that the current processing methods of sun drying and heap fermentation used in Nampula Province are inadequate even in an average year to remove cyanide. This is confirmed by high urinary thiocyanate levels in school children in October 1999, which shows unacceptably high levels of cyanide poisoning (Ernesto et al., 2002b).

3.3. Total cyanide contents in cassava flour

The distribution curve of total cyanide content over 119 cassava flour samples collected in October 1999 from our study sites in Nampula Province of Mozambique is shown in Fig. 1a, with

Table 1
Calculation of maximum root total cyanide levels (ppm), using a particular processing method, that will lead to safe cassava products

Processing method	Name of product	% retention	Max. root total cyanide levels (R_{max}) using processing method shown, to fall within less than	
			10 ppm (WHO)	40 ppm (Indo.)
Sun drying	Flour	25–33[a,b]	12–16	48–64
Heap fermentation	Flour	12.5–16.5[c]	24–32	96–128
Soaking & sun drying	Lafun/fufu	1.3–2.2[d]	181–308	727–1230
Soaking, fermentation & roasting	Farinha/gari	1.8–2.4[d,e]	167–222	667–889
Crushing & sun drying	Flour	1.5–3.2[b,f]	125–267	500–1066

[a] Mlingi and Bainbridge (1994).
[b] Nambisan and Sundaresan (1985).
[c] Heap fermented flour normally contains about one half the total cyanide compared with sun dried flour (Essers et al., 1995; Cardoso et al., 1998; Ernesto et al., 2000, 2002a).
[d] Oke (1994).
[e] Dufour (1994).
[f] Nambisan (1994).

a mean total cyanide value of 41 ppm. The methodology for obtaining the data and mean values have already been published (Ernesto et al., 2002b). The distribution curve is similar to that found for 80 flour samples in 1996 from the same sites with a mean value of 45 ppm (Cardoso et al., 1998). These curves are typical of cyanide levels of flour from cassava grown in years of average rainfall. The mean total cyanide content for flour in Indonesia was 54 ppm (Djazuli and Bradbury, 1999).

3.3.1. The effect of low rainfall on total cyanide levels in cassava roots and flour

Total cyanide levels in roots increase in a year of low rainfall or drought due to water stress on the plant (Bokanga et al., 1994). The results of water stress during root development on total cyanide contents in cassava flour are given in Figs. 1b and 1c, which show the distributions of cyanide contents of flour samples from the same study sites as in Fig. 1a, but obtained in November 1998 and July 1999, respectively, from roots grown during the poor rainy season of 1997–98 (Ernesto et al., 2002b). The effect of low rainfall has been to greatly increase the total cyanide content of the flour (Cardoso et al., 1999).

Under conditions of low rainfall 16–26% of flour samples in Figs. 1b and 1c fall below 40 ppm total cyanide, compared with 51–67% in an average year (see above). Furthermore, the percentage of flour samples with a total cyanide content of >100 ppm increased from 6% in an average year (Cardoso et al., 1998 and Fig. 1a) to 43% (Fig. 1b) and 65% (Fig. 1c) due to low rainfall. During collection of flour samples in November 1998 and July 1999, communities reported many cases of acute intoxication and these high cyanide flour samples are a likely source of konzo (Ernesto et al., 2002b). In areas of eastern, central and southern Africa, where flour is produced by sun drying/heap fermentation, the cyanide content is too high in a normal year, but the situation becomes very serious in years when rainfall is low, a recurring feature of the climate.

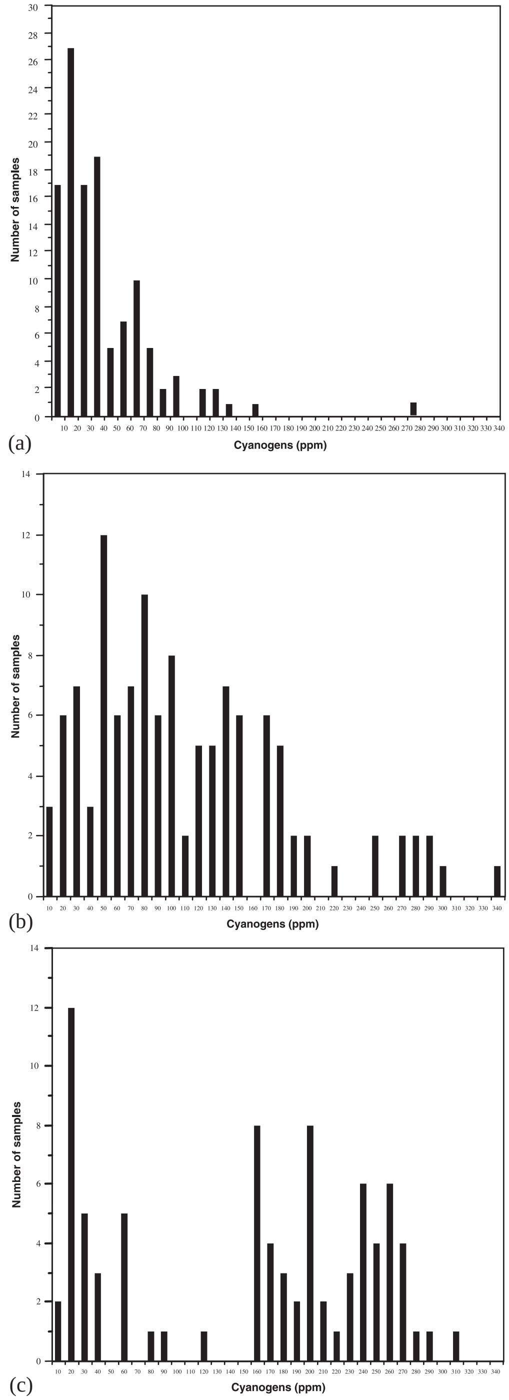

Fig. 1. The distribution curves of total cyanide contents (0–10, 11–20, 21–30, - - - - - - 331–340 ppm) of (a) 119 cassava flour samples collected in October 1999 from Acordos de Lusaka, Cava, Mujocojo and Terrene-A, (b) 119 samples of cassava flour collected in November 1998 from Acordos de Lusaka, Cava, Mujocojo and Terrene-A and (c) 84 cassava flour samples collected in July 1999 from Acordos de Lusaka, Mujocojo and Terrene-A.

3.4. Improvements in processing to reduce the cyanide content of cassava flour

There is a great need for development of improved processing methods to greatly reduce the total cyanide content of cassava flour. Such methods were developed by trial and error hundreds of years ago by indigenous peoples in Amazonia for the preparation of farinha (Dufour, 1994). A related process is used in West Africa in the production of gari. Both gari and farinha are roasted products, which are also used in southern Mozambique (Cardoso et al., 1999), but communities in northern and central Mozambique and in other parts of eastern and central Africa are accustomed to non-roasted cassava flour. Flour has been produced by crushing and sun drying with a retention of 1.5–3.2% (Nambisan and Sundaresan, 1985; see Table 1). Methods which use grating and crushing are very effective in removing cyanide because of the intimate contact in the finely-divided wet parenchyma between linamarin and the hydrolysing enzyme linamarase, which promotes rapid breakdown of linamarin to hydrogen cyanide gas that escapes into the air. Unfortunately, an attempt to introduce a similar method that involved hand grating into Nampula Province failed, because of the extra labour required compared with sun drying or heap fermentation, the cost and availability of the hand grater and perhaps other factors. Despite this failure, methods of this type should be investigated further because of their efficacy in removal of cyanide, but taking due account of the requirements of the processors.

Intimate contact between linamarin and linamarase does not occur with sun drying or heap fermentation, because the peeled roots are usually cut in half longitudinally and most plant cells remain intact, with the linamarin stored inside the cell separately from the linamarase, located in the cell walls (Mkpong et al., 1990). The halfing of % retention of total cyanide brought about by heap fermentation as compared with sun drying (see Table 1) is mainly due to a solid state fermentation process in which microflora break down the linamarin (Padmaja et al., 1993; Essers, 1994). It should be possible to improve this fermentation process to reduce further the cyanide content of heap fermented flour.

The flour processors in our study area in northern Mozambique have the choice of using sun drying (retention 25–33%) or heap fermentation (retention 12.5–16.5%). In July 1999, a period of very high cyanide flour (Fig. 1c) and much evidence of acute intoxication, heap fermentation was being used by 84% of the processors in Mujocojo, Terrene-A and Acordos de Lusaka. However, in October 1999, with average flour cyanide conditions (Fig. 1a) there was a change in the processing to 73% sun drying. Furthermore, in Mujocojo, the only village in which konzo had been reported in the previous two years, the reversion to sun drying by October 1999 was much less (57%) than in the other two villages that had not reported konzo (87%) (Ernesto et al., 2002b). Clearly, the flour processors use the limited options of sun drying and heap fermentation available to them to achieve an outcome that limits the effect of cyanide intoxication and the occurrence of konzo. What is badly needed is the development of another processing method that is far more effective in removal of cyanide than heap fermentation, and is in other ways acceptable to the processors and the consumers of the flour.

3.5. Boiling, steaming, baking and frying of cassava

Nambisan and Sundaresan (1985) boiled cassava parenchyma pieces of three different sizes from 2 to 50 g for 30 min in water and were able to account for most of the cyanide lost from the sample by analysis of the water. The enzymatic breakdown of linamarin was small because of heat denaturation of linamarase at 100°C. The retention increased from 25% to 75% as the sample size increased from 2 to 50 g. Cooke (1983) found that after 25 min boiling of fresh cassava chips in water, 45% of linamarin was retained. The retention of cyanide on sun drying (25–33%) is of the same order as that for boiling, which shows that both these methods are only suitable for the processing of sweet cassava.

Losses of cyanide on steaming, baking or frying are much smaller than on boiling (Nambisan and Sundaresan, 1985), because of the stability of linamarin in neutral or weak acid conditions to temperatures of 100°C (Bradbury et al., 1991). All these methods of cooking cassava parenchyma are only suitable for sweet cassava, such as occurs quite generally in the South Pacific (Bradbury and Holloway, 1988).

3.6. Total cyanide contents of gari and farinha

The total cyanide content of gari is generally much less than flour, with reported values of 0–32 ppm over 200 samples (Oke, 1994), and 1–39 ppm (Aletor, 1993). Total cyanide in gari, fufu and tapioca ready to eat products from markets in Port Harcourt, Nigeria ranged up to 30 ppm (Adindu et al., 2003). These levels are much lower than those found in cassava flour in East Africa, but still exceed the WHO safe level of 10 ppm. Even with % retention of only 1.8–2.4% for farinha/gari (Table 1), the maximum root cyanide level is 222 ppm in order to achieve gari of 10 ppm. Presumably, maximum root cyanide levels in excess of 222 ppm have been used to give total cyanide levels in gari up to 39 ppm (Aletor, 1993). Thus, the danger from cassava cyanide is not eliminated in gari-eating areas of West Africa, which is confirmed by the occurrence of TAN, a chronic condition in older people that is very likely due to a monotonous diet of cassava. (Osuntokun, 1994; Howlett, 1994; Onabolu et al., 2001)

4. Conclusion

In southern, eastern and central Africa, where cassava flour is made by sun drying and heap fermentation, there is high retention of cyanide in flour after processing. The situation is made much worse in years of low rainfall, which are a normal feature of the climate, because of the increased total cyanide content of cassava roots due to water stress. We need improved methods of processing that greatly reduce the total cyanide content of flour, together with broadening of the diet by introduction of other edible plants and lower cyanide, high-yielding cassava varieties. The occurrence of konzo in eastern, central and southern Africa is very probably due to high cyanide intake over several weeks from mainly high cyanide cassava flour (Fig. 1). By contrast, TAN in West Africa occurs in older age groups and is associated with the long-term consumption over many years of gari of much lower cyanide content.

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