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Chronic Cassava Toxicity

Proceedings of an interdisciplinary workshop
London, England, 29-30 January 1973

Editors: Barry Nestel and Reginald MacIntyre



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Cassava as Food: Toxicity and Technology

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Abstract The toxicity of cassava (*Manihot* spp.) is caused by the presence of the cyanogenic glycoside linamarin, together with much smaller amounts of the closely related lotaustralin. These substances hydrolyse under the influence of the endogenous enzyme linamarase to liberate hydrogen cyanide (HCN).

The quantities of toxic principle vary greatly between cultivars and, although the so-called "sweet" cultivars are generally of lower toxicity than the "bitter" ones, the correlation is not exact. Cyanide levels cannot be related to formal botanical taxa. Some variation in cyanogen content with ecological conditions of plant growth also occurs.

A wide variety of traditional food preparation techniques are used for processing cassava in different parts of the world and an important element in all of these is an attempt to reduce the cyanide content by liberation of the HCN either by solution in water or by volatilisation. These processes involve maceration, soaking, boiling, roasting, or fermentation of the cassava roots, or a combination of these processes. The amount of analytical data available on the efficacy of these processes is limited and generally unreliable. It appears that normally the greater part of the cyanide is liberated in such processes, but there are often substantial residual quantities which may well be sufficient to produce chronic toxic symptoms, and occasionally even acute poisoning, in those who consume large quantities of cassava products.

Little reliable information is available as to whether linamarin itself constitutes a toxic factor, or whether toxicity only arises from hydrolysis of this compound to free cyanide.

Résumé Le manioc doit sa toxicité à un glycoside cyanogène, la linamarine, et à des quantités beaucoup plus faibles de son proche parent, la lotaustraline. Ces substances s'hydrolysent sous l'influence de l'enzyme endogène linamarase pour libérer de l'acide cyanhydrique.

Les quantités d'élément toxique varient considérablement d'une culture à l'autre et, bien que les soi-disant cultures "douces" soient généralement moins toxiques que les cultures "amères", il n'y a pas d'étroite corrélation. Le niveau de cyanure ne peut pas, non plus, être associé à des taxa botaniques formels. Il existe une certaine relation entre le contenu en cyanogène et les conditions écologiques dans lesquelles la plante croît.

Le manioc est traditionnellement préparé sous une grande variété de formes dans différentes parties du monde. Un élément important de ces préparations vise à réduire le contenu en cyanure par libération d'acide cyanhydrique, soit par dissolution dans l'eau soit par volatilisation. Ces procédés incluent macération, trempage, ébullition, rôtissage ou fermentation des racines du manioc, appliqués seuls ou en combinaisons. Les données analytiques sur l'efficacité de ces traitements sont peu nombreuses et généralement peu fiables. Les procédés semblent en général libérer

la plus grande partie du cyanure, mais il y a souvent des quantités résiduelles substantielles, suffisantes pour causer une toxicité chronique et, occasionnellement, un empoisonnement aigu chez ceux qui consomment le produit en grandes quantités.

Le peu de renseignements fiables que nous ayons ne nous permet pas de déterminer si la linamarine est elle-même un élément toxique ou si la toxicité provient de l'hydrolyse de ce composé en cyanure libre.

Cassava Toxicity

Toxic Principle of Cassava

THE fact that cassava (*Manihot esculenta* Crantz) can be toxic must have been known to the Amerindians since the earliest days of its domestication, if not before. The first reference to cassava toxicity in western literature appears to be in the writings of Clusius (1605) and there are many subsequent references in the accounts of travellers in tropical America and Africa in the following centuries. The association of the toxicity with the presence of hydrocyanic acid (HCN) was first made by Henry and Boutron-Charland (1836), while the identification of the occurrence of the HCN in the form of a cyanogenic glycoside, originally named mannihotoxin, is due to Peckolt (1886, quoted by Cerighelli 1955). This compound, the principal cyanogen of cassava, was subsequently (Dunstan et al. 1906) shown to be identical with the better-known glycosides phaseolunatin and linamarin of *Phaseolus* and *Linum* respectively. The presence of HCN in "sweet" and "bitter" cassava was established by Francis (1878) and investigated further by Carmody (1900), Collens (1915), and Turnock (1937) who concluded that HCN was the only poisonous substance in cassava. Linamarin is structurally 2-(β -D-glucopyranosyloxy)isobutyronitrile; under enzymatic or acidic hydrolysis it liberates free HCN, together with acetone and glucose. Earlier work on the occurrence of linamarin in cassava has been reviewed by Jones (1959), Wood (1965a), Johnson and Raymond (1965), and Oke (1968).

More recent studies (Butler 1965; Nartey 1968; Bissett et al. 1969; de Bruijn 1971) have shown that a small proportion, between 2 and 8%, of the total cyanogenic glycoside present in cassava tubers consists of a methyl linamarin, believed to be identical with lotaustralin. This substance hydrolyses under similar conditions to linamarin, to yield HCN, methyl ethyl ketone, and glucose.

The toxicity of cassava thus appears to arise from the presence of cyanogenic glycosides, which

may hydrolyse readily to free HCN, and it is with this aspect that this paper is concerned. It should be noted in passing, however, that earlier work (Clark 1936; Turnock 1937; Johnson and Raymond 1965) also refers to the presence of a toxalbumin. Compounds of this class are typical of the Euphorbiaceae, to which cassava belongs, while Clark (1936) specifically mentions post-mortem indications suggestive of toxalbumins in studies of cassava poisoning. This aspect appears to have been neglected recently, and would repay further study.

Occurrence of Cyanogenic Compounds

The cyanogenic glycosides are distributed throughout the cassava plant, but the concentration varies greatly between varieties, and also with climatic, edaphic, and cultural conditions. Numerous publications discuss the range of cyanogen content of the edible tubers; among the more useful are: Greenstreet and Lambourne 1933; Dean 1937; Raymond et al. 1941; Joachim and Pandit-tesekere 1944; Bolhuis 1954; Oyenuga and Amazigo 1957; Wood 1965a; Johnson and Raymond 1965; Oke 1968, 1969; Sinha and Nair 1968; de Bruijn 1971. The normal range of cyanogen content is from 15 to 400 ppm, calculated as mg HCN/kg fresh weight but occasional samples as low as 10 mg/kg or over 2000 mg/kg (Rogers 1963) have been reported. Most commonly, cyanogen content falls between 30 and 150 mg/kg.

Cassava is often described as "bitter" or "sweet" according to the amount of cyanide present, but these are at best only approximate terms, and to attempt to associate cyanide levels with particular botanical taxa is quite incorrect (Bolhuis 1954). No exact correlation between sweetness or bitterness of taste can be made (Pereira and Pinto 1962). In general, bitter cassava has a high cyanide content while sweet cassava tends to have lower values, but there is a great deal of overlapping between classes, as is clearly illustrated by a graphical presentation of the results of Sinha and Nair

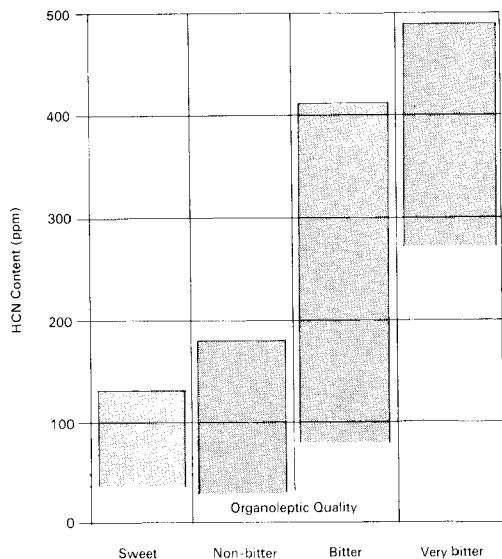


FIG. 1. Hydrocyanic acid content of different organoleptic categories of cassava (after Sinha and Nair 1968).

(1968) in Fig. 1. A substantial mythology has built up around the subject of cassava toxicity and bitterness, much of which has been demolished by Bolhuis (1954). In most varieties, under most cultural conditions, the concentration of cyanogenic glycoside is very substantially higher in the "peel" fraction of the tuber than in the flesh, the ratio being usually 5 or 10 to 1. As a rough guide to acute toxicity (Koch 1933; Bolhuis 1954; de Bruijn 1971), the following may be adopted:

- Innocuous*: Less than 50 mg HCN/kg fresh peeled tuber
- Moderately poisonous*: 50–100 mg HCN/kg fresh peeled tuber
- Dangerously poisonous*: Over 100 mg HCN/kg fresh peeled tuber

The factors responsible for sweetness or bitterness, apart from cyanogenic glycoside content, need further investigation. The free sugars normally present in cassava are glucose, fructose, sucrose, and traces of mannose (Ketiku and Oyenuga 1970) but the quantities would not normally be sufficient to cause a great degree of sweetness, although an early paper (Ewell and Wiley 1893) mentions sucrose content as high as 17%. The mannitol which occurs in cassava tubers may also play a part. However, as has been noted by Johnson and Raymond (1965), many of the publications dealing

with the chemical composition of cassava are old and "in some cases the information cannot be substantiated." A thorough reexamination of the chemistry of the minor constituents of cassava could probably prove fruitful.

The cyanogenic glycosides of cassava are accompanied in the plant tissue by a hydrolytic enzyme, linamarase (occasionally known as linase), similar but not identical to emulsin (Armstrong and Horton 1910; Wood 1965b, 1966). In active, healthy tissue of the growing plant, enzyme and substrate do not come into contact, but contact occurs when the tissues are mechanically damaged, or when loss of physiological integrity occurs as a result of post-harvest deterioration of the tubers, or of wilting of the leaves; hydrolysis then takes place, liberating HCN.

Nature of the Toxicity

Toxicity in cassava and its products is associated primarily with the free HCN in the material that is formed when the cyanogenic glycosides have been hydrolysed. To what extent the linamarin and methyl linamarin are themselves toxic to mammalian life is by no means clear. On the basis of a single rabbit experiment, Charavanapavan (1944) states categorically that linamarin is toxic, while Nijholt (1932) also suggests that hydrolysis of the linamarin can take place within the alimentary system, leading to poisoning. It has even been suggested (Boorsma 1905) that drinking water after a meal of cassava can increase the danger of poisoning. Other authors, such as Greenstreet and Lambourne (1933) and Montgomery (1969), consider that the toxicity of the linamarin, ingested as such, in the absence of linamarase, is unproven. General experience of the use of cassava-based foods would suggest that residual amounts of linamarin are at least not highly toxic, if the enzyme system has been deactivated, but this is a field which clearly needs further investigation. Although the toxicity of the glycosides present in cassava may be in doubt, HCN itself is one of the most powerful poisons known: large doses can cause acute poisoning, usually resulting in death, while the habitual ingestion of smaller quantities, even so small as to produce no immediate symptoms, can result in chronic effects. The division of cassava into "bitter" and "sweet" types relates to the likelihood of acute symptoms occurring after consumption of the product with-

out special care being taken to detoxify it. The classification already given is based on the statement of Boorsma (1905) that 50–60 mg HCN is a lethal dose for an adult male weighing 50 kg (Bolhuis 1954).

Acute poisoning as a result of eating cassava by man or domestic animals is not particularly common, but is by no means unknown; a considerable number of reports occur throughout the literature which will not be reviewed here. Chronic effects resulting from the continued ingestion of cassava products are probably a potentially much more serious factor limiting the use of cassava as human or animal nutrition. This aspect has been reviewed recently by Osuntokun (1972), and also forms the subject of other papers presented at this Workshop.

Toxicity and Utilization

Processing Requirements

Quite apart from any considerations relating to toxicity, cassava is normally processed in some way before being used. Unlike many other starchy staple foods, fresh cassava deteriorates extremely rapidly after harvest (Ingram and Humphries 1972), and any processing must therefore be undertaken within hours or at the most a day or two of harvest, unless the material is to be consumed immediately in the fresh state. A typical proximate analysis of peeled root (Winton and Winton 1935) is given in Table 1. The processes of post-harvest deterioration themselves result in hydrolysis of the glycosides present in the tuber, and as a result, stale cassava can be more toxic than fresh (Charavanapavan 1944; Greenstreet and Lambourne 1933).

In common with other starchy materials, processing usually by some form of heat treatment is necessary to render the material soft enough to be palatable. This involves heating the material to a temperature high enough for the starch to undergo gelatinization, either by boiling in water, or in the case of a high water-content material such as cassava, roasting or some similar treatment. In some cases, the heating is carried out at a higher temperature, causing a partial breakdown of the starch to dextrins. Occasionally, heat treatment is replaced by some form of soaking or steeping of the material in water, usually after shredding or other comminution. Under these conditions, a

TABLE 1. Proximate analysis of cassava (after Winton and Winton 1935).

Composition of peeled root	%
Water	61.3
Protein	0.6
Fat	0.2
N-free extract	36.5
Starch	31.0
Fibre	0.9
Ash	0.5

softening occurs in association with autolytic enzymatic processes.

A second requirement for processing cassava is the need to eliminate, or at least reduce to acceptable levels, the toxic HCN, and the traditional processing techniques appear to be designed to do this.

Traditional Processing Technology

A wide variety of techniques have been devised in various parts of the world to detoxicate the more poisonous varieties of cassava. Variants of most of these are to be found among Amerindian ethnic groups, and to some extent the spread of cassava utilization in other parts of the world has depended on the spread of these technologies—for example the transfer of the Amerindian technique for the production of “farinha de mandioca,” via Brazilian negroes repatriated to West Africa, into the African technique for making the very similar “gari.” In other cases, however, there has probably been independent invention on the processing technique after the crop has been introduced. For example, some of the African techniques involving shredding and soaking may derive from indigenous techniques for processing toxic yams (Jones 1959).

If linamarin is itself non toxic, presumably all that is necessary would be heating sufficient to denature the hydrolytic enzyme, and so prevent the release of free HCN. In practice, however, most traditional food preparation techniques appear to be designed to bring together enzyme and substrate by cell rupture, followed by elimination of the liberated HCN by either volatilization or solution in water. In some processes, the initial hydrolysis of the linamarin is assisted by the use of fermentation processes.

TABLE 2. A tentative classification of traditional cassava processing.

1.	<i>No special detoxication techniques applied</i>
1.1	Totally unprocessed (i.e. eaten raw)
1.2	Simple cooking techniques only (as used for nontoxic starchy staples)
1.21	Boiling, stewing, etc.
1.22	Roasting, baking
1.23	Frying
1.3	Sundrying
1.31	Sundrying without subsequent processing
1.32	Sundrying with subsequent processing
	1.321, etc. Different types of milling, grinding, etc.
1.4	Kiln or Hot-air drying
	(Subdivide as for 1.3)
2.	<i>Special detoxication techniques applied</i>
2.1	Detoxication by solution
2.11	Soaking of whole roots or large pieces
2.111	Soaking in static water
2.112	Soaking in running water
2.113	Soaking in salt water
2.12	Soaking after comminution
	(Subdivide as for 2.11)
2.13	Boiling
2.131	Simple boiling
2.132	Repeated boiling, in changes of water
2.14	Wet extraction processes for starch
2.141	Starch extraction without subsequent gelatinization
2.142	Starch extraction with subsequent gelatinization
2.2	Detoxication by fermentation
2.21	Spontaneous fermentation
2.211	Fermentation followed only by washing
2.212	Fermentation followed by washing and heat treatment
	2.2121 Roasting
	2.2122 Steaming
	2.2123 Drying in hot air
2.22	Fermentation with use of inoculum from earlier preparations
	(Subdivide as 2.21)

So great is the range of food products made from cassava and the diversity of the processes, that I have not been able to effect a complete classification. It is, however, the primary detoxication stage that is of greatest interest, and an attempt has been made (Table 2) to indicate the different types of *initial* process in the form of a taxonomic key. It is emphasized that this classification is tentative and probably incomplete. It is put forward as a first attempt to render some kind of order out of a widely distributed and somewhat chaotic literature. Account should also be taken of the classification of Schwerin (1971).

It is also emphasized that this scheme only classifies the earlier stages of the processes. For

example, several of the different categories could lead to the production of some form of cassava flour, which, in turn, could be incorporated into a variety of porridges, doughs or bread-type or biscuit-type products. Most of the detoxication processes described are followed by some process for the reduction of the water content to a level which will permit the safe storage of the product. This level should be around 12% (Ingram and Humphries 1972), although this is not always attained in practice. The first stage of the drying process to achieve a level of around 50% usually involves physical expression of the water. This process was traditionally, in many Amerindian communities, accomplished by means of a tipiti

(Dole 1956), but in other parts of the world by the application of weights to the wet material contained in sacks or baskets, by various types of manual squeezing processes, by the use of mechanical presses (Jones 1959; Sturtevant 1969), or, in the case of industrial operations, by centrifugation (Akinrele et al. 1962). After this initial dewatering, the water content is reduced further by heating, which may also assist in driving off the last traces of free HCN.

Processes of group 1 (Table 2) can only be applied to cassava containing small amounts of glycoside—essentially the “innocuous” varieties in the Koch classification; only the “sweetest” varieties would be eaten raw. Nevertheless, all these processing methods appear to contribute very considerably to the reduction of available HCN in the tubers, and boiling, in fact, warrants a place not only here but also in group 2, as an actual detoxication technique. In some cases, within group 2, the distinctions made may be more philosophical than real. For example, some processes of steeping or soaking, especially in static water, may involve some degree of fermentation by extraneous microflora, at the same time that autolytic hydrolysis of the linamarin and the subsequent extraction by solution of the liberated HCN is taking place.

Even in the case of the typical fermentation processes, it is by no means clear to what extent the microorganisms responsible for the fermentation actually influence the linamarin content directly, or whether they serve merely to increase the acidity of the medium, thus aiding the endogenous enzymatic process.

It has been shown (Collard and Levi 1959; Collard 1963; Akinrele 1964) that in the fermentation of mashed cassava under conditions simulating the detoxication stage of gari manufacture, the pH of the medium falls during the first 24 h of the process under the influence of lactic and formic acid produced by *Corynebacterium manihot*. The level of pH 5 attained is, however, the optimum range for the action of endogenous linamarase and it may be that the effect of fermentative microorganisms is mainly in the acidification of the substrate.

The details of the methods of production of cassava-based food products in various parts of the world have been given by numerous authors. Among the most useful are: Adriaens 1942; Pynaert 1951; Jones 1959; Normanha 1969, 1970;

Normanha and Pereira 1963; Sturtevant 1969; Ekandem 1961; Favier et al. 1969; Oke 1968; and Schwerin 1971; other references may be found in these papers, and in Ingram and Humphries (1972). The products used in the animal feedstuff industry are described in Anonymous (1968) and Maner (1972).

Most of these accounts are almost entirely descriptive, however, and contain little discussion of the biochemical and food technological parameters involved in the processes, and most are oriented to particular areas of the world.

There is a serious need for a major study, on a global basis, of traditional cassava processing technology, coupled with investigations, using modern analytical techniques, of the efficacy of the various processes in removing both glycosides and free HCN.

Traditional Detoxication Methods

Although there is no doubt that fatal cases of poisoning due to ingestion of cassava do occur in both man and animals, and that the evidence for a causative link between habitual large intakes of cassava and various types of chronic degenerative conditions is strong, the fact remains that both these types of intoxication are comparatively rare. Millions of the world's population habitually consume cassava as a staple, and millions of tons of dried cassava products are incorporated into animal feed in European countries, apparently without complaint. This suggests that traditionally used detoxication processes are, in general, very effective. A problem certainly exists, but it must be kept in perspective.

Some of the earlier workers stated that properly prepared cassava products are free from toxicity. For example Vuafart (1908, quoted by Oke 1968) says that hydrocyanic acid is “rarely present” in manioc flour, although he mentions an example of flour that contained 41 mg HCN/kg; samples of gari from various parts of francophone West Africa were reported (Vignoli and Cristau, 1950) as being free of HCN, as were samples of manioc flour from Brazil (Bethlem 1950, quoted by Oke 1968). Normal cooking methods were reported by Collens (1915) to remove all HCN from samples of sweet cassava, but with bitter varieties the cooked product still contained 20 mg HCN/kg, and even sweet varieties showed the presence of up to 17 mg HCN/kg after having been left overnight in the

water used for boiling. Nemoto (1940) categorically states that when manioc flour containing a little HCN is used in breadmaking, "all trace of HCN is removed," while Paula and Rangel (1939) state that the best flours are free from cyanide. Little attention seems to be paid by the animal feeds industry to cyanide content in dried cassava products. Of the several published standards for such products, only the Indian Standards Institution (1959) mentions the subject of HCN level, and sets a limit as high as 300 mg HCN/kg.

There is extremely little published information on HCN levels in actual cassava food products, and little of what there is relates these levels to the initial level in the unprocessed root. Simple drying of the sliced or rasped root was shown by Charavanapavan (1944) to be capable of removing up to 90% of the HCN when the drying was conducted at 60°C, but drying at temperatures approaching 100°C was less efficient; this latter result is not surprising, as drying at such elevated temperatures could denature the enzyme systems, and prevent autolytic hydrolysis of the glycosides taking place. However, Paula and Rangel (1939) reported the opposite effect, material initially containing 39 mg HCN/kg being reduced to sun-dried product at 17 mg HCN/kg, but by oven-drying to 6 mg HCN/kg. Results quoted by Joachim and Pandittsekere (1944) indicated a loss of only one third of the total HCN present on drying at the controlled temperature of 60°C and even lower losses at higher temperatures. The results obtained by Razafimahery (1953) indicate however that about two thirds of the HCN present was lost during sun-drying for 7 days. Kokonte (a flour prepared from sun-dried chips) contains 20 mg HCN/kg (Wood 1965b).

Simple boiling of the roots reduces the HCN levels very considerably. A variety originally containing 332 mg HCN/kg (Raymond et al. 1941) contained only 10 mg HCN/kg after boiling; Paula and Rangel (1939) detected no HCN in a variety originally containing 39 mg HCN/kg after only 10 min boiling; the observations of Collens (1915) have already been mentioned. The effect of boiling on a number of varieties ranging from 103 to 232 mg HCN/kg fresh was studied by Joachim and Pandittsekere (1944); the boiled products ranged from 27 to 87 mg HCN/kg, with no particular correlation with the initial HCN content. The authors commented that the varieties which lost least toxicity were those that did not

become soft and floury on boiling. They also showed that steeping in warm water for short periods before drying can greatly reduce the HCN levels, especially if the material is grated. The Madagascan food product Bononoka, prepared by steeping the roots in running water for several days, followed by steaming, is free of HCN (Razafimahery 1953).

The HCN levels (in milligrams HCN per kilogram) of samples of a number of African cassava-based food products have been given by Oke (1968): Fresh Cassava 380, Gari 19, Fufu 25, Lafun 10, and Kpokpogari 11. Wood (1965b) gives a value of 25 mg HCN/kg in fresh gari, falling to 2 mg HCN/kg after storage for 1 month. During the extensive investigation conducted in Nigeria in connection with the mechanised production of gari (Akinrele et al. 1962) a value of 30 mg HCN/kg was regarded as acceptable in the product. In Brazil, where cassava flours are extensively used in the baking industry, Paula and Rangel (1939) state that crude flours made from bitter cassavas contain 10–200 mg HCN/kg, but the better grades of table flour are free from HCN; Nemoto (1940) gives 27–37 mg HCN/kg as the normal range, but that grated manioc flour may contain as much as 125 mg HCN/kg. Both reports state that these residual quantities of HCN are destroyed in the baking process when the flours are incorporated in bread. However, in studies on the manufacture of rotis (a roasted product) with cassava flours containing 57–118 mg HCN/kg, Joachim and Pandittsekere (1944) found losses ranging from 47 to 80% during cooking, which would indicate a fairly high degree of retention.

It thus appears that cassava food products, as commonly prepared by many of the various detoxication methods outlined in Table 2, can still contain appreciable traces of HCN. The cases of acute poisoning that are reported probably have arisen after the consumption of products which have been carelessly prepared, or from unusually high HCN material, by operators who are more familiar with less toxic varieties, and/or have been taken in meals components of which contained active enzymes capable of hydrolysing linamarin. There may also be variations in individual susceptibility to HCN poisoning, while an abnormal gut microflora might lead to any unusually high release of hitherto unhydrolysed linamarin, after ingestion. In the context of chronic cassava toxicity, however, the traces of cyanide that appear

frequently in cassava-based foods probably constitute a more serious problem.

Quite apart from the small amount of analytical data that exist on the HCN content of food products, doubt must be cast on the reliability of some of the analyses, especially the older ones—an observation that also applies to data on the HCN contents of fresh material. As pointed out by Joachim and Pandittesekere (1944) "the standard method for the estimation of HCN in materials containing cyanogenetic glucosides gives low results with manioc and its products." They found that the amount of HCN released autolytically in the analysis increased very considerably with the period allowed for autolysis up to 24 h, while even when the autolysis was essentially complete, a further quantity of HCN could be released by acid hydrolysis. Similar observations were given by Normanha (1965).

More reliable methods have been developed for the assay of both glycoside and HCN (Wood 1965b, 1966) and there have been alternative approaches to the subject (Adriano and Ynalvez 1932) some of which have been reviewed by Oke (1969). However accurate the analysis for HCN in the extract from the material may be, the accuracy of final result will be prejudiced when only incomplete liberation of HCN from the experimental material takes place. Cassava tuber is such a variable material that it is necessary to pay exceptionally close attention to the sampling regime, if anything approaching a true sample is to be obtained.

The incomplete release of HCN that takes place in analytical procedures also indicates that, under traditional food technology processes similarly aimed at achieving autolytic liberation, it is likely that not all the glycosides present are broken down. This was indeed anticipated as early as 1900 by Carmody who found that several successive water extractions each removed further quantities of HCN from the tubers. It is not, therefore, in any way surprising that cassava food products, even when carefully prepared, contain some residual HCN, still in bound form, which can under certain circumstances be liberated. The amount and quality of the analytical data available in the published literature do not permit a very detailed appreciation of the situation, but such indication that can be given would be that at least many cassava-based foods make appreciable contributions of HCN to those diets in which they are con-

sumed in large quantities and that an association with chronic symptoms of HCN poisoning, especially in highly susceptible individuals, cannot be ruled out.

Suggestions for Further Investigations

Although the evidence reviewed is suggestive, it is too inadequate to be definitive, and a program of food technological investigation should be initiated in this field. The following points would appear worthy of attention:

1. Evaluation of existing analytical techniques for the determination of glycosides, glycosidases, and free HCN in cassava and its products, and the refinement of these techniques;
2. The study, initially from the literature, but also later from direct field observations, of traditional detoxication techniques, and their critical evaluation using reliable analytical procedures. The key to the classification of such techniques given here may be useful, but it may well be modified in the course of this investigation;
3. A definitive examination of the degree to which unhydrolysed linamarin and lotaustralin are toxic when ingested in the absence of active linamarase;
4. A study of reported cases of acute toxicity of cassava or its products in both man and domestic animals, with the aim of determining the factors involved;
5. A study of the hydrolysis of linamarin and lotaustralin by linamarase in model systems, in the hope of defining the reasons for the incomplete hydrolysis that occurs during at least some detoxication processes;
6. A re-examination of the chemistry of the minor constituents of cassava, with a view to detecting toxic substances, other than cyanogens.

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