THE TOXICITY OF CASSAVA ROOTS [1]

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INTRODUCTION

The degree of toxicity of cassava roots has been the subject of much discussion in the past, and the amount of literature on it is far from small. However, study of the items available of that literature inevitably produces the impression that many opinions on the toxicity of cassava roots are given without being supported by evidence. Many authors quote common convictions on the matter; but this, of course, by no means proves that such convictions are correct. Here again, the final verdict rests with scientific research.

It is generally agreed that the toxicity of cassava roots is due to the presence of a glucoside, linamarin, which, as a result of the action of an enzyme, linase, liberates the highly poisonous prussic acid. The authors also concur in thinking that this glucoside plays a part in the plant's metabolism; but opinions still differ as to exactly what part. In this respect, unfortunately, the extensive investigations of ADRIAENS (1946) have brought no further enlightenment. Comparison of the toxicity of cassava with that of other plants such as sorghum is a tempting proposition but, in the view of the present writer, is fraught with more dangers than benefits.

Another difficulty in comparing the pronouncements of various authors lies in the fact that, as a rule, they fail to define and distinguish adequately what they mean by "bitter" and "sweet" cassava. It is commonly realized that the taste of any article is a subjective conception; and use of terms such as "bitter" and "sweet" would only be permissible if this conception were a generally applicable – i.e., objective – one. The systematic division of *Manihot utilssima* Pohl into a sweet and a bitter subspecies is now generally recognized as having no scientific justification.

Furthermore, the authorities are fairly unanimous in agreeing that no clear dividing line can be drawn between poisonous and non-poisonous cassava roots, since it has been found (BOLHUIS, 1952) that a gradual transition takes place in the toxicity values, from completely innocuous to highly poisonous. Moreover, it has been proved that the terms "sweet" and "bitter" cannot be entirely identified with specific toxicity values.

KOCH (1933) states that, in his opinion, "bitter"-tasting roots are invariably poisonous, whereas "sweet"-tasting roots may be either innocuous or poisonous. He also says that the bitter taste is more pronounced when the roots are raw than when they are cooked; taste tests should therefore always be carried out on the raw roots, the mouth being thoroughly rinsed out with fresh water after each test. GREENSTREET and LAMBOURNE (1933) write that "the toxity of tapioca roots does not appear to be a well defined characteristic", while COURS states "en fait tous les maniocs sont un peu amers".

KOCH is also the only author who has tried to classify cassava roots according to their degree of toxicity. He based his investigations on BOORSMA's statement (1905) that 50–60 mg HCN is the theoretically lethal dose for an adult

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man weighing 50 kg. This led him to compile the following classification system, based on analyses of peeled roots.

Less than 50 mg HCN per kg fresh root	Innocuous
50–100 „ „ „ „	Moderately poisonous to poisonous
More than 100 „ „ „ „	Very poisonous

This classification has great advantages over the indication of toxicity by percentages of HCN in fresh root, or by mg HCN per 100 grams of fresh root, as it makes comparison of values found much more simple. If KOCH's classification scheme were to be generally adopted, comparison of the values given in different publications could be carried out at a single glance. When making such comparisons, however, care should be taken to ensure that all sampling has been performed in the same way in each case. At Buitenzorg at least 4 or 5 roots of the same plant or variety were peeled and partly rasped, and from the well-mixed raspings a sample was taken.

Another system of classification applied by KOCH is that according to GUIGNARD's colour reaction (NIJHOLT, 1931–1932).

O (orange)	Innocuous	R (red)	Moderately poisonous to poisonous
DO (dark orange)	„		
LR (light red)	„	DR (dark red)	Very poisonous

There is no absolute correspondence between the number of mg HCN per kg fresh root and the above-mentioned colour classes, but as a rough means of classification they are certainly quite adequate (BOLHUIS, 1952).

In addition to samples conforming to the colour series proposed by KOCH, a sample was occasionally encountered during the tests at Buitenzorg which produced no colour reaction at all (indicated by Z); when the sample was analyzed this characteristic proved to correspond to a content of less than 10 mg of HCN per kg fresh root. These cases were, however, so rare that they can safely be ignored. The limits given by various authors for possible quantities of HCN per kg lie between 10 and 370 mg HCN per kg fresh root.

Once again we should like to emphasize the fact that only figures for *peeled* roots are valid, as the root-bark – especially in the case of the non-poisonous varieties – contains much more HCN per kg than the root core. Consequently, observations carried out on unpeeled roots may lead to quite erroneous conclusions.

Those factors capable of influencing the degree of toxicity of the roots will now be examined in succession. In doing so, the opportunity has also been taken of including some hitherto unpublished results from experiments carried out at Buitenzorg (Java) before the last world war.

The factors which may exert an influence on the toxicity of the roots of a cassava plant are:

1 The conditions of soil and climate under which the plants have been growing.
2 The production capacity of the clone.
3 The age of the plant.
4 The size of the roots.
5 Special methods of cultivation.
6 Colchicine treatment of cuttings.
7 Bud variation.

1 Soil and climate

Almost all authors are convinced that differences in local conditions have a considerable influence on the toxicity of the roots. Most of them, however, produce no evidence, but content themselves with assuming that what is "generally known" is obviously correct as well.

Greenstreet and Lambourne quote figures for 14 varieties grown in both Mauritius and Malaya (Kuala Lumpur), from which it can be seen that only 6 varieties produce similar quantities of HCN in mg per kg of fresh root; the differences between the other 8 vary from considerable to very considerable. Moreover, not only have varieties which were harmless in Mauritius been found to be poisonous in Malaya, but the reverse has also been proved to be the case – a situation which is entirely in accordance with the statements of Graner et al. (1944).

On the other hand, Koch, on the basis of his figures, is inclined to think that the influence of external conditions on the degree of toxicity must be comparatively small.

In an earlier publication (Bolhuis, 1952), the present writer has already shown that, in this respect, certain varieties are more susceptible than others. His findings are therefore in agreement with those of Greenstreet and Lambourne.

The enormous influence which the soil may have on the poisonousness of cassava roots is clearly illustrated by figures given by Darjanto (1952). These figures were obtained from cassava planted on two plots situated fairly close to each other on the same type of soil, viz. rather old laterite. One of these plots had been regularly used as a wet paddy field, while the other had been used for many years for the cultivation of citronella grass (*Andropogon nardus* L.) and upland rice; later on they are referred to as respectively "wet field" and "dry field". The fertility of this latter plot had very much decreased, and the plants on it showed distinct symptons of potassium deficiency. Both plots were planted at the same time with cuttings of the cassava variety *Mangi* – the roots of which do not, as a rule, contain more than 30 mg of HCN per kg fresh root, and are consequently quite innocuous – and the variety *Saö Pedro Preto,* the roots of which normally contain about 150 mg of HCN per kg of fresh root, and must therefore, according to Koch's classification, be reckoned among the very poisonous varieties.

The results of this test have been collected in Table 1.

Table 1. Results of an Experiment with Two Cassava Clones on Different Soils, on the Estate of Tjitajam, Java.

Variety	Age at harvest	mg HCN per kg fresh root	
		wet field	dry field
Mangi	6 months	32	98
	8 months	29	116
	10 months	41	137
	12 months	36	148
S.P.P.	6 months	183	562
	8 months	164	537
	10 months	166	516
	12 months	152	451

Scrutiny of these results shows immediately what an enormous effect the fact of being planted on dry soil had on the toxicity of the roots of both varieties. The toxicity of the, normally innocuous, variety *Mangi* increased to such an extent as to place it in the "highly poisonous" group. Accordingly, great care would be necessary in utilizing for consumption purposes such cassava roots as these, grown on dry soil. Under these conditions the roots of the S.P.P. variety, already highly poisonous, were rendered three times as poisonous, like those of *Mangi*, and reached an entirely unprecedented level of toxicity.

In this connection it may be remarked that ADRIAENS cites JUMELLE to the effect that, if cassava is grown continuously in the same field, ultimately only poisonous roots will be harvested.

Furthermore, some authors state that the bitterness – by which they probably mean the toxicity – of roots greatly increases on soils which have previously had a leguminous cover. BONNET (1949) also points to a connection between the N content of the soil and the degree of toxicity of the roots. These statements are, however, at variance with those of KOCH and NIJHOLT. For KOCH, on the grounds of his own statistics, comes to the conclusion that the percentage of N in the plant shows no correlation with the degree of toxicity. NIJHOLT (1934–1935) found the same percentage of N in the innocuous variety *Mangi* and in the highly poisonous variety *Saò Pedro Preto,* at all ages from 2 to 14 months.

The fact that *climate,* as well as soil, plays an important part in this question, is generally accepted, but is not confirmed by figures. It may be assumed that the differences in toxicity found by GREENSTREET and LAMBOURNE in respect of the same varieties grown in different locations are due not only to the difference in the soil but also to the difference in climate. BURKILL (1935) says: "wet season tubers are more wholesome than those of the dry season." Similar statements are made by COURS and ADRIAENS. AGLADETTE (1949) gives statistics regarding six varieties which were grown in Tonkin for three successive years, from which it can be concluded that the differences found in the number of mg HCN per kg fresh root were caused more by differences in climate than by differences in soil (see Table 2).

Table 2. Results of Analysis of Six Varieties grown for Three Successive Years in Tonkin.

Variety	mg HCN per kg fresh root		
	1938	1939	1940
Criolinha	210	129	265
A. Paraguay	84	45	97
Zaailing Java	111	51	86
Manioc indigène	76	60	102
Camanioc	47	–	65
Man. doux du Réunion	59	55	54

It seems that if the less poisonous varieties are affected at all by the change in climate, they are, at any rate, affected less than the more poisonous ones.

NIJHOLT (1931–1932) and KOCH both point out that cases of cassava poisoning in Java are more frequent in the dry than in the wet season. This, however, does not prove that the cultivated varieties produce roots which become more poisonous in the dry season. The casualties mentioned may just as likely be due to a shortage of other foodstuffs, leading to increased consumption of cassava roots. Another cause may be consumption of cassava by people insufficiently familiar with the processing of poisonous roots. The powers of resistance of the victims had probably already been lowered by undernourishment.

According to MOSCRIP (1940) no case of cassava poisoning has ever been known in the United States. This he attributes to the short growing season and to the climatic conditions, different from those in the tropics, which should tend to cause a decrease in the amount of HCN present in the roots.

2 THE PRODUCTION CAPACITY OF THE CLONE

Occasionally the opinion is expressed that varieties with bitter – i.e., poisonous – roots can be expected to yield more than those with sweet-tasting roots. ADRIAENS writes: "On sait en effect, qu'au point de vue de rendement la culture du manioc doux est moins intéressante que celle de la variété amère." PEYNAERT (1951), on the other hand, writing about a number of Brazilian imports from Java, says: "Parmi celles-ci il y avait des variétés douces à rendement aussi élevé que les variétés amères."

GREENSTREET and LAMBOURNE give no opinion on this subject, but, since they published not only the yields per ha but also the amounts of HCN in the roots in respect of 43 varieties, it is possible to demonstrate, by plotting their results in graph form, that there is no connection whatever between a variety's yield capacity and its degree of poisonousness. As it happens, the most productive variety of these two authorities is also the most poisonous; but this isolated case has no certain general applicability.

From his figures KOCH concludes that degree of toxicity and size of yield tend to go together; but, in the opinion of the present writer, his correlations are too low to warrant this conclusion.

3 AGE OF THE PLANT

The extent to which the age of the plant affects the toxicity of roots still remains to be seen. The results given in Table 1 show that the situation in this respect as regards the *Mangi* and *S.P.P.* varieties more or less indicates the opposite. In *Mangi* we see that, in a wet field, the toxicity remains practically unaltered with age, whereas in a dry field it increases very distinctly. With *S.P.P.*, on the other hand, toxicity decreases very markedly with increase in age, in both fields. GRANER et al. quote figures from GODOI from which can be seen that, in 10 varieties, the toxicity of the roots at the age of 12 months is sometimes very much less than at the age of 4½ months; in one case, however, the reverse is true.

4 THE SIZE OF THE ROOTS

The size of the roots can also have an influence on toxicity. GREENSTREET and LAMBOURNE found 150, 170 and 120 mg HCN per kg fresh root in the case of small, medium and large roots, respectively. PEYNAERT quotes MOORE to the effect that the percentage of HCN in small roots is higher than in large ones. MOUTON (1949) says only that both bitter and sweet roots occur on the same plant, and that the consequence of this would be that the variety might be classified at one time as bitter, at another time as sweet.

Figures given by DARJANTO are embodied in Table 3.

Table 3. Mg HCN per kg Fresh Root in Cassava Plants of the Mangi Variety planted on the Estate of Tjitajam, Java.

No. of plant	Small roots	Medium-sized roots	Large roots
1	89	200	126
2	104	66	112
3	152	133	270
4	92	102	181
5	72	116	115
6	100	63	85
7	83	83	118
8	53	86	114
9	129	78	84
10	74	52	81
Average	94.8	97.9	127.6

These figures show a considerable range of variation, even within each group of roots. On an average, the large roots were found to be more poisonous than the medium-sized and small roots – though this, of course, does not mean that the same would necessarily be the case with other varieties.

5 Special methods of cultivation

As far back as 1905 Boorsma reported a belief, widespread among the native population of Java, that roots from cassava cuttings planted upside down are more poisonous than those from cuttings planted in the normal manner. However, an experiment carried out by him with a non-poisonous variety produced no conclusive result. In 1939 this experiment was repeated at Buitenzorg (Bolhuis, 1939), with the result given in Table 4.

Table 4. Results from an Experiment in Methods of Planting Cassava at Buitenzorg.

Variety	Method of planting	Guignard's reaction	mg HCN per kg fresh root
Mangi	normal	R	53
Mangi	upside down	LR	32
Valenca	normal	R	81
Valenca	upside down	R	59
Basiorao	normal	–	55
Basiorao	upside down	–	51
E 53	normal	–	77
E 53	upside down	–	70
Bogor	normal	DR	89
Bogor	upside down	DR	110
S.P.P.	normal	DR	236
S.P.P.	upside down	DR	310

These results show that the native belief is *not* true as regards innocuous and less poisonous varieties, but *is* true of the more poisonous varieties. This also explains why Boorsma's result was inconclusive, for he worked only with one of the less poisonous varieties.

6 Colchicine treatment of cuttings

By treating cassava cuttings with a colchicine solution (Bolhuis, 1949), it is possible to obtain fairly easily cuttings which contain more than the normal number of chromosomes (36). In the case of the three varieties treated the roots formed on the cuttings with more than 36 chromosomes proved not to differ greatly, as regards degree of toxicity, from those formed on normal cuttings (see Table 5).

Table 5. HCN Contents of Roots from Cuttings of the Varieties *Mangi*, *Betawi*, and *Bogor*, either treated with Colchicine or Untreated.

Varieties	*Mangi*		*Betawi*		*Bogor*	
	untreated	treated	untreated	treated	untreated	treated
mg HCN per kg fresh root	41–50	31–46	30	40	109	82

Accordingly, in two of the three cases the increase in the number of chromosomes can be said to have reduced the toxicity of the roots rather than aggravated it.

7 Bud variation

This phenomenon is not infrequently encountered in cassava, but mention has rarely been made of it in the literature of the subject, and where note *has* been taken of it no determinations of toxicity have been carried out. At Buitenzorg in 1938, on a plant of the *Saõ Pedro Preto* variety, a tiller was found the colour of whose stem bark was distinctly lighter than that of the original variety. This difference persisted in subsequent cropping, but chemical examination showed that the roots of the abnormal plants contained about the same number of mg HCN per kg fresh root as those of the original variety. A colour mutant discovered later in the Tapicuru variety produced corresponding results.

Inheritance of root toxicity

The number of places in the world where cassava breeding is carried out is rather limited; and, even there, the breeding programme has usually not progressed far beyond selecting the best of native or imported varieties. Where a start *has* been made with hybrid selection, investigation of the inheritance of toxicity will not be the first item on the programme, if only because such investigations require a not inconsiderable amount of labour and take up a large part of the experimental garden. At Buitenzorg in 1934 an attempt was made to get an impression of the degree of inheritability of root toxicity in a number of monoclonal plots of seedlings grown from freely pollinated seeds. It can, however, be assumed that most of these seedlings originated from selfing of the clones, as the plots were rather large and the seeds were harvested only from the innermost plants. The first 30 seedlings of every clone – in so far as they possessed enough thickened roots – were lifted by hand and their toxicity determined by taste since, at that moment, chemical analysis was not possible. The seedlings were evaluated as follows: 1 bitter, 3 some-what bitter, and 5 sweet. The average taste-value was ascertained in the case of each clone.

The results of this experiment are given in Table 6.

Table 6. Results of Taste Tests on Freely Pollinated Seedlings from Different Clones at Buitenzorg.

Clone	Toxicity of clone	Taste of roots	Average taste value of 30 seedlings
No. 353	innocuous	sweet	4.7
E 17	innocuous	sweet	3.4
E 19	poisonous	bitter	2,9
E 20	fairly poisonous	sweet	4.4
F 333	innocuous	sweet	4.6
F 357	innocuous	sweet	4.6
F 500	poisonous	bitter	2.1
F 522	very poisonous	bitter	3.1

From these results it will be seen that the taste of the parent clone is inherited to a fairly marked extent in its progeny. Since there is no hard-and-fast connection between taste and toxicity, no well-founded conclusion can be drawn from this; nevertheless, in the present author's opinion, it constitutes an indication that not only the taste but also, perhaps, the toxicity of cassava roots can be influenced by the selection of parent plants.

Investigation of a number of seedlings from two crosses of well-known innocuous parent clones yielded the following results (Table 7).

Table 7.

Cross	Number of seedlings	Taste			Guignard's colour reaction					
		5	3	1	Z	O	DO	LR	R	DR
F 357 × E 17	40	32	7	1	–	4	7	5	12	12
Singapore × F 357	47	42	3	1	3	3	13	11	7	10

The number of seedlings involved is too small to warrant a conclusion being drawn regarding inheritance, but the results given above show that, as was to be expected, the degree of poisonousness of cassava roots is not based on a small number of genes. The results of the second cross were much more favourable than those of the first for the selection work at Buitenzorg, the principal aim of which was to obtain non-poisonous varieties.

Discussion

In general, it is assumed that the toxicity of cassava roots is entirely due to the presence of glucosides, which occur in all parts of the plant, and in varying quantities in the roots. These quantities may differ considerably in plants of the same clone, under the influence of diverse conditions. Under suitable circumstances the glucosides may liberate HCN.

As regards the influence of soil and climate, the available statistics have clearly shown that differences therein may exert a very great influence on the degree of toxicity of cassava roots; in this connection, however, it is clear that the various clones react to these two factors in different ways. It is commonly presumed that long periods of drought have an unfavourable effect on the degree of toxicity, but this, in the opinion of the writer, has by no means been proved. No figures regarding it have yet been published. The figures obtained at Buitenzorg, from quantities planted on comparable plots of soil which had been used in the past for various purposes, definitely show that the toxicity of cassava roots can be influenced to a very large extent by a deficiency of K in the soil. This, for the rest, is in conformity with the fact that K has a substantial influence on the occurrence of alkaloids and glucosides in plants, i.e., K deficiency causes this content to increase, K surplus causes it to decrease. The connection between the N content of the soil and the degree of toxicity of the roots has likewise not yet been proved.

Not enough is known about the connection between the production level of cassava clones and their toxicity. Although it is generally accepted that the glucosides play a part in the plant's metabolism, not enough evidence has been found to date to prove that a high content of glucosides is accompanied by a high production capacity.

Apparently, the age of the plant may have a distinct influence on the degree of toxicity of the roots, but this influence differs from one clone to another. CIFERRI's assertion (1938) that the roots of cassava plants change from bitter to sweet, and vice versa, during their development, seems improbable, to say the least of it.

Nor can any definite conclusion be drawn from the data mentioned regarding the connection between the size and the degree of toxicity of the roots. The data of GREENSTREET and LAMBOURNE do not correspond with those of DARJANTO. The figures given do show, however, that a good deal of care will have to be observed in taking samples for determining the toxicity even of one particular plant. Not only will such a sample have to consist of several roots, but these, again, will have to be of different sizes.

The influence of special cultivation measures, such as planting upside down, is evidently small, while, for the rest, this method of planting is decidedly not to be recommended from the point of view of production. This also applies to increasing the number of chromosomes in the plants by colchicine treatment.

Too little is known regarding the effect of bud variation on toxicity to permit a conclusion to be drawn.

As regards the inheritance of the toxicity of roots, the scanty statistics available have clearly demonstrated that this is not a property which is dependent on one or two factors only. The evidence does, however, give the impression that the choice of certain subsidiary clones can affect the general level of toxicity of their descendants.

CONCLUSION

The foregoing pages have shown that, as yet, very little is known regarding the toxicity of cassava roots and the influence of external circumstances on it. In many cases published opinions are entirely at variance with each other. Nevertheless, expert views are sufficiently in agreement to justify abolishing altogether the conceptions of "sweet" and "bitter" cassava, and classifying the varieties exclusively according to their degree of toxicity. The present writer considers that the system of classification proposed for this by Koch is the most suitable one. Expression of the degree of toxicity in mg of HCN per kg of fresh root will greatly facilitate the comparison of data.

It is considered that co-ordinated scientific research, for the purpose of acquiring more knowledge of one of the most important food plants of the tropics, would be extremely desirable.

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