ELSEVIER

0308-8146(95)00098-4

Food Chemistry, Vol. 55, No. 4, pp. 319-325, 1996
Copyright © 1996 Elsevier Science Ltd
Printed in Great Britain. All rights reserved
0308-8146/96 $15.00+0.00

Cyanogen removal from cassava roots during sun-drying

A. J. Alexander Essers,* Remco M. Van der Grift,† & Alphons G. J. Voragen

Department of Food Science, Wageningen Agricultural University, Bomenweg 2, 6703HD Wageningen, The Netherlands

(Received 3 February 1995; accepted 25 May 1995)

Linamarin levels in sun-drying cassava root pieces showed an exponential decrease, parallel with the moisture loss, and stabilized when moisture levels reached about 15%. Linamarin degradation in thin root segments was significantly slower and less complete than in thick ones. Disinfected longitudinal root halves, oven-dried at 40°C for 24 h, had significantly higher residual linamarin levels than the matched ones subjected to humid incubation at 25°C. Interrupting for one or two days the sun-drying of peeled roots resulted in significantly lower residual levels of linamarin and of cyanohydrins plus HCN. Linamarin degradation was greater when the interruption was earlier or longer. The rate of dehydration influences linamarin degradation negatively — mechanisms are discussed. Cyanohydrin removal was completed by prolonged drying.

Sun-drying is not very effective in linamarin removal, and speeding up the drying process, e.g. by reducing the size of the pieces, aggravates this. There is a potential for increasing the effectiveness of cyanogen removal by reducing the initial drying rate, followed by thorough final drying. Copyright © 1996 Elsevier Science Ltd.

INTRODUCTION

Two drawbacks of the tropical staple food crop cassava are its potential toxicity and the perishability of the starchy storage roots. Once harvested, the roots deteriorate rapidly and may become unsuitable for consumption within 4 days (Booth & Coursey, 1974). Although cassava is widely consumed and usually without problems, toxic effects from insufficiently processed cassava have been reported from several areas (Rosling *et al.*, 1993). The potential toxicity comes from cyanogenic glucosides, mainly linamarin, which are present in the cell vacuoles. Disruption of the cells leads to contact with the enzyme linamarase which is located in the cell walls, and to subsequent hydrolysis into glucose and cyanohydrins (White *et al.*, 1994). Cyanohydrins are relatively stable in acid environments but rapidly decompose at a neutral or higher pH into ketones and the toxic hydrogen cyanide (Cooke, 1978). The formed HCN has a boiling point of 26°C and can easily escape into the air.

*Address for correspondence: Department of Toxicology, Wageningen Agricultural University, P.O. Box 8000, 6700EA Wageningen, The Netherlands. Tel.: 31 317485142; Fax: 31 317484931; e-mail: Sander.Essers@ALGEMEEN.TOX.WAU.NL

†Present address: Namulonge Agricultural and Animal Research Institute, P.O. Box 7084, Kampala, Uganda.

Effective reduction of cyanogen levels therefore requires two separate treatments. First, a treatment which enhances linamarin–linamarase contact by thorough disintegration of the cell structure. This can be done by crushing, grating or by (microbial) cell-wall-degrading enzyme activity. A second treatment is necessary to degrade the cyanohydrins formed and to volatilize the HCN. This can be done by heating or drying at an adequate pH. Traditional processes that fulfil these requirements are applied in several parts of the tropics (Dufour, 1989; Westby & Choo, 1994; Lancaster *et al.*, 1982). A drawback of the most effective and fast methods, like the ones leading to *gari* in West Africa and *farinha* in Brazil, is that they are quite labour demanding (Hahn, 1988; Dufour, 1994).

Sun-drying of peeled cassava roots is the easiest way to obtain a storable and transportable product, practised in many parts of the tropics (Cock, 1985; Nweke, 1994). The dried pieces can eventually be processed into flour for human consumption or animal feed. In large parts of Africa cassava roots are mainly processed into flour, which is used for preparing a paste, the generally preferred form for consumption of staple foods (Lancaster *et al.*, 1982). Pieris *et al.* (1974) found high residual cyanogen levels in sun-dried cassava, suggesting ineffective cyanogen removal.

The rate of dehydration of (sliced) cassava roots by sun-drying depends on moisture level, particle size, the

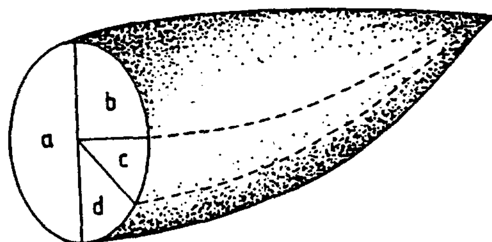

Fig. 1. Longitudinal division of roots for comparing thick (a) and thin (c) segments.

material, temperature and loading of the drying floor, the air humidity and temperature, solar radiation, and wind. If the peeled roots are regarded too thick by the processors, they are split and cut into smaller pieces to standardise or shorten the drying process. Shortening the lengthy drying process is desired to limit microbial spoilage, to reduce the risk of theft, to quickly have food available and to comply with financial and market demands. Nambisan & Sundaresan (1985) found that thin root discs retained more cyanogenic glucoside than thicker ones, and attributed this to earlier reaching a low moisture level which would inactivate linamarase. Sun-drying is sometimes interrupted or slowed down, provoking fungal growth, to reduce cassava's potential toxicity (Essers *et al.*, 1995). The effect of the dehydration in these processes is not known in detail.

This work was undertaken to study the dynamics of the cyanogen levels and the relation with moisture levels in sun-drying cassava root pieces, to seek practical measures to enhance cyanogen removal.

MATERIALS AND METHODS

Experimental

A: Monitoring cyanogen and moisture levels during sun-drying

In January 1991, 30 thick straight roots of the bitter cultivar *Karangwa* were harvested around 0800 h (t = 0) in Kiryandongo village, Masindi district, Uganda, and transported to Kampala, where they were measured, peeled rapidly and split lengthwise into 4 segments of similar size, which were dispersed on a cane mat and exposed to sunshine before 1400 h. The segments were turned once a day, and sheltered during the night, which is common practice there. Samples of 12 randomly selected segments were taken right after peeling and after 3, 6, 10, 17 and 38 days. Samples were diced into 1 cm^3 cubes, hand-mixed, and 4 sub-samples of approx. 70.00 g were extracted. Cyanogen extraction and pH measurement were conducted within 2 h of sampling, and analysis for cyanogens within 24 h of extraction.

In January 1992, the experiment was repeated in exactly the same way, but to get a more detailed picture, sampling was performed after 0, 1, 2, 3, 4, 6, 9, 14 and 30 days.

To measure the reliability of the sampling procedure, 4 samples of 12 fresh roots were taken, sub-sampled and analyzed.

To examine the cyanohydrin and HCN levels in very fresh cassava, two roots of the cultivar *Karangwa* were peeled, the parenchyma middle disc cut with a sharp knife and cyanogens extracted within 15 min after uprooting. Analysis of cyanogens in the extracts was within 1 week.

B: Examining the effect of chunk size on cyanogen levels in sun-drying cassava

The effect of chunk size was tested after different extents of sun-drying, by pair-wise comparison of residual cyanogen levels in sun-dried thick and thin segments of the same root.

Twenty thick straight roots of the bitter cultivar *Karangwa* were harvested around 0800 h (t = 0) in Kiryandongo village and transported to Kampala, where they were peeled and split lengthwise into segments a, b, c, d as shown in Fig. 1. Of each root, segments b and d were jointly extracted and analyzed on the same day (0) to indicate the initial level of cyanogens, moisture and the pH of that root. Segments a and c were labelled and placed on a mat exposed to sunshine for drying, and sheltered during the night. At days 3, 7, 10 and 21, five segment pairs a and c were randomly selected and each piece extracted individually and analyzed for cyanogen levels, moisture and pH.

C: Comparison of cyanogen levels after drying or humid incubation

To test the effect of dehydration on linamarin degradation, residual cyanogen levels of root segments submitted to either drying or humid incubation, were compared pair-wise.

Cassava roots from Costa Rica, obtained commercially in the Netherlands, were peeled and cut into pieces. Ten pieces were disinfected by submerging them for 2 h in 70% ethanol, to reduce microbial outgrowth. Then, with a disinfected knife, each piece was split lengthwise into two similar segments, which were labelled. This resulted in 10 pairs of segments with pair-wise similar levels of cyanogens (De Bruijn, 1973). One segment of each root was placed in a ventilated oven at 40°C and the other segment in a covered glass jar at 25°C, avoiding anaerobiosis by leaving a small aperture. After 24 h each segment was extracted and analyzed for cyanogens. Moisture was determined in two combined samples of the dried and two of the humid incubated segments.

D: Interrupted sun-drying

To study the effect of deliberately delaying dehydration of cassava roots on cyanogen levels, residual cassava cyanogen levels after sun-drying and interrupted sun-drying were compared with the initial ones. Equal size roots of the bitter cultivar *Karangwa* were harvested around 0800 h in Kiryandongo village and transported

to Kampala, where they were peeled and randomly divided over 6 batches at 1400 h. One batch was sampled immediately as reference and the others were exposed to sunshine for the remaining 3 h and subsequently submitted to sun-drying and incubation in a bag following an 8-day schedule, as indicated at Table 2. A "sun day" means that the roots were scattered on a cane mat and exposed to sunshine from 0900 to 1700 h. A "bag day" means that the roots were kept during the same period in a woven polypropylene bag in the shade, to reduce the drying rate. Outside these hours, the roots were kept uncovered in a room to protect them against possible rains and rodents. On day 9, moisture and pH were determined and cyanogens were extracted from sub-samples of each batch. Analysis for cyanogens was within two weeks.

Experiment D1 was conducted in February 1993. Each batch had 12 roots, which resulted in 4 sub-samples of 3 roots each, as suggested by Bokanga (1994). Each sub-sample resulted in one extract, totalling 24 extracts for the experiment. *Experiments D2* and *D3* were conducted in March 1993. Then the six batches consisted of 36 roots each: 6 sub-samples of 6 roots each, resulting in 36 extracts. In *experiment D3*, one initial drying day was added to all treatments to prevent mould growth during the humid weather at that time.

Table 1. Aggregated data on cyanogenic potential of fresh cassava roots and the residual cyanogen and moisture levels in pairs of thick and thin segments of the same roots after several days of sun-drying

Drying time (days)	Initial levels	Residual levels					
		Thick segments			Thin segments		
	Cyanogenic potential	Cyanogenic glucosides	Cyanohydrins plus HCN	moisture (%)	Cyanogenic glucosides	Cyanohydrins plus HCN	moisture (%)
3	378 ± 94	86.5 ± 33.7	34.8 ± 23.6	35.7 ± 6.3	116.5 ± 33.0	25.5 ± 21.3	23.1 ± 1.8
7	376 ± 98	76.3 ± 21.5	32.2 ± 13.6	22.0 ± 3.7	103.6 ± 28.3	32.0 ± 10.1	15.0 ± 1.1
10	369 ± 57	64.4 ± 26.6	15.0 ± 7.8	15.6 ± 2.7	85.7 ± 24.6	17.7 ± 5.3	11.8 ± 0.3
21	433 ± 77	66.8 ± 16.4	6.1 ± 1.1	10.0 ± 1.6	97.5 ± 13.5	5.6 ± 0.9	9.4 ± 1.0

Means ± SD of 5 repetitions are given as mg CN equivalent/kg dry weight.

Table 2. Mean levels (± SD) of cyanogenic glucosides, cyanohydrins plus HCN, and moisture in fresh cassava roots and after different sun-drying treatments in experiments *D1*, *D2* and *D3*

Treatment[a]	Cyanogenic glucosides (mg CN eq./kg dry wt)	Cyanohydrins + HCN (mg CN eq./kg dry wt)	Moisture (%)
D1 fresh[b]	490.9 ± 20.6	8.4 ± 0.7	57.1
A[b]	31.5 ± 23.2	15.8 ± 4.9	18.6
B[b]	7.0 ± 4.1	9.5 ± 1.8	16.9
C[b]	4.3 ± 3.9	7.9 ± 3.5	17.7
D[b]	5.9 ± 3.8	10.9 ± 1.8	18.0
E[b]	1.7 ± 1.6	3.9 ± 0.9	17.8
D2 fresh[c]	779.9 ± 80.3	5.4 ± 1.9	59.5
A[c]	83.3 ± 10.1	16.5 ± 7.8	16.1 ± 1.7
B[c]	59.7 ± 16.3	11.7 ± 4.2	14.1 ± 2.5
C[c]	25.6 ± 9.2	10.4 ± 5.5	15.0 ± 2.0
D[c]	42.3 ± 12.0	4.6 ± 2.6	13.0 ± 0.5
E[c]	15.4 ± 8.6	5.3 ± 1.9	14.1 ± 2.2
D3 fresh[c]	783.0 ± 63.4	6.4 ± 1.9	58.5
A+[c]	123.8 ± 27.7	6.9 ± 2.2	20.0 ± 1.0
B+[c]	78.8 ± 23.9	3.1 ± 1.2	18.9 ± 1.7
C+[c]	35.4 ± 7.1	1.5 ± 1.3	21.1 ± 2.6
D+[c]	45.2 ± 6.6	8.1 ± 3.4	17.5 ± 2.3
E+[c]	19.2 ± 3.6	0.5 ± 0.7	13.3 ± 1.2

[a]Number of days in the

	sun	bag	sun
A:	8	0	—
B:	2	1	5
C:	2	2	4
D:	1	1	6
E:	1	2	5

[b]$n = 4$; [c]$n = 6$; + = one additional sun day

Cyanogen, pH and moisture determination

Moist sub-samples of approx. 70.00 g, 1 cm^3 cubes were homogenised in 250 ml, 0.1 M H_3PO_4, followed by centrifugation. Samples of dry root pieces were crushed and pounded to flour. Of this, two sub-samples of 4 g were each suspended in 25 ml 0.1 M H_3PO_4, swirled for 5 min, followed by centrifugation. The supernatant was analyzed for cyanogens by enzymic (purified linamarase, BDH, Poole, U.K.) conversion to HCN and colorimetric measurement (Beckman DU-62 in experiment C, otherwise Milton Roy Spectronic 20) after coloration with 1,3-dimethyl barbiturate/isonicotinate reagent according to Essers *et al.* (1993). The pH was measured 10 min after homogenizing 40 g moist sample in 150 ml or suspending 10 g flour in 100 ml of cooled, previously boiled, distilled water.

Moisture levels were assayed by oven drying at 105 ± 5°C until constant weight.

Statistical analysis

Random sampling was obtained by lining up all roots or segments and, starting at one end from a randomly determined figure, collecting e.g. every sixth root. The presence of treatment effects was verified by F-test and subsequently judged with Students' *t*-test (Protected Least Significant Difference test, PSD) (Snedecor & Cochran, 1980). Significance of differences are related to two-tailed probability (*P*) values.

RESULTS

Experiment A: dynamics of cyanogen and moisture decrease

The cyanogen and moisture levels during the sun-drying of root segments are presented in Fig. 2a,b. The pH of the roots remained between 6.3 and 7.2 in both experiments. The coefficient of variation (*cv*) of cyanogenic potential of 4 samples at $t = 0$ was 10.4%. The mean (± SD) root diameter was 6.5 cm (± 1.0) in experiment 1 and 5.5 cm (± 0.8) in experiment 2. Cyanogenic potential in the two roots harvested 15 min before extraction was 1197 and 866 mg CN equivalent/kg dry weight, and the cyanohydrin levels 2.0 and 2.4, respectively. HCN was not detectable.

Experiment B: thin versus thick segments

The mean (± SD) root diameter was 6.1 cm (± 1.0). Cyanogen and moisture levels in drying pairs of thin and thick segments are presented in Table 1. Measured from 3 days of drying onwards, cyanogenic potential and cyanogenic glucoside levels were significantly lower ($P < 0.001$), and moisture levels significantly higher ($P < 0.001$) in the thick segments than in the corresponding thin segments. The cyanogenic glucoside levels in the thick segments were on average (mean ± SD) 72%(± 12) of those in the corresponding thin segments. This percentage was not significantly different after 3, 7, 10 or 21 drying days. After 3 and 7 drying days there was still a strong correlation ($r > 0.90$) between initial and residual cyanogenic potential or linamarin levels in the dried pieces. After 10 and 21 drying days, this relationship was weaker, especially in the thick segments.

Experiment C: dried versus non-dried segments

Mean moisture level was 33% in the dried samples and 63% in the non-dried disinfected incubated ones. Mean (± SD) cyanogenic glucoside levels were 67.3 (± 13.4) mg CN equivalent/kg dry weight in the dried segments and 48.8 (± 14.6) in the corresponding ones that were prevented from moisture loss. Mean (± SD) non-glucosidic cyanogen levels were 16.2(± 6.1) mg CN equivalent/kg dry weight in the dried segments and 65.1(± 17.4) mg CN equivalent/kg in the corresponding non-dried ones. Cyanogenic glucoside levels were significantly higher ($P < 0.005$), and levels of cyanohydrins plus HCN were significantly lower ($P < 0.001$) in the dried segments than in the corresponding ones that were prevented from moisture loss. No apparent fungal or

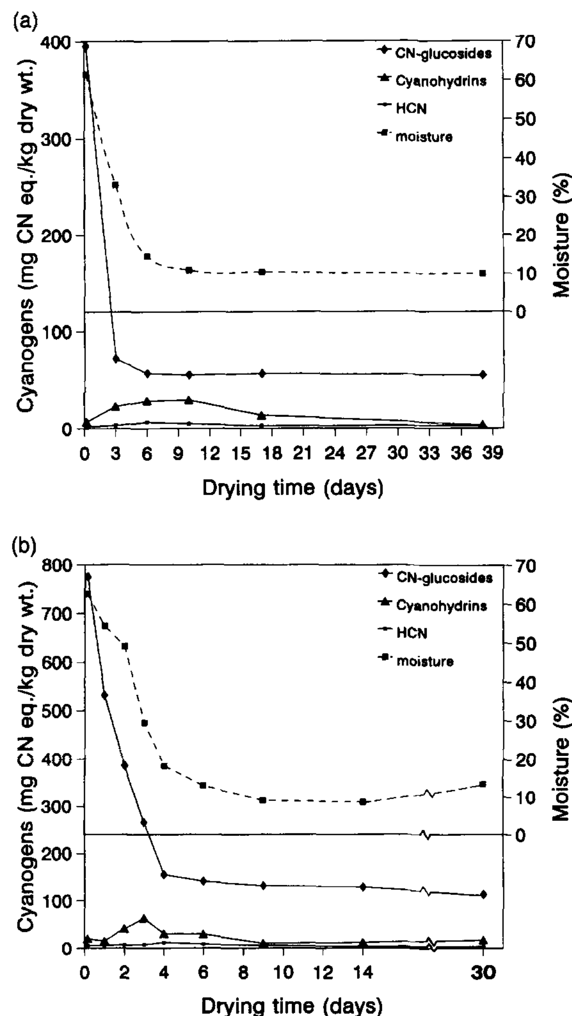

Fig. 2. Cyanogen and moisture levels in 2 batches (a and b) of sun-drying cassava root segments (cultivar *karangwa*) over time (batch a, 1991; batch b, 1992).

bacterial growth was visible on the dried or incubated pieces.

Experiment D: interrupted sun-drying

Results from the experiments with interrupted sun-drying are presented in Table 2. pH range in the fresh and treated roots was between 6.0 and 7.1 with a mean (±SD) of 6.5(±0.3). Coefficient of variation (*cv*) of cyanogenic potential in fresh root samples was 4.1% for 4 sub-samples of 3 roots, and 10.1 and 7.9, respectively, in two experiments with 6 sub-samples of 6 roots. The batches which were processed by interrupted sun-drying had significantly lower ($P<0.01$) residual cyanogenic potential and linamarin levels than the ones submitted to straight forward sun-drying. Mean (±SD) linamarin levels in interrupted-sun-dried batches were 15%(±7.3), 43%(±23) and 36%(±20) of straight sun-dried batches in experiments 1, 2 and 3, respectively. The batches which were incubated after only one day of initial sun-drying had significantly ($P<0.01$) lower residual linamarin levels than when incubated after two days of initial sun-drying. The batches that were incubated for two days had significantly ($P<0.05$) lower cyanogenic potential and linamarin levels than when incubated for one day. The residual levels of cyanohydrins plus HCN together were significantly lower ($P<0.05$) in the cassava pieces that had been submitted to interrupted sun-drying than in the straight forward sun-dried ones.

In several batches a slight fungal growth on the root surface was observed, but not comparable to the degree observed during heap-fermentation (Essers *et al.*, 1995); nor had the roots become soft. This growth was most pronounced on the roots that had been incubated for two days after only one initial day of sun-shine.

DISCUSSION

Due to the heterogenic distribution of cyanogenic glucosides within and between roots, a good sampling procedure is crucial in such comparative experiments. The reproducibility of the sampling procedures, indicated by the *cv* of the cyanogenic potential of the duplicate samples at $t = 0$, was good. Higher *cv* has been reported as common by Bokanga (1994). The absence of detectable quantities of HCN and the extremely low cyanohydrin levels (below 0.3% of cyanogenic potential) in very fresh roots, are consistent with the theory that these compounds are nearly absent in intact living cassava tissue (White *et al.*, 1994). The small amount of cyanohydrin present must have been formed in the disrupted cells at the cutting edge. We can therefore consider all initial values of cyanogenic potential in our experiments to represent exclusively cyanogenic glucosides at harvest.

In the drying experiments A and B, the glucoside degradation was highest at the start, slightly decreasing over the following days, and practically stopped, rather abruptly, before being completed. This decrease coincided with the loss in moisture; the glucoside degradation practically stopped at a moisture level somewhere between 33 and 15% in the first batch, and between 18 and 13% in the second batch. This is slightly higher than the 12 or 13% estimated by Mlingi *et al.* (1995). We consider the estimate from the second batch more accurate, because of the more detailed information by the shorter measuring-time intervals. Experiment B shows that reducing the size of the pieces accelerated the dehydration and reduced the breakdown of linamarin. Contrary to our expectation that the difference in linamarin levels between thick and thin segments would arise or increase after thin segments having reached moisture levels below about 15% while thick segments still having well above 15%, i.e. after about 7 days, there was no such trend. The main difference in residual linamarin levels was determined in the first part of the drying stage. Experiment C shows that drying at 40°C caused less linamarin breakdown than humid incubation at 25°C over a 24 h period, even long before a moisture level of 15% was reached. Experiment D shows that extending the period with a higher moisture level enhanced the linamarin breakdown, and that the breakdown was more pronounced in those batches where moisture was retained longer or at a higher level.

This all suggests an important role of moisture levels and dehydration rate in glucoside degradation. During drying, water evaporates at the root surface. To restore the water balance in the tissue, water must pass the cell walls. It then depends on the integrity of the membrane system if the glucosides remain within the vacuoles, or are transported along through the linamarase containing cell wall. This forced transport of liquid might be a factor in enabling contact between the glucosides and the linamarase. If this factor would be important, drying pieces should have lower residual linamarin levels than the pieces prevented from dehydration. As the results from experiment C contradicted this hypothesis, we conclude that the dehydration *per se* does not play an important positive role in establishing glucoside–linamarase interaction, but rather the autolytic processes that occur during the drying period, by affecting the membrane and cell-wall integrity.

The pattern of the decreasing linamarin levels during the sun-drying process may be explained by one or more of the following: The enzymic breakdown of a substrate in solution follows a first or higher order reaction, resulting in a negative exponential curve of linamarin level in grated cassava (Ofuya *et al.*, 1989), and we found this also in homogenized cassava tissue (unpublished findings). The higher initial substrate level therefore logically results in a steeper decline than the lower level which is present after some days. This is irrespective of the drying process or the stage in the incubation or drying process.

Okolie & Ugochukwu (1988) studied several enzyme activities in harvested cassava roots. They found that endogenous cell-wall-degrading enzyme activity is highest

during the first 24 h after harvest and decreasing during the subsequent days. This cell-wall degradation may reduce the compartmental separation of the linamarase and linamarin and as such imply a higher initial linamarin breakdown. The linamarin levels in our studies showed a similar decrease over time as the pectinase and polygalacturonase activity in their study. The decrease in linamarase activity during the first three days after harvest, shown by Iwatsuki *et al.* (1984), may enhance this effect. The reason for the lowering enzyme activity is not known, but is possibly related to the formation of enzyme-inhibiting compounds such as polyphenoles. This mechanism may be independent from the drying process. It should be noted that, contrary to Okolie & Ugochukwu, Padmaja & Balagopal (1985) found an increase in polygalacturonase activity over the first few days.

Figure 2 suggests that glucoside degradation practically stops when moisture levels are below about 15 or 16%. Decreasing moisture levels of 23, 15 and 13% in cassava starch correspond with a water activity (a_w) of 0.80, 0.42 and 0.33, respectively (Van den Berg, 1981). In cassava tissue the corresponding a_w must be slightly lower due to the few percent of non-starch cell compounds. In foodstuffs, enzyme interactions are increasingly suppressed from an a_w of 0.8 downward and are absent below an a_w of 0.4 (Belitz & Grosch, 1987).

Upon dehydration, the diffusion coefficient decreases faster for big than for small molecules (Menting, 1969). This would make linamarin diffuse increasingly slower than the small water molecule during the drying, and one can imagine that part of the linamarin molecules finally remains immobilized in the vacuoles due to a lack of bulk water. This would prevent their interaction with linamarase. Menting (1969) found that acetone retention in a drying malto-dextrin solution was higher when the drying was more rapid. Drying rate is higher in thinner than in thicker cassava pieces, as the surface-to-volume ratio is greater. This different drying rate may explain why in smaller drying pieces linamarin levels remain higher from the start onward, and not only after reaching moisture levels of some 15%.

During drying, the cyanohydrins resulting from the breakdown of the glucosides hardly accumulated during the first 3 days, in spite of the large quantities which must have been formed. Probably, the conversion of cyanohydrins takes place rapidly because of the favourable pH (between 6.3 and 7.1) in an aqueous environment, the presence of α-hydroxynitril-lyase and a temperature of 25–45°C. The low levels of HCN throughout the processing indicate that the formed HCN escaped easily, thereby pulling the equilibrium between cyanohydrin and its metabolites to the latter. The high cyanohydrin levels in the humid incubated root pieces from experiment C show the importance of drying for cyanohydrin removal. It was therefore remarkable that the residual moisture and cyanohydrin levels were lower in the interrupted sun-dried root pieces than in their straight forward sun-dried pairs. The enhanced enzyme–substrate interaction by the moisture retention, together with the final drying step was apparently an effective combination for cyanogen removal.

Although Nambisan & Sundaresan (1985), Mlingi *et al.* (1992) and our experiments clearly showed that reducing chip size led to relatively higher linamarin levels after sun-drying, exceptions are possible. As long as the number of cells disrupted by the cutting is small compared to the amount of intact tissue, this will lead to higher residual linamarin levels in thinner particles, as described here. When the number of disrupted cells becomes high compared to that of intact cells, which is achieved by grating, pounding, or dicing with a blunt knife, this relationship may be overruled by the enhanced accessability of linamarin and linamarase. Drying of fresh peeled whole and pounded roots as compared by Mlingi *et al.* (1992) therefore resulted in lower linamarin levels of the latter.

Extending the period with medium moisture levels, practised with the interrupted sun-drying, led to lower residual levels of cyanogenic glucosides, as well as cyanohydrins plus HCN, over the same period of time. Higher moisture levels during the incubation led to lower residual glucoside levels but unfortunately also to some mould growth. These fungi may have contributed to the enhanced reduction of the linamarin levels (Essers *et al.*, 1994, 1995), but not much, as they were only superficial and in small amounts, while root softening as in heap-fermentation had not occurred.

Considering the potential toxicity of linamarin (Rosling, 1994), and the levels of residual cyanogens in sun-dried roots in these experiments exceeding by far the FAO/WHO (1991) recommended limit of 10 mg hydrocyanic acid equivalents per kg flour, we conclude that sun-drying alone is not appropriate for cassava roots with high cyanogenic potential. For such roots, speeding up the drying process e.g. by reducing chip size is certainly not appropriate. There is a potential for increasing the effectiveness of cyanogen removal in sun-drying cassava by extending the time span with a higher moisture content for linamarin breakdown, followed by a thorough final drying step to reduce the cyanohydrin levels. This may be advisable for roots with medium levels of cyanogenic potential, where water-soaking or more labour-intensive methods are inconvenient. It remains to be tested if, by sufficient initial drying, microbial contamination can be controlled and the formation of mycotoxins prevented.

ACKNOWLEDGEMENTS

We are grateful to the Department of Food Science and Technology of Makerere University, Kampala, for providing conditions for the experimental work, to Margaret Bosveld for cyanogen analyses and to Hans Rosling for critically reading this manuscript. This study was financed by The Netherlands' Minister for Development Co-operation.

REFERENCES

Belitz, H. D. & Grosch, W. (1987). *Food Chemistry*. Translation from the second German edition. Springer, Berlin, Heidelberg.

Bokanga, M. (1994). The cyanogenic potential of cassava. In *Root Crops and Food Security: Proceedings of the Fifth Triennial Symposium of the International Society for Tropical Root Crops — Africa Branch, Kampala 26–29 November 1992*, ed. Akoroda, M. O. International Institute of Tropical Agriculture, Ibadan, Nigeria, pp. 336–9.

Booth, R. H. & Coursey D. G. (1974). Storage of cassava roots and related post-harvest problems. *International Development Research Centre Monographs*, Ottawa, Canada, IDRC-031e, pp. 43–9.

Cock, J. H. (1985). *Cassava, New Potential for a Neglected Crop*. Westview Press Inc., Boulder, Colorado.

Cooke, R. D. (1978). An enzymatic assay for the total cyanide content of cassava (*Manihot esculenta* Crantz). *J. Sci. Food Agric.*, **29**, 345–52.

De Bruijn, G. H. (1973). The cyanogenic character of cassava (*Manihot esculenta*). In *Chronic Cassava Toxicity: Proceedings of an Interdisciplinary Workshop. London, England*, eds Nestel, B. & MacIntyre, R. International Development Research Centre, Ottawa, pp. 43–8.

Dufour, D. L. (1989). Effectiveness of cassava detoxification techniques used by indigenous peoples in northwest Amazonia. *Interciencia*, **14** (2), 86–91.

Dufour, D. L. (1994). Cassava in Amazonia: Lessons in utilization & safety from native peoples. In *Proceedings of the International Workshop on Cassava Safety. 1–4 March 1994, IITA, Ibadan, Nigeria*, eds Bokanga, M., Essers, A. J. A., Poulter, N., Rosling, H. & Tewe, O. *Acta Horticulturae*, **375**, 175–82.

Essers, A. J. A., Bosveld, M., Van der Grift, R. M. & Voragen, A. G. J. (1993). Studies on the quantification of specific cyanogens in cassava products and introduction of a new chromogen. *J. Sci. Food Agric.*, **63(3)**, 287–96.

Essers, A. J. A., Witjes, C. M. J. W., Schurink, E. W. & Nout, M. J. R. (1994). Role of fungi in cyanogens removal during solid substrate fermentation of cassava. *Biotechnol. Lett.*, **7**, 755–8.

Essers, A. J. A., Ebong, C., Van der Grift, R. M., Nout, M. J. R., Otim-Nape, W. & Rosling, H. (1995). Reducing cassava toxicity by heap-fermentation in Uganda. *Int. J. Food Sci. Nutr.*, **46(2)**, 125–36.

FAO/WHO (1991). Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission, **XII**, Supplement 4. FAO/WHO, Rome.

Hahn, N. (1988). Cassava production/utilization and social change. *International Society for Tropical Root Crops Symposium. October 30–November 5, 1988, Bangkok, Thailand.*

Iwatsuki, N., Kojima, M., Data, E. S. & Villegas-Godoy, C. D. V. (1984). Changes in cyanide content and linamarase activity in cassava roots after harvest. In *Tropical Root Crops — Postharvest Physiology and Processing*, eds Uritani, I. & Reyes, E. D. Japan Scientific Press, Tokyo, pp. 151–61.

Lancaster, P. A., Ingram, J. S., Lim, M. Y., & Coursey, D. G. (1982). Traditional cassava based foods: Survey of processing techniques. *Econ. Botany*, **36(1)**, 12–45.

Menting, L. C. (1969). *Retention of Volatiles during the Air Drying of Aqueous Carbohydrate Solutions.* Thesis. Wageningen Agricultural University, The Netherlands.

Mlingi, N., Poulter, N. H. & Rosling, H. (1992). An outbreak of acute intoxications from consumption of insufficiently processed cassava in Tanzania. *Nutr. Res.*, **12**, 677–87.

Mlingi, N. L. V., Bainbridge, Z. A., Poulter, N. H. & Rosling, H. (1995). Critical stages in cyanogen removal during cassava processing in southern Tanzania. *Food Chem.*, **53**, 29–33.

Nambisan, B. & Sundaresan, S. (1985). Effect of processing on the cyanoglucoside content of cassava. *J. Sci. Food Agric.*, **36**, 1197–203.

Nweke, F. I. (1994). Processing potentials for cassava production growth in Africa. *COSCA Working Paper No. 11*, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Ofuya, C. O., Ukpong, E. & Adesina, A. A. (1989). Modelling of the rate data from the fermentation of cassava slurry. *Lett. Appl. Microbiol.*, **9**, 13–16.

Okolie, N. P. & Ugochukwu, E. N. (1988). Changes in activities of cell-wall-degrading enzymes during fermentation of cassava (*Manihot esculenta* Crantz) with *Citrobacter freundii. J. Sci. Food Agric.*, **44**, 51–61.

Padmaja, G. & Balagopal, C. (1985). Cyanide degradation by *Rhizopus oryzae. Can. J. Microbiol.*, **31**, 663–9.

Pieris, N., Jansz, E. R. & Kandage, R. (1974). Cyanogenic glucoside content of manioc. I. Enzymic method of determination applied to processed manioc *J. Natl. Sci. Counc. Sri Lanka*, **2(1)**, 67–76.

Rosling, H., Mlingi, N., Tylleskär, T. & Banea, M. (1993). Causal mechanisms behind human diseases induced by cyanide exposure from cassava. In *Proceedings from the First Meeting of the Cassava Biotechnology Network, Cartagena, Colombia, 25–28 August 1992*, eds Roca. W. N. & Thro, A. M. CIAT, Cali, Colombia, pp. 366–75.

Rosling, H. (1994). Measuring effects in humans of dietary cyanide exposure from cassava. In *Proceedings of the International Workshop on Cassava Safety, Ibadan, Nigeria, March 1–4, 1994*, eds Bokanga, M., Essers, A. J. A., Poulter, N., Rosling, H. & Tewe, O. *Acta Horticult.*, **375**, 271–83.

Snedecor, G. W. & Cochran, W. G. (1980). *Statistical Methods*, 7th edn. Iowa State University Press, U.S.A., p. 234.

Van den Berg, C. (1981). *Vapour Sorption Equilibria and other Water–Starch Interactions: a Physico-Chemical Approach.* Thesis, Wageningen Agricultural University, The Netherlands, p. 49.

Westby, A. & Choo, B. K. (1994). Cyanogen reduction during lactic fermentation of cassava. In *Proceedings of the International Workshop on Cassava Safety, Ibadan, Nigeria, March 1–4, 1994*, eds Bokanga, M., Essers, A. J. A., Poulter, N., Rosling, H. & Tewe, O. *Acta Horticult.*, **375**, 209–15.

White, W. L. B., McMahon, J. M. & Sayre, R. T. (1994). Regulation of cyanogenesis in cassava. In *Proceedings of the International Workshop on Cassava Safety, Ibadan, Nigeria, March 1–4, 1994*, eds Bokanga, M., Essers, A. J. A., Poulter, N., Rosling, H. & Tewe, O. *Acta Horticult.*, **375**, 69–77.