Pre-Harvest Environmental Effects on Cassava Root Susceptibility to Post-Harvest Physiological Deterioration

Authors: C.C. Wheatley, J.C. Lozano, J. Marriott, and W.W. Schwabe, Post-doctoral fellow, Wye College (TPI-CIAT Cassava Deterioration Proj.); Plant Pathologist, Cassava Program, CIAT, Cali, Colombia; Formerly of Tropical Products Institute, London; and Professor, Horticulture Department, Wye College, London University, England.

ABSTRACT

Poor post-harvest storage life of cassava roots is due to physiological and microbial processes rendering the roots inedible within 2 to 5 days of harvest. These studies demonstrate that main factors controlling susceptibility of cultivar to physiological deterioration are environmental: plants defoliated due to severe stresses were more resistant than non-defoliated plants of the same cultivar. Site and prevailing pre-harvest environmental conditions also affected degree of susceptibility. Pruning experiments gave results which closely agreed with the defoliation effects and confirmed reports that pre-harvest pruning induced resistance to physiological deterioration. Such induced resistance was obtained for at least 9 weeks after pruning and was unaffected by subsequent regenerative growth. A reduction in root dry matter content occurred following pruning but is not causally related to resistance to physiological deterioration.

Introduction

Cassava (*Manihot esculenta* Crantz) is the most important staple tropical root crop (FAO, 1981). One of the major factors limiting its increased use as a fresh food is the extremely short root post-harvest storage life caused by the rapid development of a blue-black discoloration (Averre, 1967; Booth, 1976; Lozano et al, 1978; Marriott et al, 1978, 1979), termed "vascular streaking" (Montaldo, 1973) or "vascular deterioration" (Marriott et al, 1978). A physiological reaction initiated between 2 to 3 days after harvest causes the initial loss of acceptability (Booth, 1976; Lozano et al, 1978) followed 5 to 7 days after harvest by microbially induced rotting and fermentation (Lozano et al, 1978) also causing tissue discoloration. Booth (1976) defined the two processes as primary (physiological) and secondary (microbial) deterioration.

Booth (1976, 1977) found that physiological deterioration was initiated near regions of mechanical damage and that curing (high temperature and humidity conditions which encourage wound healing) markedly restricted the development of physiological deterioration. Reduced root susceptibility to physiological deterioration was obtained by pre-harvest pruning of the aerial portion of the plant (Lozano et al, 1978). A translocatable inducing factor was postulated to explain the resistance which developed.

Observations that root susceptibility to physiological deterioration can vary greatly between plants of the same clone (Lozano and Booth, personal communication) lead to work reported here. The susceptibility of several cultivars was evaluated over a 2-year period at one site (CIAT-Palmira), and 26 cultivars were evaluated at a range of sites (Table 1) to document and investigate this observed variability. On the basis of these experimental results, a hypothesis involving preharvest environmental factors is proposed to explain some of this intracultivar variation and results of experiments testing this hypothesis are presented.

Table 1. Climatic and edaphic characteristics of five sites in Colombia.

	CIAT-Palmira	Carimagua	Caribia	Media Luna	Popayán
Climatic					
Altitude (m)	1,020	200	35	10	1,760
Mean Tem (°C)	24.0	26.1	26.0	17.0	18.0
Rainfall (mmy^{-1})	1,000	2,031	1,308	780	2,500
Dry season (months)	5 (bimodal)	3	4	4	5 (bimodal)
Edaphic					
Soil pH	6.0	4.7	6.2	6.0	4.5
Soil fertility	Good	Low	Good	Low	Moderate
Soil texture	Clay	Clay-loam	Sandy-clay	Sandy	Clay-loam
Al concentration	Low	High	Low	Low	High

Materials and Methods

Experiments were at Centro Internacional de Agricultura Tropical (CIAT) station at Palmira, Colombia and also at sites in four different regions of Colombia (Table 1). Stem cuttings were treated with orthocidebavistin (3,000 ppm a.i.) and planted vertically on ridges with 1x1 m spacing. Where possible, plants were irrigated during the 2-month establishment period. In several experiments at each location, plots were evaluated before harvest for defoliation on a percentage basis.

Plants were harvested at 10 to 12 months of age unless otherwise stated. When required, foliage and roots were weighed directly after harvest. Storage rots were harvested manually with care taken to keep mechanical damage to a minimum.

Physiological deterioration was evaluated using a 15 cm root section with minimal mechanical damage (Marriott, 1979; CIAT, 1980). The distal end was covered with 50 gauge PVC film, restricting development of physiological deterioration to the proximal cut surface. After 3 days of storage, the root sections were evaluated by cutting transversely at 2 cm intervals and assigning a 0 to 10 score to each cut surface based on percentage of periphery of the parenchyma deteriorated. The total physiological deterioration susceptibility was obtained by calculating this as a percentage of the maximum possible score for each treatment group (Deterioration %). Roots were stored prior to evaluation either in field conditions, protected from rain and rodents, or in laboratory conditions of 22°C and 60% to 80% relative humidity.

The specific gravity of three roots per treatment was used when required to estimate root dry matter content (CIAT, 1977; Wholey and Booth, 1979). Root cyanide content was determined using the enzymatic method of Cooke (1978). Five roots per treatment were peeled, quartered longitudinally and a longitudinal slice taken from each quarter was rapidly diced and pooled. Three duplicate samples per treatment were analysed.

Experimental designs are described for each experiment individually. Generally, 10 roots were used per deterioration evaluation, taken at random from those of at least five plants. Treatments were assigned at random within field plots.

Results and Discussion

Variation in susceptibility to physiological deterioration

The results of evaluating physiological deterioration in several clones during 2 years' trials at CIAT-Palmira are in Figure 1. The amount of variation between the plants of one cultivar grown at the same site was large. M Col 22 previously considered (CIAT, 1977) very susceptible to physiological deterioration, showed Det. % values typical of both resistance and susceptibility. Indeed, M Col 22 has been described (Booth, 1976) as "slightly resistant," while M Col 113 and Llanera were "susceptible." These repeated observations of one cultivar demonstrate that intra-cultivar variation is great and that the indiscriminate use of the terms "susceptible" and resistant" should be avoided.

A further example of this variation was provided by an experiment in which 20 plants, each of four cultivars, were planted at 2-month intervals from May 1978 to January 1979 at CIAT-Palmira. Plots were harvested in August and October 1979, with sufficient plants harvested each time for 20 roots to be obtained per evaluation per plot. Ten roots were evaluated for their Det. %, the remainder being used to determine specific gravity, cyanide and root fiber content.

The Det. % of the four cultivars examined was not stable during the experimental period, although in both harvests M Col 22 was consistantly more susceptible to physiological deterioration than the other three cultivars (Table 2). Plant age did not appear to affect deterioration, although both M Ven 218 and CMC-40 did decrease in Det. % with age in the October harvest only. M Col 22, the cultivar with the highest Det. %, also had the highest dry matter content, thus agreeing with previous findings that the two are positively correlated (CIAT, 1977).

The total and free cyanide contents of the root tissues varied greatly, but there was no general significant correlation between either of these parameters (fresh or dry weight basis) and the Det. %, although isolated significant results did occur. There was no correlation between Det. % and the root fiber content. Further experiments, in which the Det. % and cyanide content were determined in individual roots, also failed to find any general correlation between the two parameters.

Location effects on physiological deterioration

Since at one site a range of Det. % values were found for one cultivar over a 2-year period, the possibility that pre-harvest or post-harvest environmental components could affect the deterioration was investigated using an experiment in five diverse Colombian edapho-climatic regions (Table 1). Three plots of 30 plants of each of 26 clones were planted at CIAT-Palmira and four regional sites. The 26 cultivars included representatives from each of the experimental regions and some CIAT-produced hybrid. All cultivars were planted at each site, although not all produced storage roots. No pest control, disease prevention or irrigation beyond the initial establishment period was used to fully expose plants to the prevailing environmental conditions. Plants were harvested at 12 months, except at the cold-climate site of Popayán (15 months). Ten roots per cultivar were selected at random from the three plots and evaluated for physiological deterioration. Root specific gravity and cyanide content (picrate paper method, IITA, 1974) were also determined.

Table 2. Deterioration (%) of M Col 22, Llanera, CMC-40 and M Ven 218 at each of five ages harvested in August and October 1979 at CIAT-Palmira.

		Cultivar			
Harvest	Age	M Col 22	Llanera	CMC-40	M Ven 218
August	7	66.3	27.7	8.6	22.0
	9	70.9	32.7	31.1	13.7
	11	65.9	18.4	19.3	32.0
	13	87.0	22.3	17.7	14.0
	15	76.3	26.9	10.3	25.4
mean		73.3	25.6	17.4	21.4
October	9	84.1	13.3	27.1	40.9
	11	61.7	28.0	18.9	35.3
	13	57.9	6.6	5.9	15.4
	15	70.3	15.7	6.0	9.1
	17	37.7	19.3	11.3	7.7
mean		62.3	16.6	13.8	21.7

Results are for the 20 clones which produced roots in all five sites (Table 3). At CIAT-Palmira a wide range of Det. % was observed, although the overall mean Det. % was rather low (26.3%) and only three cultivars exceeded 60%. At Carimagua, situated in a region in intense climatic, edaphic and biotic stresses, all cultivars were resistant, 12 of them totally so. Similar results were obtained following evaluations at the two sites on the north coast of Colombia, Media Luna and Caribia, although the resistance was not so complete as at Carimagua. At Popayán a range of Det. % values was found with a mean of 27.2% but the response of individual cultivars was often different from that at CIAT-Palmira. The correlation between Det. % and root dry matter content as estimated by specific gravity was significant at CIAT-Palmira and Popayán, i.e. at the two sites where a wide range of Det. % values occurred (Table 4).

The effect of pre-harvest environmental stresses on physiological deterioration

In the previous experiment it was observed that plants most resistant to physiological deterioration were in general those which were least adapted to climatic, edaphic and biotic environmental stresses of the site and had consequently suffered defoliation, stunting, dieback.

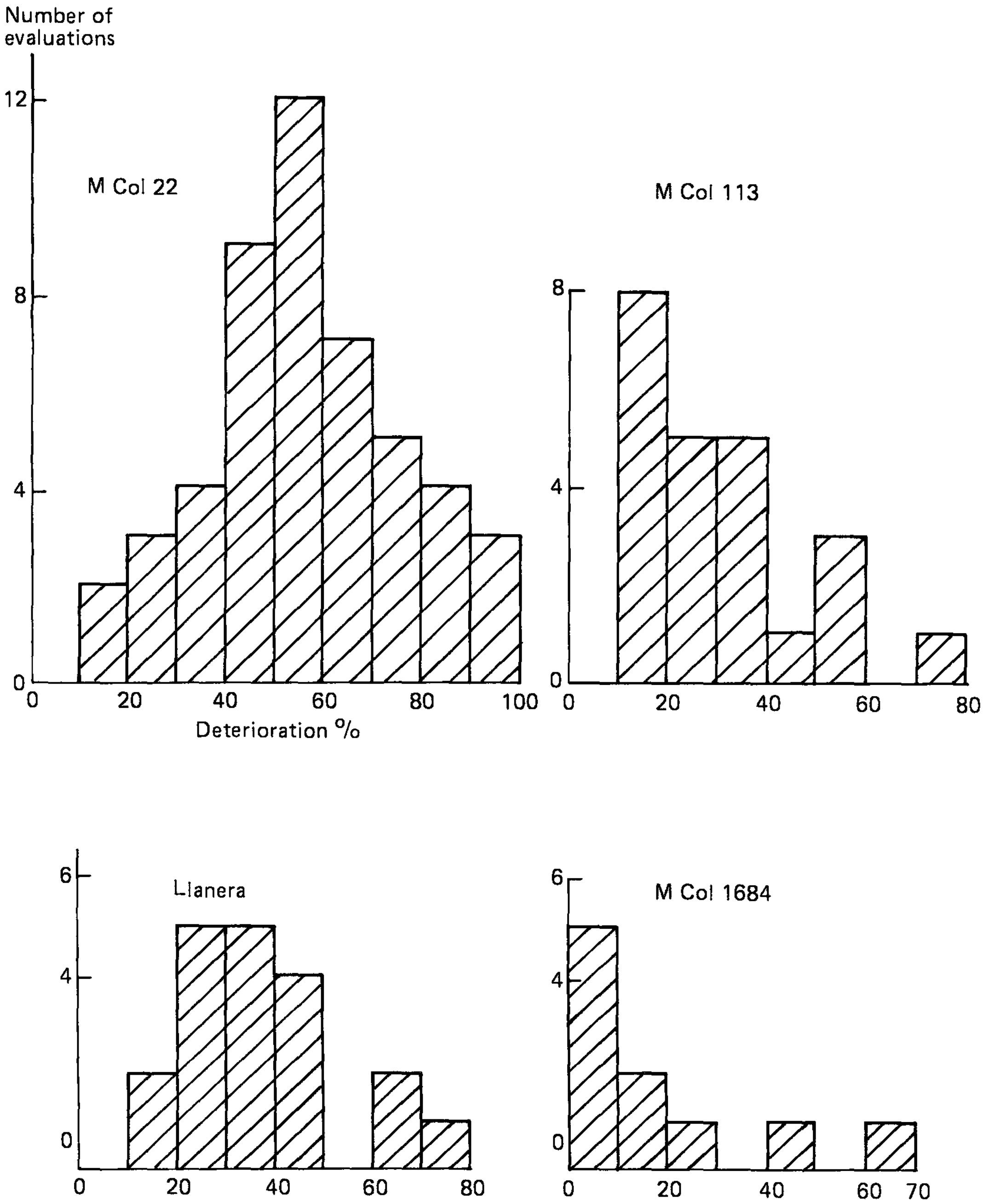

Figure 1. Frequency distribution of Physiological Deterioration Evaluations of Four Cultivars at CIAT-Palmira during 1979-1980.

Table 3. Results of the evaluation of 20 cultivars and hybrids harvested at each of five sites in Colombia as regards their susceptibility to physiological deterioration (%).

Cultivar	CIAT-Palmira	Carimagua	Media Luna	Caribia	Popayán
CM 305-120	32.4	0.0	1.8	1.7	9.3
CM 305-122	69.9	0.3	3.7	2.9	62.9
CM 321-188	60.6	0.0	0.4	4.3	68.3
CM 323-64	19.5	0.0	1.1	0.1	26.0
CM 340-30	29.4	0.0	0.9	0.9	14.4
CM 344-71	18.4	0.0	1.1	0.4	64.5
CMC-40	1.6	0.1	1.8	1.5	8.5
M Col 113	12.0	0.0	3.9	0.3	32.7
M Col 1684	12.7	1.6	1.3	6.5	3.6
M Col 72	50.2	4.0	1.4	1.1	2.3
M Pan 70	15.3	0.0	0.9	0.6	57.5
M Pan 114	2.1	0.0	0.4	1.0	5.9
M Bra 12	23.3	0.0	0.4	0.1	10.2
Sata Dovio	12.6	0.0	2.7	0.2	72.0
Reg. Negrita	31.6	0.0	0.9	0.1	34.3
M Col 22	90.1	0.0	1.4	1.7	3.8
M Col 638	27.1	0.2	1.1	0.6	8.8
M Pan 19	5.7	0.1	2.5	26.9	30.9
M Equ 82	8.4	1.1	1.8	1.8	4.1
M Ven 77	3.0	0.3	1.6	6.9	24.7

Table 4. Correlation coefficients for the relationship between deterioration (%) and dry matter content calculated for each site.

Site	n	Correlation coefficient, r
CIAT-Palmira	26[1]	0.68 ***[2]
Popayán	23	0.56 **
Caribia	25	0.37
Carimagua	23	0.26
Media Luna	26	0.34

[1]All cultivars evaluated for both parameters were used, hence variable n.

[2]Significant at ** $P \leq 0.01$, *** $P \leq 0.001$.

This possible relationship between environmental stresses and the level of physiological deterioration was investigated further at Popayán during 1980. The cultivars chosen included several native to Popayán or similar regions (Regional Negrita, Regional Amarilla, Sata Dovio, CMC-92) as well as some from hot, lowland areas (M Mex 59, M Col 22, M Col 1684). Plots were planted at 3-month intervals in 1978/79 for harvesting 15 months later.

The Det. % did not remain constant throughout the year (Table 5). The locally adapted cultivars increased in susceptibility, as did the less adapted group to a lesses extent. The non-local cultivars, however, maintained a high level of resistance throughout the experiment. The changes in deterioration correlate well with changes in other pre- and at-harvest characters (Table 6). The adapted cultivars increased in yield, foliage weight and dry matter content and defoliation decreased due to improving climatic conditions in line with their increasing susceptibility to physiological deterioration. The non-adapted cultivars, however, consistantly yielded low root and foliage weights and dry matter contents as well as being totally defoliated. In an environment of variable stresses, the fluctuations in susceptibility to physiological deterioration thus here follow the changing status of the preharvest crop.

Table 5. Deterioration (%) of 10 cultivars harvested during 1980 at Popayán.

		Harvest			
Cultivar		March	April	July	September
1.	Regional Amarilla	7.7	10.1	82.6	84.1
2.	Regional Negrita	1.9	31.9	34.3	80.7
3.	Sata Dovio	[1]	46.0	72.0	62.4
4.	CMC-92	3.6	11.1	33.3	78.6
5.	CMC-29		43.9	65.4	62.0
6.	CMC-40		27.0	8.5	41.7
7.	M Col 113		37.3	32.7	72.9
8.	M Mex 59		6.3	2.1	6.0
9.	M Col 22		- [2]	4.0	0.0
10.	M Col 1684		-	3.9	2.9

[1]Not included in this harvest.

[2]Insufficient roots produced for evaluation.

Table 6. Correlations between deterioration (%) and other plant characters.

	Harvest		
Character	April	July	September
Dry matter %	+0.23	+0.69* [1]	+0.81**
Defoliation %	-0.50	-0.83**	-0.88***
Foliage weight (kg plant^{-1})	+0.17	+0.80**	+0.80**
Yield (tons ha^{-1})	+0.10	+0.80**	+0.90***

[1]Significant at * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$.

To test effects of a period of water stress on the level of physiological deterioration of cassava roots, plants of M Col 22 and Secundina were grown individually in plastic containers with a 50:50 mixture of CIAT soil and sand. After 7 months growth, plants were subjected to differing levels of water stress (100%, 60%, 30%, and 10% soil moisture content) for one month, a period sufficient to produce defoliation in the plants of the most severe treatment. Roots from six replicate plants per treatment were harvested after the 1-month stress period. All stress treatments resulted in a significant reduction in the Det. % of the roots compared with the unstressed controls (Table 7), showing that a period of stress can induce resistance to physiological deterioration. The control plants did not, however, produce the high levels of deterioration usually encountered, at least in M Col 22 (compare with Figure 1). This was probably caused by stresses associated with growth restrictions imposed by container size.

Table 7. Effect of defoliation resulting from a period of controlled water stress on the deterioration (%) of roots of M Col 22 and Secundina grown in individual containers at CIAT-Palmira.

Treatment	M Col 22	Secundina
100% soil moisture content[1]	22.23 a[2]	27.17 a
60% soil moisture content	1.01 b	0.17 b
30% soil moisture content	1.63 b	1.34 b
10% soil moisture content	4.94 b	2.38 b

[1]Approximate values, monitored using a Bouyoucus meter.

[2]Means with the same letter were not significantly different ($P \leq 0.01$) when tested using Duncan's multiple range test.

The previously noted effect of pre-harvest pruning on the susceptibility of roots to physiological deterioration can thus also be seen as a stress-related response. The necessity of postulating a translocatable factor is thus removed. Roots of M Col 22 evaluated after various times between pruning and harvest showed a prolonged resistance to physiological deterioration even when there was no removal of regrowth (Table 8). The resistance continued up to 9 weeks after pruning, when regrowth had reached 0.44 kg/plant (fresh wt.). Associated with the decrease in susceptibility to physiological deterioration was a decrease in root dry matter content from 36.0% to 32.5% during the 9 week period, presumably due primarily to the utilization of root carbohydrate reserves to form the new foliage. The application of gramoxone to the cut stump to inhibit regrowth appeared to lessen this loss of dry matter while not affecting the acquisition of resistance to physiological deterioration, at least during the first 5 weeks of the experiment. Long-term resistance to physiological deterioration and a decrease in dry matter content were also found in 10 cultivars harvested at CIAT-Palmira (Table 9), suggesting that the effect is general.

Table 8. Effect of pruning with and without partial herbicide suppression of regrowth on the deterioration (%) in roots from M Col 22 plants on six dates over a 2-month period.

Pruning-harvest interval (days)	Control	Pruned	Pruned + Gramoxone	Mean
2	60.1	52.0	34.9	49.0
4	42.4	29.3	25.9	32.5
8	54.3	24.1	18.9	32.4
16	59.7	20.0	16.7	32.1
32	48.3	6.6	5.3	20.0
64	47.3	12.7	11.1	23.7
Mean	52.0	24.1	18.8	

Table 9. Changes in susceptibility to physiological deterioration (%) and in root dry matter content following pre-harvest pruning of 10 cultivars harvested at CIAT-Palmira.

	Pruning-harvest interval (weeks)					
	0 (unpruned control)		2	6	9	
Cultivar	Det. %	Dry matter %	Det. %	Det. %	Det. %	Dry matter %
CM 305-120	32.4	29.7	1.6	0.0	0.0	28.0
CM 305-122	69.9	40.2	20.0	1.4	6.4	42.1
CM 344-71	18.4	33.4	0.4	0.0	0.1	26.8
M Col 22	90.1	34.7	1.1	0.1	0.0	31.7
M Col 113	12.1	36.4	1.7	0.0	0.0	23.4
M Col 638	27.2	33.1	1.7	0.1	0.1	25.2
CMC-40	1.6	29.2	2.7	0.2	0.0	22.4
Llanera	0.6	24.2	1.9	0.1	0.0	21.7
Ven 77	3.0	29.7	2.4	0.0	0.0	26.5
CMC-92	24.6	30.0	2.3	0.0	0.0	19.5
Mean	28.0	32.1	3.6	0.2	0.7	26.7

Conclusions

The method used in these studies for the assessment of physiological deterioration permits standardization of mechanical damage and avoidance of microbial contamination through a short 3-day storage period, unlike some previously used methods in which these variables were not standardized. Hence the substantial variation in response obtained by several workers is hardly surprising.

Results show the pre-harvest environment is the major variable which determines the susceptibility of roots to physiological deterioration once other variables (damage, fungal contamination) are removed. Defoliation, whether due to insect, disease or drought stresses, or pruning, induces resistance to physiological deterioration but also leads to a lower root dry matter content once regrowth occurs. Thus, the correlation between these two characters is clearly not causal but the result of parallel plant stress response mechanisms.

The terms "susceptible" and "resistant" are often applied to varieties following one or a few evaluations of physiological deterioration. Results show that, as the environmental component is of overriding importance, repeated evaluations in a number of environmentally different sites would be necessary before any genetically based "resistance" could be confidently reported. One would expect locally-adapted cultivars to show a maximal expression of susceptibility in their native regions. Similarly, plants to be evaluated should be in an unstressed state (i.e. disease and pest-free and with adequate water supply) particularly in the immediate pre-harvest period. The pre-harvest environment could be crucial in determining susceptibility since the standard CIAT "susceptible" cultivar, M Col 22 could be "resistant" even at CIAT-Palmira. This could have an important bearing on harvest time in some localities where natural defoliation, which should produce resistant roots, occurs as a result of seasonal climatic conditions.

The use of pre-harvest pruning to induce resistance needs further study, especially as regards quality, before any commercial recommendations can be made. However, the inhibition of regrowth, and hence of carbohydrate reserve depletion, could be a promising treatment. Presumably, some reduction in root quality would be acceptable given an increased root storage life: economic analyses of this are necessary.

Acknowledgements

C.C. Wheatley thanks the Tropical Products Institute for providing the postgraduate studentship, the Centro Internacional de Agricultura Tropical (CIAT) for use of the research facilities and R.A. Laberry for help with the field experiments. C.C. Wheatley,; J.C. Lozano, and W.W. Schwabe acknowledge their gratitude to John Marriott whose death occurred while this work was in progress.

References

Averre, C.W. Vascular streaking of stored cassava roots. Proceedings of the 1st International Symposium of Tropical Root and Tuber Crops, Trinidad, 1967. 2, 31-35.

Booth, R.H. Storage of fresh cassava I. Post-harvest deterioration and its control. Experimental Agriculture, 1976. 12, 103-111.

Booth, R.H. Storage of fresh cassava II. Simple Storage Techniques. Experimental Agriculture. 1977. 13, 119-128.

CIAT. Cassava Program Annual Report 1976. Cali, Colombia, 1977.

CIAT. Cassava Program Annual Report 1979. Cali, Colombia, 1980.

Cooke, R.D. An enzymatic assay for the total cyanide content of cassava (Manihot esculenta Crantz). Journal of the Science of Food and Agriculture. 1978. 29, 345-352.

Cooke, R.D., A.K. Howland, and S.K., Hahn. Screening cassava for low cyanide using an enzymatic assay. Experimental Agriculture 14. 1978. 327-342.

FAO. Production Yearbook 1980. FAO, Rome, Italy. 1980. Vol. 34.

IITA. Screening for acyanogenesis in cassava. IITA, Ibadan, Nigeria. Technical Bulletin No. 4. 1974.

Lozano, J.C., J.H. Cock, and J. Castaño. New Developments in Cassava Storage. In Proceedings of the Cassava Protection Workshop, held at CIAT, Cali, Colombia. Ed. Cock, J.H.; MacIntyre, R., and Graham, M. IDRC, Ottawa, Canada, IDRC-080e. 1978. pp. 156-160.

Marriott, J., B.O. Been, and C. Perkins. The Aetiology of Vascular Discoloration in Cassava Roots after Harvesting: Association with Water Loss from Wounds. Physiologia Plantarum 44. 1978. 38-42.

Marriot, J., B.O. Been, and C. Perkins. The Aetiology of Vascular Discoloration in Cassava Roots after Harvesting: Development of Endegenous Resistance in Stored Roots. Physiologia Plantarum 45. 1979. 51-56.

Montaldo, A. Vascular Streaking of Cassava Root Tubers. Tropical Science 15 (1) 1973. 39-46.

Wholey, D.W. and R.H. Booth. A comparison of simple methods for Estimating Starch Content of Cassava Roots. Journal of the Science of Food and Agriculture 30. 1979. 158-164.