Physiological Studies on Postharvest Deterioration of Cassava Roots

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Introduction

Various tuber crops are cultivated or grow wild in the tropics. Except cassava and sweet potato, they are minor crops. Cassava, amounting to 130 million tons in terms of yearly production throughout the world,[8] is one of the most important tuber crops, especially in tropical regions. It is mainly produced in the developing countries and used as main staple foods, feedstuffs and industrial materials. It has many useful agronomic characteristics such as tolerance to high acid soil and drought condition. However, many problems related to its storage and processing remained unsolved.[7,18,24,30]

The rapid postharvest deterioration of cassava roots is well known,[24,30] and it is generally understood that there are 2 distinct types of deterioration.[1-6,15,18-21,23,29,30,37] To protect the roots from these deteriorations, it is important to elucidate the mechanism of the deterioration from the physiological, pathological and biochemical view points, as described in our reports.[10-13,32-36]

During 1981 to 1984, experiments focused on the postharvest handling of cassava roots were carried out by Japanese and Filipino scientists in cooperative works at Visayas State College of Agriculture, Baybay, Leyte, Philippines.

This paper summarized mainly the results of physiological studies of postharvest deterioration.

Detailed observation of the postharvest deterioration process in cassava roots

The root deterioration was classified into primary deterioration and secondary deterioration by Booth,[4], while, Lozano et al.[18] reported them as physiological and microbial deterioration.

The secondary deterioration named by Booth,[4] which is caused by microorganism, corresponds to the microbial deterioration reported by Lozano et al..[18] The primary deterioration previously reported as vascular streaking (VS),[21] first appears as fine blue-black or brownish discoloration of vascular bundles and finally results in death and breakdown of root tissues. However, Lozano et al.[18] reported that VS was commonly present with the initiation of microbial deterioration though it was also associated with physiological deterioration. Thus, the delineation of these 2 types of root deterioration was still rather vague when we began to study the postharvest deterioration of cassava roots.

Therefore, our first attempt was to observe in more detail the incidence of these 2 types of deterioration and to study the relation between deterioration process and environmental factors.

1) *Physiological and microbial deterioration in cassava*

Cassava roots of cv. Golden Yellow (GY) and Hawaiian-5 (H-5) were mainly used. Roots without any damage were selected and stored at temperature ranging from 24 to

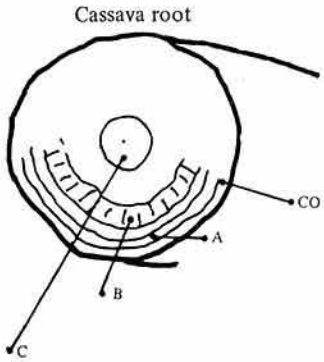

Fig. 1. Four parts of cassava (cv. GY) root, 5 to 6 cm in diameter
CO, cortex (1.0–1.5 mm); A, 2–3 mm just under the cortex; B, 7–8 mm, PD-showing part; C, 16–18 mm in diameter.

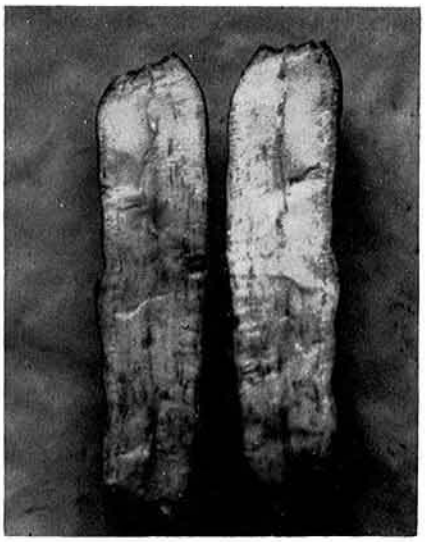

Plate 1–1. Blue-black pigmentation of xylem vessels in the parenchymatous tissue adjacent to regions infected by many kinds of microorganism

30°C and relative humidity ranging from 75 to 90%. Root deterioration was evaluated daily for 5 to 6 days after harvest by using the PRCRTC's scoring method.[10] Two types of deterioration was apparently observed. One was a ring of brownish or blue-brownish coloration occurred in the intervening part (B-part tissue in Fig. 1) between the outermost part (A-part tissue) and the innermost part (C-part tissue) of parenchymatous tissue, while the other was softened and discolored tissues infected by various fungi,[4] and blue-

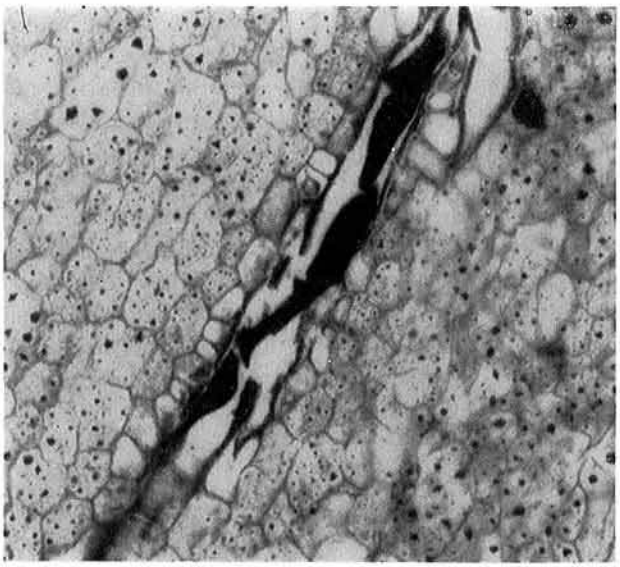

Plate 1–2. Blue-black pigmentation of xylem vessels
Double-stained with FCF.

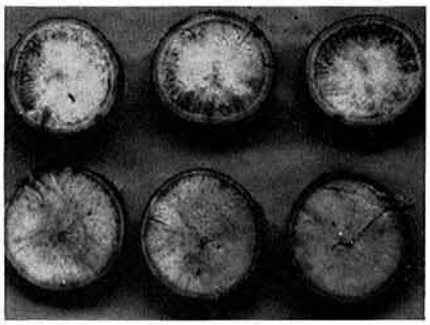

Plate 2. Two kinds of deteriorations
Upper: physiological
Lower: microbial

black pigmentation of xylem vessels in tissues adjacent to infected regions (Plate 1–1 & 1–2). Thus, the 2 types of deterioration are distinguished as physiological (PD) and microbial deterioration (MD), respectively (Plate 2). One to three days after harvest of cassava roots, the physiological deterioration occurs, and a little later MD often appears. It is therefore suggested the assessment of PD should be made not later than 3 to 4 days after harvest so as not to confuse it with MD.[10] Effects of cut and injuries on occurrence of PD were recognized. PD commenced at both cut ends of root pieces, progressing towards the central part, and PD was greater and more rapid in root samples with periderm and cortex removal than intact roots. Moreover, such severe injuries as boring or cortex removal seemed to accelerate MD.[10]

Roots placed in bags deteriorated more slowly than those stored without bagging. The latter lost much more water than the former. It seems that the increase in water loss has some influence on the occurrence of PD and that artificial injury stimulates the development of PD.[10,18,30]

2) *Difference among cultivars in resistance to PD*

Twelve cultivars, 15 months of age, were used to observe the process of PD development. Both roots[a] and tissue blocks[b] 1.5 cm thick were prepared. They were stored in a room (24 to 28°C and 80 to 84% of relative humidity). The degree of PD in both samples was assessed according to the PRCRTC's score.[10]

Table 1 shows the assessment of PD. The degree of PD 3 days after harvest was higher in tissue blocks than roots. A high positive correlation was obtained between the degrees of both samples ($r=0.6079^{*}$), as shown in Fig. 2. However, varietal difference in PD was seen more clearly and earlier by 1 to 2 days in tissue blocks than roots.

The degree of PD observed on the 5th day after harvest showed that most local cultivars, such as GY, Lakan, Vassourinha and Java Brown were susceptible, while cultivars introduced from CIAT were, in general, moderately resistant to postharvest deterioration.

The degree of PD was negatively correlated with moisture content of roots at harvest ($r=-0.7001^{**}$ with roots and $r=-0.5791^{*}$ with tissue blocks) as shown in Fig. 3, and also positively correlated with starch content ($r=0.7455^{**}$ with roots and $3=0.6582^{*}$ with tissue blocks). This result shows, as many works pointed out,[4,18,30] that it is difficult, if not impossible, to find out varieties of low moisture content combined with low PD.

3) *Effects of underground storage and pruning treatment on PD*

Using GY and H-5, effects of underground storage (burying) and pruning at 30 cm above the ground on the occurrence of root PD were examined.[10] Experimental treatments were as follows:

1. Pruning 3 weeks before harvest.
2. Pruning 2 weeks before harvest.
3. Non-pruning.
4. Underground storage for 3 weeks after harvest using artificially injured and healthy roots.

The underground storage was carried out by separately burying healthy and artificially injured roots in clumps about 220 cm in length, 70 cm in width and 25 to 30 cm in depth. As shown in Table 2, for GY, about 84% of the buried healthy roots were still healthy, while most of the artificially injured roots were

a) Intact roots separated from stems
b) Roots transversally sectioned

Table 1. Physiological deterioration rating of 12 cultivars

Cultivar		Nov. 17 PD*	Nov. 18 PD	Nov. 19 PD
Brancha de St. Catarina	T	1.0	1.3	1.8
	R	1.0	–	1.0
Lakan	T	2.8	5.0	5.0
	R	2.1	–	2.8
Bogor 397	T	1.4	2.1	3.3
	R	1.0	–	1.0
Golden Yellow	T	2.1	3.7	3.7
	R	1.7	–	2.2
Vassourinha	T	1.8	3.6	3.5
	R	1.3	–	2.1
Java Brown	T	2.4	3.8	3.8
	R	1.1	–	1.2
M Ven 218	T	1.0	1.3	1.8
	R	1.0	–	1.6
MPTR-26	T	1.0	1.8	2.3
	R	1.0	–	1.4
CM 323-52	T	1.0	1.4	1.8
	R	1.0	–	1.0
CM 308-197	T	1.0	1.8	1.7
	R	1.2	–	1.8
M Mex 59	T	1.4	2.6	2.6
	R	1.0	–	1.0
CMC 40	T	1.0	3.1	2.6
	R	1.0	–	1.6

* PRCRT's score, T: Tissue block, R: Root
All cultivars were plantated on Aug. 9, 1982 and harvested on Nov. 16, 1983.

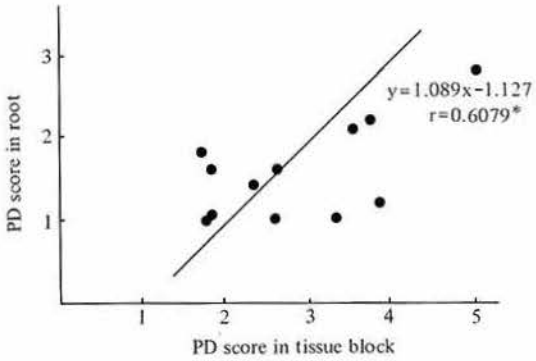

Fig. 2. Relation of the degree of PD between intact roots and root tissue blocks

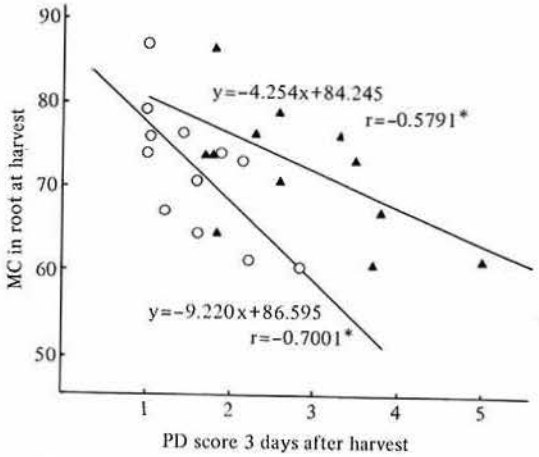

Fig. 3. Relation between the degree of PD and moisture content of roots at harvest
○, the degree of PD in intact roots; ▲, the degree of PD in root tissue blocks

already in decay when pulled out from the soil 3 weeks after burying. For H-5, most of the healthy roots buried were normally in good condition. Even with the injured roots, rotten areas were limited only to naturally or

Table 2. Effect of storage conditions on root deterioration

Storage condition	Root condition	Golden Yellow (GY)			Hawaiian-5 (H-5)		
		No. of roots	Normal %	Microbial rot %	No. of roots	Normal %	Microbial rot %
In room* 3 weeks	Healthy	38	0	100	27	37.0	63.0
	Artificially injured	27	0	100	40	7.5	92.5
In soil 3 weeks	Healthy	38	84.2	15.8	49	100	0
	Artificially injured	26	0	100	51	62.7	37.3

* At temperature 24 to 31°C and relative humidity 75–90%.

Table 3. Effect of pruning and underground storage on starch content of roots (cv. Golden Yellow)

Sample	Total sugar (%)	Soluble sugar (%)	Starch content (%)
1. Starting time of pruning (1st: July 12)	89.2	1.6	78.8
2. Harvesting time (Aug. 2) (1st pruning)	85.1	4.7	72.4
3. Starting time of pruning (2nd: July 19)	91.2	1.6	80.6
4. Harvesting time (Aug. 2) (2nd pruning)	87.3	2.3	76.5
5. No-pruning (Aug. 2)	89.3	1.3	79.2
6. Stored underground (Aug. 2)	93.3	2.6	81.6

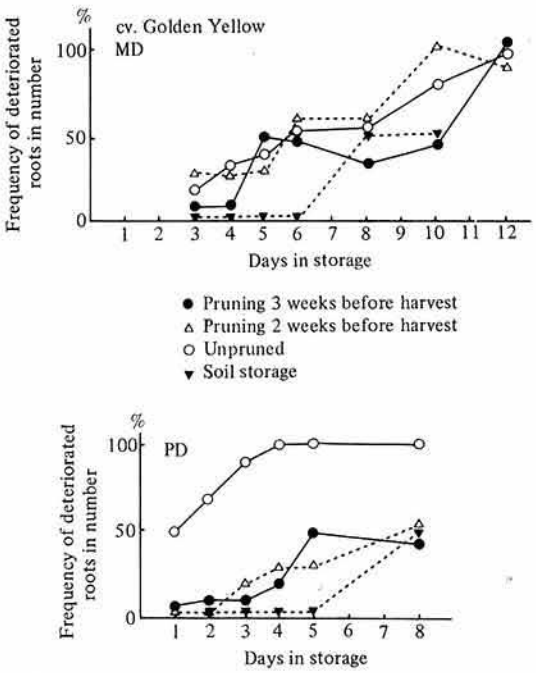

Fig. 4. Effect of pruning treatment practiced 2–3 weeks before harvest and root storage in soil for 3 weeks on root deterioration (cv. Golden Yellow)

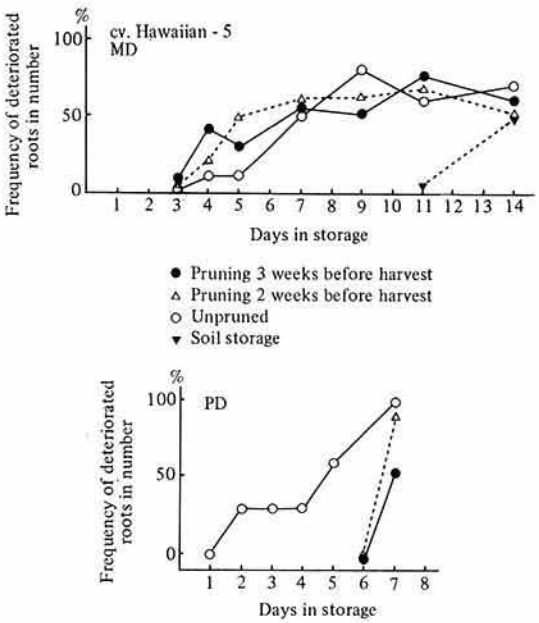

Fig. 5. Effect of pruning treatment practiced 2–3 weeks before harvest and root storage in soil for 3 weeks on root deterioration (cv. Hawaiian-5)

artificially injured sites and the rotten areas hardly expanded. The data proved that H-5 was more resistant to MD than GY.[10]

Effects of pruning treatments on root PD are shown in Figs. 4 and 5, together with effects of burying treatments.[10] With GY, roots taken from pruned plants showed only slight sympton of PD 3 days after harvest though roots from non-pruned plants showed serious PD even 1 day after harvest. With H-5, on the other hand, pruned plant roots did not show any PD indication up to 5–6 days after harvest. But they showed MD appearing 3–4 days after harvest, resulting in complete decay 9 to 10 days after harvest. The roots buried underground for 3 weeks showed almost no deterioration during storage, though some deterioration was observed 11 days after storage in a room.

Studies at CIAT[18,37] showed that pruning reduced the susceptibility to PD for a considerably long period and that MD was prevented by fungicide treatment. In our experiments,[10] pruning was effective in preventing PD, but not MD.

Starch content of the roots of plants pruned prior to harvest was determined by the Somogyi-Nelson method.[31] The starch content was reduced by 3–7% as compared with that of non-pruned plants. It probably is associated with a decrease in root quality (Table 3).[10]

Physiological changes in cassava roots in relation to postharvest deterioration

This section deals mainly with physiological factors affecting postharvest deterioration as well as physiological changes occurring in deteriorated roots.

1) Changes in respiration of cassava roots after harvest

Experiments were conducted to examine the changes in respiration as related to the occurrence of PD after harvest.[12]

Cassava roots were given the treatments shown in Fig. 6, and respiratory rate was measured by using an infrared gasanalyzer. Roots injured by removing cortex or periderm showed apparently higher respiratory rates than intact roots (Fig. 6). Respiratory rates of injured roots reached their peak on the first day of storage except those of the intact roots and root with 25% periderm removal. The respiratory peak of the latter was delayed one day. Then, the respiratory rates decreased

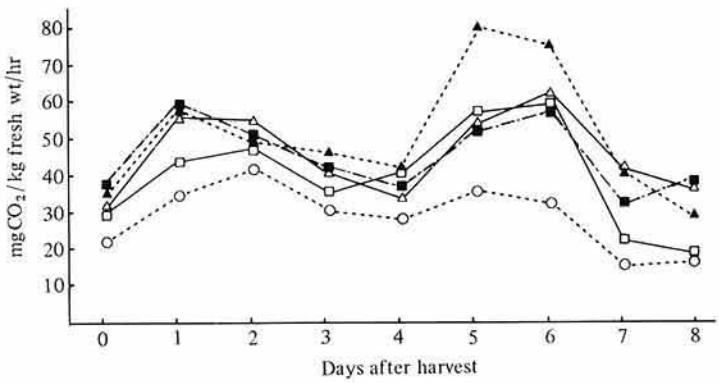

Fig. 6. Respiratory rates of cassava roots with different kinds of injury (25.0°C)
○, intact; □, 10 cm piece, 25% periderm removed; ■, 10 cm piece, 50% periderm removed; △, 10 cm piece, 25% cortex removed; ▲, 10 cm piece, 50% cortex removed.

Table 4. Development of physiological deterioration in cassava roots, which received different injury treatments, during storage at room condition (25.0°C)

Kinds of injury	Place*	Days after harvest			
		3	6	9	12
Control (intact root)	P	1.0**	1.0	1.2	2.0
	M	1.0	1.0	1.3	1.3
	D	1.0	1.0	1.5	1.5
25% periderm removed	P	1.0	1.2	1.2	1.5
	M	1.0	1.2	1.2	1.7
	D	1.0	1.0	1.2	1.5
50% periderm removed	P	1.0	1.8	1.5	1.5
	M	1.0	1.7	1.5	1.5
	D	1.0	2.0	1.2	1.3
25% cortex removed	P	1.3	1.3	1.3	1.7
	M	1.2	1.3	1.3	2.0
	D	1.7	1.3	1.3	2.0
50% cortex removed	P	1.0	2.0	2.0	2.0
	M	1.0	1.2	1.8	2.0
	D	1.0	1.2	1.8	2.0

* P: Proximal, M: Middle, D: Distal. ** PRCRT's score.

gradually until the 4th day after storage when they again turned to increase, reaching their maximum on the 5th or 6th day, except that of intact roots. After that, they decreased again to the low level shown at the time of harvest.

Marriott et al.[19,20] reported that when roots (100 mm long) were injured by removal of periderm, the respiratory rate at high humidity was unaltered but at low humidity it showed an increase after one day. This result accords with the data in Fig. 6, but respiration after 4 days of storage was not shown by Marriott et al..[19,20]

Development of PD in the roots which were treated differently was assessed with the scoring method mentioned before. It was shown that PD developed rapidly in roots with severe injuries such as 50% cortex and periderm removal (Table 4). The rapid development of PD on the 5th to 6th day coincided with the occurrence of the maximum rate of respiration (Fig. 6). On the 8th day, however, the respiratory rate decreased nearly to the level at the time of harvest, although root deterioration developed further.

Passam et al.[25] reported that wound healing in yam was normally accompanied by respiratory increase. Uritani and Asahi[34] mentioned that the upsurage of respiration in mechanically cut root tissues was associated with the healing process of root crops, and that the rate might decrease to the level observed before wounding on completion of the wound-healing layer.

It was presumed that the first peak of respiratory rate observed in cassava roots was due to the wound respiration induced by mechanical cutting and the second peak to biochemical changes induced by the development of PD.[12]

2) Changes in ethylene production and development of PD in cassava roots after harvest

Ethylene is a plant hormone causing metabolic changes in plant tissues.[14] An experiment was done to know whether or not ethylene is produced in cassava roots during storage, and also to know effects of endogenous ethylene, if any, and exogeneous ethylene on the occurrence and development of PD.

A root was cut transversely into slices, 1 cm thick. Each slice was cut crosswise into 4 parts, and 25 g of them were placed in an Erlenmeyer flask (280 ml), which was then sealed with a double stopper and kept at 24 to 27°C. Ethylene evolved from the root

slices in each flask was measured after several hours by a semi-conductor detector gas chromatograph (Sensortec Inc., Ltd.).[22]

Ethylene production began after 15 to 16 hr of incubation, then increased gradually and reached maximum one day after incubation. Ethylene production in cassava root slices was higher than in sweet potato slices (Fig. 7).

Varietal differences in the rate of ethylene production were found among 4 cultivars tested (Fig. 8). CCS-1984 showed the highest value 16 hr after incubation, whereas GY showed the highest 18 hr after incubation. Then, ethylene production in each cultivar decreased gradually, and differences among cultivars disappeared 44 hr after incubation. On the other hand, comparison of ethylene production between deteriorated root slices with PD score of 4.0 and root slices without deterioration showed that the former produced 4 times as much ethylene as the latter (Fig. 9).

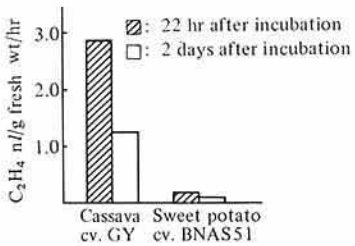

Fig. 7. Ethylene production in cassava root and sweet ptotato root

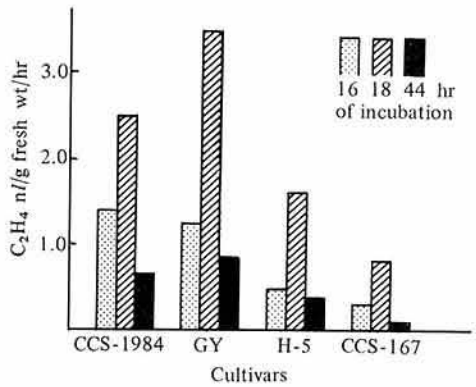

Fig. 8. Varietal difference in ethylene production

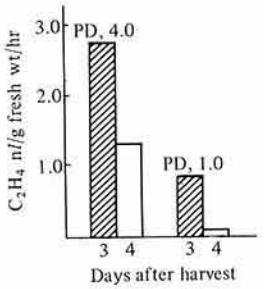

Fig. 9. Ethylene production in cassava root tissue blocks showing PD score of 4.0 and 1.0

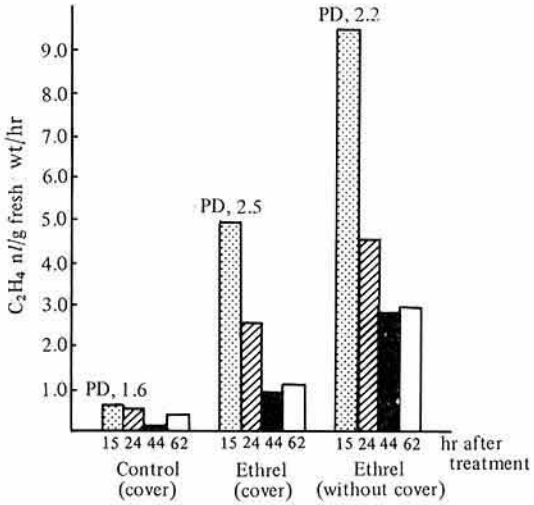

Fig. 10. Ethylene released from ethrel applied and the degree of PD

To clarify effect of exogenous ethylene, ethrel (2-chloroethyl phosphoric acid) solution (20 m*l*, 500 ppm) was sprayed on to 5 root pieces (5 cm in length) with or without a single layer of PVC film (0.03 mm) at both cut ends, and placed in the sealed tubes (2,450 m*l*). Ethylene was released more with root pieces without film cover than with film cover. Ethylene released from ethrel seemed to have a little effect on occurrence and development of PD as shown by PD scores (Fig. 10). Furthermore, to elucidate effect of endogenous ethylene on PD occurrence, tissue

blocks were incubated with or without ethylene absorbent (0.25 M HgO (Red) in 2 N perchlorid acid). Although no endogenous ethylene was detected, a comparison between the treated and untreated tissue blocks showed slight differences in their rate of PD.[35,36] Endogenous ethylene seemed to have no direct effect on occurrence and development of PD.

3) *Relation of respiration and ethylene production to postharvest deterioration in cassava roots from pruned and unpruned plants*

It is well known that pruning is effective in delaying the occurrence of physiological deterioration.[5,10,13,18,20,37] The present author also confirmed it as described in 3) in page 243.

Two weeks before harvest, GY stands were pruned to remove all the green parts leaving only stems 30 cm long. The roots of these plants and of unpruned plants were used to determine respiratory rate and ethylene production soon after harvest or incubation for one to several days in a room at 24 to 27°C and relative humidity of 67–83%.

Measurement of ethylene and respiratory rate was made by the same method as mentioned in 1) in page 246 and 2) in page 247.

Although pruning was confirmed to be effective in delaying the occurrence and development of PD, no clear difference in ethylene production was observed between the root tissue blocks taken from pruned plants and those taken from unpruned plants (Table 5). On the other hand, the respiratory rate of the roots taken from pruned plants was higher than the roots from unpruned plants (Fig. 11).[13]

This result indicates that the decreased PD development indicated by the pruning treatment is associated with the increased respiratory rate of the roots. It is not in consistent with the result (Fig. 6) of the previous work that respiratory rate of roots seems to be promoted by biochemical and physiological changes induced by PD.

Proper methods of preparing root samples for measurements must be find out for further studies.

Table 5. Ethylene production (nl/g fresh wt/hr) in root tissue blocks taken from pruned and unpruned cassava

Treatment and age		Days after harvest		
		1	2	3
1st Exp.	Pruned, 5 months	2.64	2.96	1.80
	Unpruned, 5 months	2.21	1.99	1.26
2nd Exp.	Pruned, 5 months		1.78	1.99
	Unpruned, 5 months		2.08	1.46
	Unpruned, 9 months		3.1.	2.51

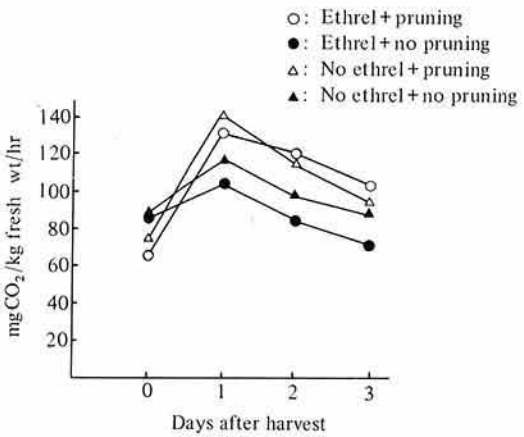

Fig. 11. Respiratory rates of cassava root tissue blocks as affected by combinations of different treatments

4) *Relationships among PD development, respiration and ethylene production in roots*

From the data so far obtained from the present study, the following relationships among PD development, root respiration, and ethylene production in the root are suggested: (1) ethylene production was induced by injury of cassava root tissue, (2) ethylene production was increased much more in the deteriorated root pieces than in the healthy ones, (3) varietal difference in ethylene production exists, (4) development of PD was promoted slightly in root tissue blocks taken from both pruned and unpruned plants by ethrel treatment, (5) respiratory rate in root tissue blocks from pruned and unpruned plants was not stimulated by ethrel treatment. In

addition, same positive correlation between development of PD and respiratory rate, and between development of PD and ethylene production in the root or tissue blocks, respectively, were suggested, but no clear relationship was obtained between respiratory rate and ethylene production, in spite of the fact that the ability of ethylene to stimulate respiration of storage plant tissues and fruits is well known.[9,14,27,28]

Plumbley et al.[26] suggested that ethylene production in cassava tissue blocks increased steadily after an initial lag of 6 hr and that it might affect tissue discoloration not only by altering the respiratory pathway, but also by changing the peroxidase enzymes. Rickard et al.[30] and Uritani et al.[32,34-36] reported that bluish fluorescent and phenolic components were produced in response to cut injury, and in relation to PD, and some enzymes were also formed in cut-injured and physiologically deteriorated tissues. In sweet potato, it was reported that increase in polyphenol content, tissue respiration and activity of some enzymes were accelerated in root slices incubated in ethylene-containing air.[14] Thus, more data should be accumulated to confirm the mutual relationships among ethylene production, respiratory rate and postharvest deterioration of cassava roots.

Summary

A series of experiments were carried out to know the details of root deterioration process, and to examine changes in respiration and ethylene production in cassava roots and tissue blocks in relation to physiological deterioration. The following results were obtained:

(1) Two distinct types of deterioration were observed, one was a ring of brownish or blue-brownish coloration in the intervening part between the outermost part and the innermost part of parenchymatous tissue, and the other was the softened and discolored tissues infected by many kinds of fungus.[4] The 2 types of deterioration are distinguished as physiological (PD) and microbial deterioration (MD), respectively, as described by Lozano et al..[18]

(2) Twelve cultivars, 15 months of age, were tested for susceptibility or resistance to PD. It was proved that varietal difference in PD was seen more clearly and earlier in tissue blocks than intact roots. The degree of PD was negatively correlated with moisture content of roots at harvest, and positively correlated with root starch content.

(3) Pruning treatment, leaving only 30 cm of the stem, practiced 2 to 3 weeks before harvest or burying roots underground for 3 weeks was effective in delaying the occurrence of PD.

(4) Respiratory rates of root pieces taken from artificially injured roots increased rapidly reaching a peak one day after harvest and another maximum peak 4 or 5 days later. The first peak was regarded wound respiration and the second one is caused by biochemical changes related to development of PD.

(5) Varietal difference in respiratory rate was observed.

(6) Ethylene was produced in root slices in detectable concentration 15 to 16 hr after incubation, reaching maximum value after one day of incubation. Varietal difference in the amount of ethylene production was observed.

(7) The amount of ethylene produced in root tissue blocks taken from pruned plants was slightly different from that taken from unpruned plants. Ethrel applied to root tissue blocks showed no or little effect on respiratory rate of the tissue blocks. Only a slight progress of PD was observed in ethrel-treated root tissue blocks. It appears that this tendency was similar to both root tissue blocks taken from pruned and unpruned plants.

(8) Thus, it was difficult to make clear the effect of pruning treatment on ethylene production and respiratory rate of roots, probably due to the use of root tissue blocks as experimental material.

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