THE CHEMICAL COMPOSITION OF CASSAVA LEAVES AND ROOT TISSUES (PEEL AND PARENCHYMA)

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ABSTRACT

The chemical composition, including the proximal composition, starch, sugar, amino acid and cyanide contents of leaves, root peel and parenchyma of four (one local and three promising) cassava cultivars at four plant ages (6, 8, 10 and 12 months) is presented. The local cultivar showed lower leaf and root parenchyma DM contents, lower crude fiber and crude protein levels in root peel, a higher sugar content and lower cyanide concentration in root tissues, than the three promising cultivars. Most of the parameters studied were affected by the cultivar as well as by plant age. Less variability was observed for all criteria in the root parenchyma than in the leaves and root peel. The sulfur-containing amino acids were rather low in the cassava tissues analyzed and a high concentration of arginine was found in the root tissue samples. The cyanide concentration of root parenchyma was less variable than that of leaves and root peel; cv. M Col 1684 showed a higher cyanide content in the parenchyma (900 to 1000 mg/kg DM) than the other three cultivars, which ranged from 100 to 200 mg/kg DM. The local cultivar was the only one in which the cyanide content of leaves was higher than that of the root peel. The hybrid CM 342-170 produced roots with the highest DM and starch contents.

INTRODUCTION

The roots are the main edible product of cassava plants. Whilst only the root parenchyma or pulp is eaten by man, the root cortex or peel is used by itself or as a component of whole-root chips as animal feed. Cassava leaves are also used in some countries as a food vegetable or animal feed.

A great deal of information is available on the chemical composition of the edible cassava tissues (2, 19, 20, 22-24). However, most of the reports deal with the comparison of root composition of different cassava cultivars at a given plant age. Only recently, some studies on the effects of variety and plant age on the chemical composition and quality of roots (11), the starch accumulation in the roots (11, 13, 26, 28) and the cyanide content of plant tissues (7, 11, 12) have been reported.

Despite the extensive literature, reviewed by Hunt et al. (17), on the growth physiology of cassava, the aspects of root quality as related to the plant physiological and the edaphoclimatic conditions under which roots are produced, have received only limited attention. Cassava root quality is crucial, considering its nutritional importance as a human staple food in most of the developing tropical regions and the potential for increasing crop productivity through breeding programs at the International Institute of Tropical Agriculture (IITA) in Africa and the

Centro Internacional de Agricultura Tropical (CIAT) in South America (5, 16, 18).

The aim of the present study was to evaluate the chemical composition, including the proximal composition, starch, sugar, amino acid and cyanide contents, of leaves and root tissues (peel and parenchyma) as produced at four plant ages (6, 8, 10 and 12 months) by four (one local and three promising) cassava cultivars, which were grown under the same edapho-climatic conditions. Information on the interaction of some of the root chemical parameters with the cooking quality and the degree of post-harvest deterioration is presented in the following paper (27). Data on foliage production and composition of these cultivars as potential animal feed as well as the chemical composition of whole-root chips have been reported separately (13-15).

MATERIALS AND METHODS

The soil characteristics, the climatic parameters recorded throughout the study and the cassava growth conditions have been described elsewhere (13). The four cassava cultivars were planted at 1 x 1 m spacing in adjacent fields, each of about 0.4 ha at CIAT in October 1981. The cv. M Col 1684 and M Col 113 (local) are classified as high- and low-cyanide-containing cultivars, respectively; the cv. M Col 22 and the hybrid CM 342-170 are considered as either low- or intermediate-cyanide-containing cultivars (10).

At 2-month intervals, starting in April 1982 (6 months of plant age) and ending in October 1982 (12 months), five plots of about 130 plants each of each cultivar were harvested. At each sampling time, leaves and roots (only those visually classified as commercial by their size and appearance) from the plants of each plot were separately sampled in the field and immediately transported to the laboratories in paper bags. Leaf and root samples were prepared for analyses the same day as harvesting.

The preparation of root parenchyma and peel samples for analyses has been previously described (11). The leaves, without petioles, were diced and manually mixed before samples were taken for analyses. Fresh leaf (10 g), root parenchyma (60 g) and peel (10 g) samples were separately weighed and rapidly transferred into phosphoric acid and homogenized, with the modified extraction solution for leaves (7); total and free cyanide contents were determined in the homogenates using the enzymatic assay (6). The dry matter (DM) content of each tissue studied was determined by drying a weighed sample of each milled tissue to constant weight at 60°C. Additional leaf, parenchyma and peel samples were oven-dried at 60°C and the dried material used for determination of the proximal analysis by the AOAC methods (1). Parenchyma and peel samples were freeze-dried for subsequent analyses of sugars (8) and starch by the acid hydrolysis method (4). Oven-dried samples of tissues from 10-month-old plants of cv. M Col 22 and M Col 1684 were analyzed for their amino acid composition following the techniques described by Blackburn (3).

Data is expressed on a DM basis, or on an air-dry basis for amino acid composition, and analyzed for statistical significance by analysis of variance using the Statistical Analysis System (25); the standard error of the mean or the pooled error mean square have been used as estimations of the standard deviation.

RESULTS AND DISCUSSION

Table 1 summarizes the overall chemical proximal composition of cassava leaves, root peel and parenchyma of the four cultivars studied throughout the period from the 6th to the 12th month of plant age. Usually, cassava roots are harvested when plants are 10- to 12-month-old and most of the data available in the literature has been obtained at these plant ages; however, in many cassava producing areas including the region around CIAT (Wheatley, personal communication) roots are harvested as early as 6 to 8 months after planting.

The chemical parameters evaluated in cassava tissues varied with plant age in all four cultivars. The DM content of leaves, root peel and parenchyma did not follow a general pattern with plant age (Figure 1). The DM content of leaves and root parenchyma of the local cultivar were different ($P < 0.05$) and consistently lower ($P < 0.05$) than those of the promising cultivars; however, such a difference was not observed with the DM content of the root peel (Figure 1).

The changes in leaf DM content were related to changes in climatic conditions affecting leaf production; the lowest rainfall and the highest ambient temperature were recorded when plants were 10-month-old (13). A similar trend was also observed in foliage (leaves, petioles and green stems).

In addition to the DM content, crude protein and crude fiber were also affected by plant age (Figure 2). A clear trend was observed in the leaf protein contents, which declined from the 6th to the 10th month of plant age and slightly increased thereafter, as a response to the rainfall recorded during the 10th to the 12th month period (13). Leaf crude fibre contents did not increase with age, as might have been expected, except in M Col 113, which reached a maximum of 16% DM at 10 months of age (Figure 2).

There were significant ($P < 0.05$) differences between the four cultivars as regards the crude protein and crude fiber contents of the root peel. Both components were lowest ($P < 0.05$) in the root peel of the local cultivar through almost all the period studied (Figure 2). The effects of plant age on the root-peel crude fiber were similar (appart from M Col 22): an increase from the 6th to the 10th month of plant age, with a decrease at 12 months (Figure 2). The crude fiber of root peel of cv. M Col 22 continuously increased throughout the period. The root peel of cv. M Col 1684 had crude fiber contents higher ($P<0.05$) than those of the other three cultivars (Figure 2). There were no clear effects of plant age on the root-peel protein contents; the crude protein contents of root peels ranged from 8 to 12% DM, whereas most of the crude fiber values, except for cv. M Col 1684, varied between 5 and 10% (Figure 2).

The chemical parameters of the root parenchyma were practically not affected by plant age. Crude fiber contents were constant at 2 to 3% DM in all four cultivars (Figure 2). If crude fiber content does increase with plant age, as it is often assumed, then this must occur in plants grown for longer than 12 months (under CIAT conditions). On the other hand, crude protein contents of the root parenchyma differed ($P < 0.05$) among the four cultivars with most values falling in the range of 3 to 5% DM (Figure 2). These levels were higher than those reported in the literature (2, 11, 20, 22, 23, 24), including those found with two cultivars which were previously grown at the same location of the present study (11). However, the two experimental plots used in this and previous studies differed in some soil characteristics. The soil used for the present study had a different texture (clay not sand) and higher levels of phosphorus (72 vs 37 ppm Bray II) and potassium (0.72 vs 0.32 meq/100 g of soil) than the soil used for the previous experiment (11). The possible effect of soil characteristics, such as texture and nutrient levels, on some of the root, and possibly of other plant tissue parameters, would require further research.

The sugar (reducing and total) and starch contents of root tissues as well as the root peel proportion as a percentage of the total root fresh weight are summarized in Table 2. Data have been grouped per cassava cultivar, irrespective of plant age, and viceversa. Apart from the reducing sugar contents of root parenchyma at the four plant ages evaluated, both cultivar and plant age effects were significant ($P < 0.05$) Root parenchyma reducing sugars and the total sugar contents of both parenchyma and peel of the local cultivar were the highest ($P < 0.05$) of the four cultivars evaluated. The classification of local cultivars as sweet varieties may be due to their relatively high sugar contents plus their low root parenchyma cyanide levels. However, the root parenchyma of the bitter cultivar (M Col 1684) had the second highest sugar concentration and the highest cyanide content.

The hybrid CM 342-170 had the highest starch content in the root parenchyma ($P < 0.05$) and the second highest in the root peel, whereas the roots of the bitter cultivar had the lowest starch content in both root tissues (Table 2). The proportion of root peel as a percentage of the total root fresh weight differed ($P < 0.05$) among the cultivars, with M Col 22 and the local cultivar having the highest values and cv. M Col 1684 the lowest. Plant age did not affect the root peel proportion ($P > 0.05$), except for roots of 6-month-old plants (Table 2). At this age, plants had the highest ($P < 0.05$) sugar and starch root peel contents, which then decreased ($P < 0.05$) with plant age. The root parenchyma showed no significant ($P > 0.05$) trend with plant age.

The examination of the climatic conditions recorded throughout the period studied (13) in relation to the effects of plant age or growth on the chemical components, and notably on the root starch content, suggests that when climatic conditions were not favorable for plant growth, such as when the highest ambient temperature and the lowest rainfall were recorded, the storage root starch reserves were mobilized to sustain plant metabolic activities. A decline in the starch content, associated with an increase in sugars as a result of starch hydrolysis, was therefore observed (Table 2).

Table 3 summarizes the amino acid composition of leaf, root peel and parenchyma samples of cv. M Col 22 and M Col 1684. The leaf amino acid composition of these cultivars was similar to that reported for leaves of African bitter and sweet cassava varieties (9) and in both cases, the concentration of the sulfur-containing amino acids were rather low. The amino acid contribution of the root tissues, and notably of the parenchyma which is the edible part of the root for human food, is quantitatively of limited nutritional importance. In both root tissues, the sulfur-containing amino acids tended to be present in the lowest concentration and a rather high content of arginine as well as small amounts of γ-amino-butyric acid were detected. The significance and nutritional implications of these findings need to be further investigated. It has been demonstrated (21) that ^{14}C-labelled hydrocyanic acid, mainly from the cyanogenic glucoside linamarin, in cassava plants was incorporated in the free amino acid pools, with most of the radioactivity being located in asparagine, aspartic acid, glutamine and glutamic acid, but not in arginine. The concentration of arginine in cassava leaves appears to be within the normal range levels, however, those of root tissues are rather high. More detailed studies are required to explain the differences in arginine contents among the cassava plant tissues.

Figure 3 graphycally summarizes the cyanide concentrations in leaf and root tissues of the four cultivars throughout the period studied. The total cyanide contents of root parenchyma of cv. M Col 1684 were the highest ($P < 0.01$), at 900 to 1000 mg/kg DM, compared to those of the other three cultivars which ranged from 100 to 200 mg/kg DM. Changes due to plant age were more noticeable in the root parenchyma of cv. M Col 1684 than in the others (Figure 3). The variation of cyanide content of root parenchyma at each sampling date was less than that observed with the cyanide contents of root peel and leaves, as shown by the size of the standard error of the means (Figure 3).

The cyanide contents of leaf and root peel of each cultivar were always higher ($P < 0.05$) than those of the root parenchyma. The cyanide concentration of the root peel was, at most plant ages and in all but one cultivar, higher than that of the leaves (Figure 3). The local cultivar was the only one in which the leaf cyanide concentration was consistently higher ($P < 0.05$) than in the corresponding root peel at all plant ages evaluated. The variation of the root peel cyanide content of the local cultivar with plant age was less marked than that of the other cultivars with values of 800 to 1200 mg/kg DM for M Col 113 and of approximately 3000 mg/kg for the other cultivars at most of the sampling periods. The cyanide concentration in the root peel tended to increase ($P \leq 0.05$) from the 6th to the 8th or 10th month of plant age and decline thereafter. The maximum root peel cyanide concentrations of cv. M Col 1684 was 4400 mg/kg DM at the 8th month of plant age. Leaf cyanide concentrations did not follow a consistent trend and in most cases the values were in the range of 2000 to 2500 mg/kg DM.

Most of the total cyanide (95 to 97%) of cassava leaves was found as bound or glycosidic cyanide, mainly as linamarin, the predominant cyanogenic glucoside in cassava (21); the remaining 3 to 5% being due to free cyanide components. The free cyanide proportion in root tissues

was always higher ($P < 0.01$) than that found in leaves ($4 \pm 1.6\%$). The root peel of cv. M Col 1684 and M Col 113 had the highest (17 ± 4 and $15 \pm 4\%$) whereas their parenchyma tissue showed the lowest (8 ± 3 and $10 \pm 4\%$) free cyanide proportions as compared to the other two cultivars. M Col 22 and the hybrid CM 342-170 showed free cyanide proportions of 11 ± 4 and $12 \pm 2\%$ in the root peel and 16 ± 5 and $13 \pm 6\%$ in the parenchyma, respectively. The free cyanide proportion did not show a significant trend with plant age in any cassava tissue.

The results of the present study complements those previously reported (11) in that most of the root parenchyma parameters of a given cultivar appear to be less variable than those of other plant tissues (leaves and root peel), as well as little affected by plant age, at least during the normal growth cycle of cassava plants. The inclusion of a local cultivar allowed the detection of some differences in several parameters when compared to those of the promising cultivars. The lowest DM contents, notably of leaves and root parenchyma, as well as of crude fiber and crude protein of root peel, the highest sugar content and the lowest cyanide concentration in root tissues are some of the distinctive features of the local cultivar when grown under similar edaphoclimatic conditions with the other three promising cultivars.

On the other hand, the high DM and starch contents in the roots of the hybrid CM 342-170 reconfirms the feasibility of improving crop productivity through plant breeding programs (18) by producing hybrids with higher DM and starch yields (13), at least under the fertile soil conditions of the present study. Testing of the improved germplasm accesions under the conditions of the principal cassava production regions is necessary before acceptance of these new promising cultivars can be achieved.

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Table 1. Overall chemical proximal composition of cassava leaves, root peel and root parenchyma[1]

Constituent	Leaves			Root peel			Root parenchyma		
	Mean ± SE	Min	Max	Mean ± SE	Min	Max	Mean ± SE	Min	Max
	% on a DM basis								
Dry matter	30.4 ± 2.7	23	28	25.1 ± 2.4	20	31	32.9 ± 3.9	24	40
Crude protein	27.6 ± 3.1	22	35	10.6 ± 2.0	6	17	3.9 ± 1.0	2	6
Ether extract	11.9 ± 2.5	6	19	2.3 ± 0.5	1	4	0.9 ± 0.2	0.6	1.3
Crude fiber	13.3 ± 2.1	10	20	8.4 ± 2.9	4	21	2.7 ± 0.5	2	4
Ash	6.9 ± 0.9	5	10	4.9 ± 1.4	3	10	3.4 ± 0.5	2	5
N-free extract	40.2 ± 3.8	33	51	74.0 ± 5.1	54	83	88.9 ± 1.8	83	94

[1] Each mean is the average of 80 samples (four cassava cultivars, four plant ages and five samples for each cultivar and plant age).

Table 2. Sugar and starch contents of root tissues and root peel proportion (% of total root weight) grouped according to cassava cultivar or plant age [1]

Root tissue and parameter	Cassava cultivar				Plant age (months)				SD
	M Col 1684	CM 342-170	M Col 22	M Col 113	6	8	10	12	
	% on a DM basis								
Root parenchyma									
Reducing sugars	0.85^{b}[2]	0.44^{c}	0.57^{c}	1.90^{a}	0.94	1.05	0.95	0.82	0.36
Total sugars	4.37^{b}	2.20^{d}	2.98^{c}	5.25^{a}	3.72^{b}	3.66^{b}	4.85^{a}	2.57^{c}	0.75
Starch	77.1^{b}	83.8^{a}	78.7^{b}	79.4^{b}	78.8^{b}	81.7^{a}	78.5^{b}	80.1^{ab}	2.67
Root peel									
Reducing sugars	4.16^{a}	3.15^{b}	3.10^{b}	2.68^{b}	4.15^{a}	3.55^{b}	2.94^{c}	2.45^{d}	0.66
Total sugars	6.22^{b}	5.42^{c}	5.25^{c}	7.13^{a}	7.28^{a}	5.80^{b}	6.24^{b}	4.71^{c}	1.16
Starch	44.5^{c}	55.7^{ab}	53.9^{b}	59.6^{a}	59.1^{a}	54.2^{b}	48.6^{bc}	51.7^{b}	5.61
Root peel as % of total root fresh weight	15^{d}	17^{c}	19^{a}	18^{b}	18^{a}	17^{b}	17^{b}	17^{b}	.73

[1] Each value is the mean of 20 samples for either cassava cultivar (five samples at each of four plant ages) or plant age (five samples for each of four cassava cultivars) ± standard deviation ($\sqrt{\text{error mean square}}$).

[2] Values of the same grouping with different letter superscripts differ ($P < 0.05$).

Table 3. Amino acid composition of leaves, root peel and parenchyma of two cassava cultivars

Amino acid	M Col 22			M Col 1684		
		Root			Root	
	Leaves	peel	parenchyma	Leaves	peel	parenchyma
	g/100 g sample, air dry basis					
Asp	2.67	0.400	0.137	2.44	0.514	0.172
Thr	1.08	0.166	0.061	1.06	0.225	0.068
Ser	1.04	0.199	0.086	1.04	0.297	0.088
Glu	2.69	0.739	0.430	2.63	0.924	0.515
Pro	1.25	0.156	0.051	1.23	0.195	0.047
Gly	1.32	0.162	0.059	1.34	0.222	0.058
Ala	1.64	0.219	0.088	1.64	0.283	0.100
Cys[1]	0.30	0.075	0.035	0.34	0.110	0.025
Val	1.45	0.204	0.078	1.46	0.285	0.079
Met[1]	0.46	0.080	0.043	0.47	0.118	0.039
Ileu	1.16	0.148	0.040	1.14	0.209	0.042
Leu	2.21	0.232	0.047	2.20	0.314	0.049
Tyr	1.00	0.144	0.051	0.98	0.194	0.054
Phe	1.36	0.164	0.053	1.35	0.220	0.056
His	0.50	0.184	0.064	0.55	0.238	0.063
Lys	1.45	0.283	0.113	1.49	0.332	0.095
Arg	1.51	3.683	1.174	1.45	2.081	0.385
γ-ABA[2]	0.16	0.065	0.215	0.13	0.068	0.197
Crude prot. Nx6.25 air-dry basis	22.13	10.56	3.63	22.19	9.25	2.88

1 From performic acid hydrolysis, measured as cysteic acid and methionine sulfoxide, respectively.

2 Gamma-amino-butyric acid..

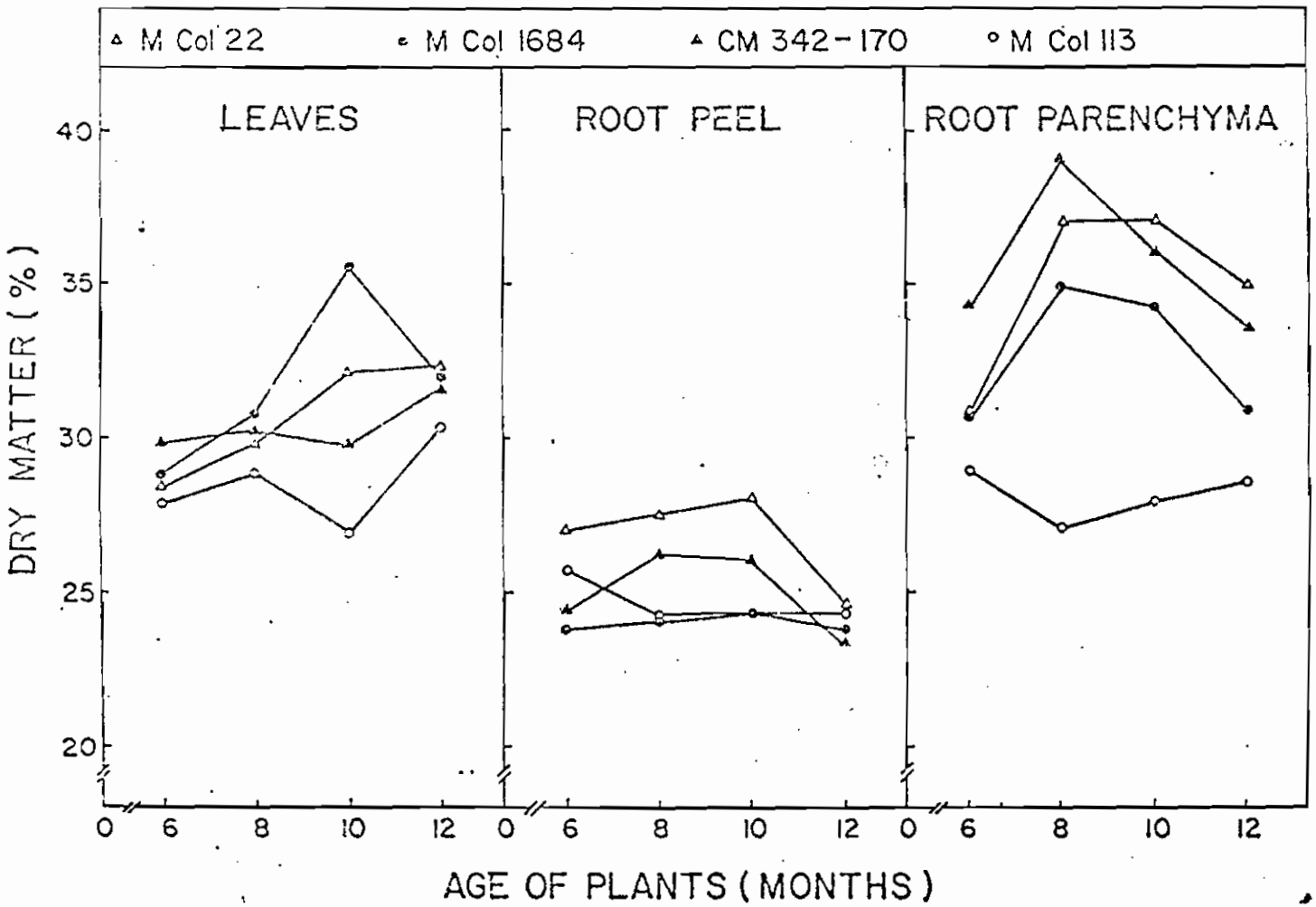

Figure 1. Dry matter content of leaves, root peel and parenchyma of four cassava cultivars as affected by plant age.

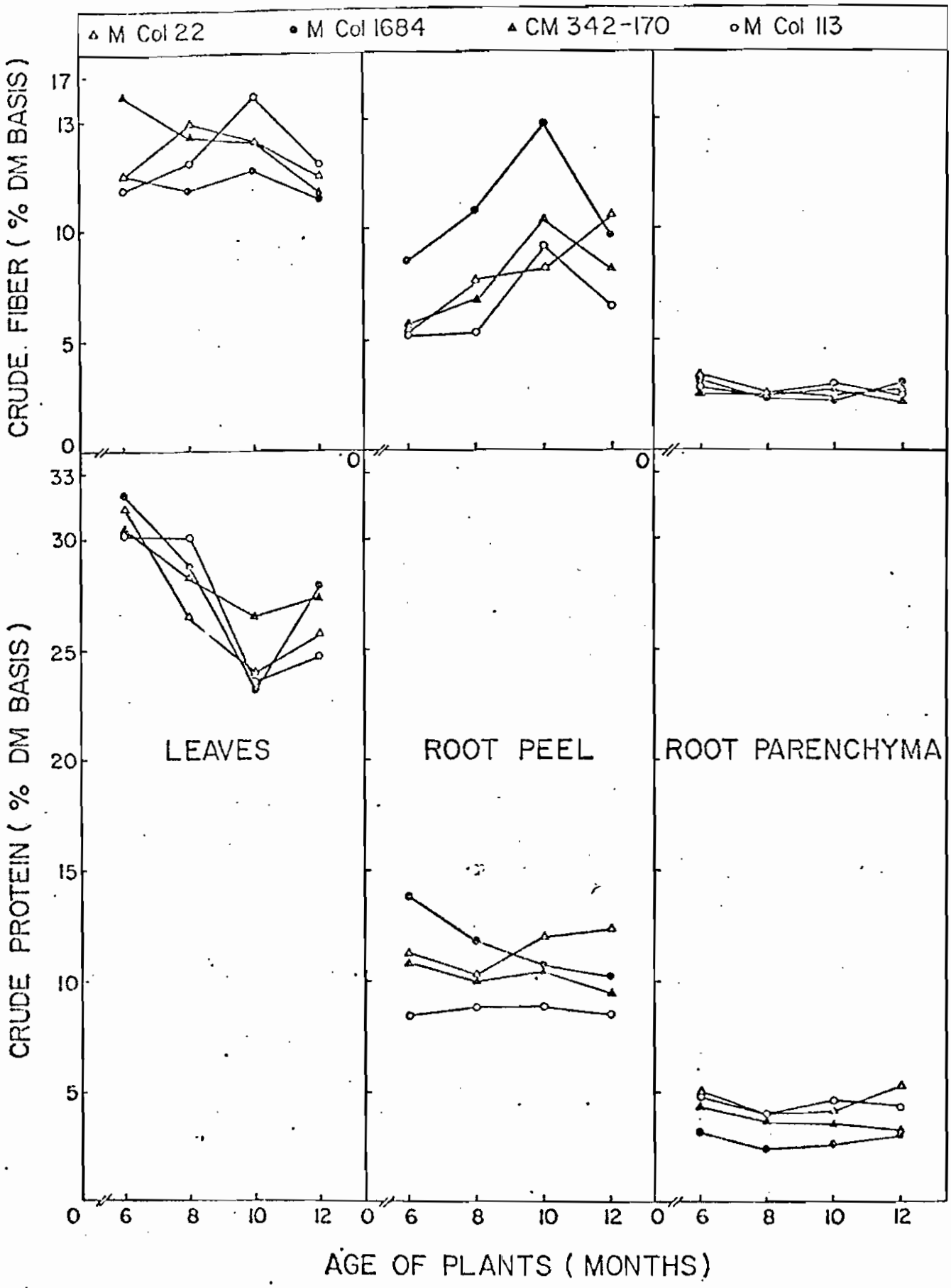

Figure 2. Crude protein and crude fiber contents of leaves, root peel and parenchyma of four cassava cultivars as affected by plant age.

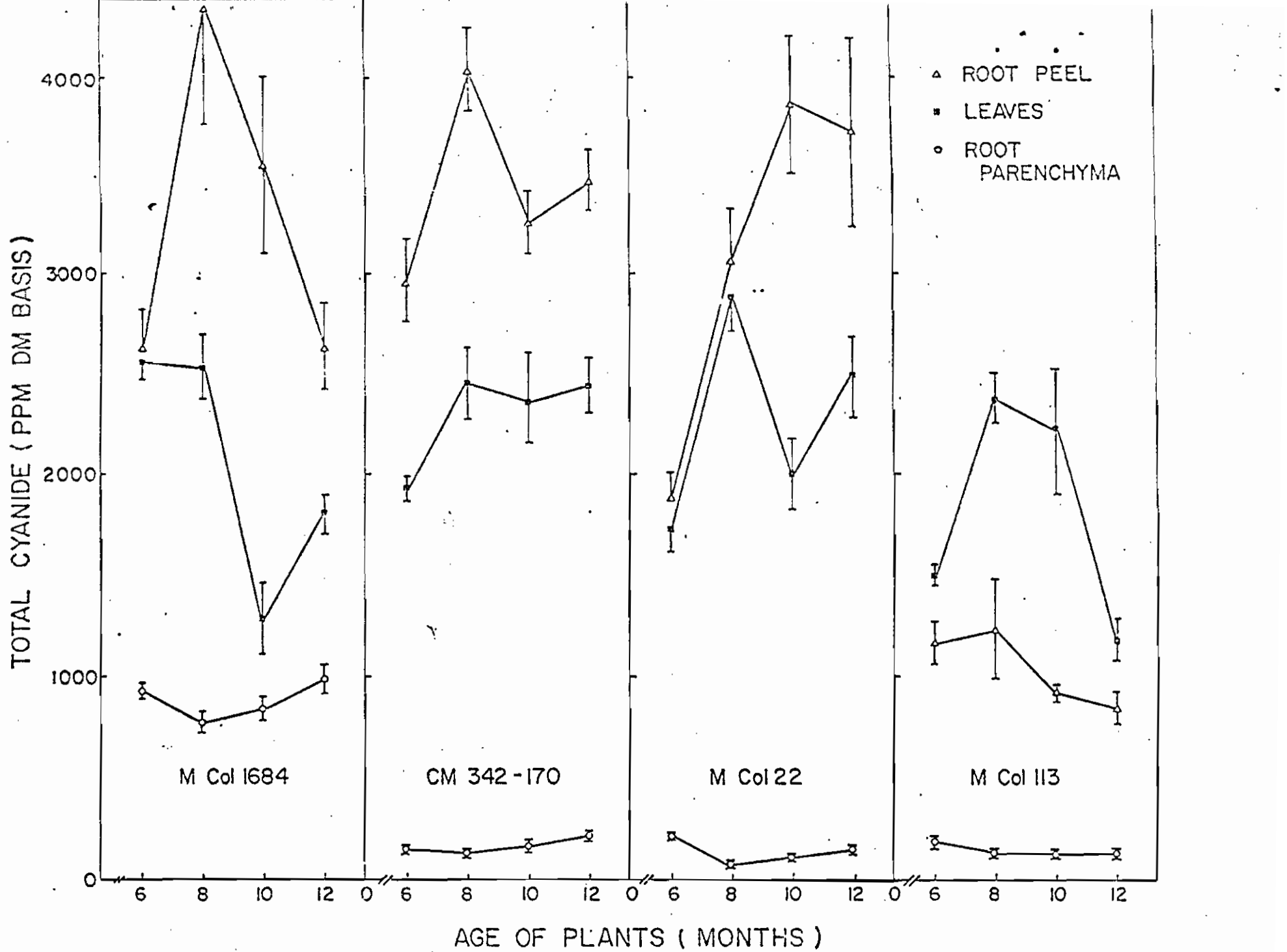

Figure 3. Total cyanide content of leaves, root peel and parenchyma of four cassava cultivars as affected by plant age.