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Biochemical changes occurring during growth and storage of two yam species

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The biochemical changes occurring during growth and storage of two yam cultivars (*Dioscorea rotundata* cv. Oshei and *Dioscorea dumetorum* cv. Jakiri) were studied. Tubers were harvested at monthly intervals from the fourth to the tenth month after 50% emergence of the planted yam setts. For storage studies, Oshei and Jakiri tubers were harvested 9.5 and 9 months post-emergence, respectively. These were stored under prevailing tropical ambient conditions (18–31°C, 62–100% RH) for 1, 2, 3 and 4 months. All samples were analysed for dry matter, crude protein, carbohydrate, essential amino acids and mineral contents. The maximum dry matter was reached in both cultivars 9 months post-emergence, being 40.4 and 26.4%, respectively for Oshei and Jakiri tubers. This was judged to be the optimum time for harvesting. Starch reached maximum values of 86.7 and 78.3 g/100 g, respectively after 6 months. Ethanol-soluble sugars declined from 9.4 to 2.3 g/100 g in Oshei but remained constant at over 6.0 g/100 g in Jakiri tubers during growth. Crude protein values increased slightly to a maximum of 5.4 and 8.0 g/100 g, respectively for Oshei and Jakiri tubers. During storage, weight losses reached 31% in Oshei tubers and 35% in Jakiri after 110 days due to sprouting and dehydration. Starch decreased by approximately 3.5–4.5 g/100 g while sugars and fibre values increased slightly in both cultivars.

Introduction

Yams are plants belonging to the *Dioscorea* genus which produce edible starchy storage tubers. They are staple foods with cultural, economic and nutritional importance in the tropics (Coursey, 1967). The annual production of yams in Cameroon has been estimated by the Ministry of Agriculture to be 420 million tonnes (Anonymous, 1990). Yam tubers being organs with a dormancy period are considered to be the least perishable of tropical root and tuber crops (Passam *et al.*, 1978). However, their storage potential varies greatly between species and the physiological state of the tubers at harvest. The primary cause of post-harvest losses in yams and reduced storage potential is sprouting and microbial rotting (Passam, 1982; Ajayi & Madueke, 1990).

In spite of their importance as a food source there is relatively little information on the biochemical changes occurring during the growth of yam tubers. However, the biochemical changes occurring during the growth of *Dioscorea rotundata* tubers have been widely reported (Sobulo, 1972a, b; Ketiku & Oyenuga, 1973; Trèche & Guion, 1979a; Osagie & Opute, 1981). In addition, there have been only a few studies reported on the biochemical changes occurring during the storage of yams (Trèche &

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Guion, 1979b; Brillouet *et al.*, 1981; Ikediobi & Oti, 1983; Mozie, 1984). In all the aforementioned studies, the yam species and cultivars were often not differentiated from each other and the physiological stage (maturity) and the storage conditions were not always clearly defined.

The object of this study was to investigate the biochemical changes occurring in two yam species during tuber growth and storage under tropical ambient conditions.

Materials and methods

Materials

Yams (*D. rotundata* cv. Oshei and *Dioscorea dumetorum* cv. Jakiri) extensively grown and consumed in Cameroon were selected on the basis of their agronomic characteristics, high starch and crude protein contents from an initial screening of 98 cultivars of Cameroonian yam germplasm (Lyonga & Ayuk-Takem, 1982; Agbor & Trèche, 1983).

Growth studies

Yam setts were obtained from the Institute of Agronomic Research germplasm, Ekona in Cameroon. Preparation of the experimental plots, planting and staking of the yams were according to the recommendations of Ngong-Nassah *et al.* (1980). Tubers were harvested from at least 10 different plants which were randomly selected; this was at monthly intervals from the fourth to the tenth month after 50% emergence of the planted yam setts. At harvest, *D. rotundata* produced one or two large tubers per plant while *D. dumetorum* produced a cluster of tubers containing at least five tubers per plant.

Storage studies

Storage experiments were initiated as soon as the Oshei and Jakiri tubers were harvested at 9.5 and 9.0 months post-emergence, respectively. At these periods of growth, the tubers had reached physiological maturity as indicated by dryness of the yam vine bases and the presence of leaf yellowing or withering. Harvested tubers obtained from each yam cultivar were divided into five groups. One group of tubers was prepared for chemical analyses and the tubers of the other groups were individually weighed and left on shelves in a dark well-ventilated warehouse for 1, 2, 3 and 4 months at prevailing tropical ambient conditions (18–31°C, 62–100% relative humidity (RH)). The mean temperature and relative humidity during the whole storage period was 24 ± 4°C and 81.1 ± 11.4%, respectively; these were recorded throughout the storage periods using a Blick bimetallic strip temperature recorder (Grant Instruments Ltd, Cambridge, UK) and a Testoterm Hydrotest 6200 hygrometer (Testoterm Ltd, Emsworth, Hamphire, UK). Tuber weight losses and the physiological changes that occurred during storage were noted. At each observation, when sprouting occurred, vines with a length greater than 30 cm were cut and the sprouting index determined. The sprouting indices were calculated from the sum of indices (1, budding; 2, sprouts <5 cm; 3, 5–10 cm; 4, 10–30 cm; 5, sprouts >30 cm) obtained at each storage observation.

Sample preparation

Samples obtained from the growth and storage studies for each defined period were peeled, washed, sliced into cubes and vacuum dried at 45 ± 2°C. Prior to chemical analyses the vacuum-dried samples were ground in a Wiley (Christison Scientific Equipment Ltd, Gateshead, UK) mill and sieved (250 μm).

Chemical analyses

Ground samples were analysed in triplicate for moisture, crude protein and ash content using AOAC (1990) methods. Minerals were determined by atomic absorption spectrophotometry, phosphorus levels were evaluated by the vanado-molybdate colorimetric method (Stuffins, 1967) and the iron content was estimated by the ortho-phenanthroline method (Saywell & Cunningham, 1937). The extraction of ethanol-soluble sugars was by refluxing samples (5 g) with 80% ethanol for 120 min. Starch was determined by the Ewers' (1965) polarimetric method using optical rotation coefficients defined for these yam species by Mbome-Lape *et al.* (1982). Estimation of ethanol-soluble sugars was by the Loewus (1952) method while reducing sugars and sucrose sugar levels were determined by the Johnson *et al.* (1964) method as modified by Cerning-Beroard (1975). The acid and neutral detergent fibres were estimated after sample

glucoamylase EC 3.2.1.3 (Sigma Co, Poole, UK; number A7225 from *Rhizopus* spp.) hydrolysis followed by the procedures of Van Soest (1963) and Van Soest & Wine (1967), respectively.

Estimation of amino acids

Ground vacuum-dried samples were defatted with light petroleum (boiling point 60–80°C) and dried in a forced circulation oven overnight. Amino acid analysis of hydrolysates was performed on a LKB 4150 Alpha (Pharmacia LKB Biotechnology, Uppsala, Sweden) automatic analyser. Separation of the amino acids was based on cation exchange chromatography using a stepwise elution with different pH buffers. Post-column detection was with ninhydrin at 570 and 440 nm. Tryptophan was determined separately after hydrolysis in base following the Hugli & Moore (1972) procedure.

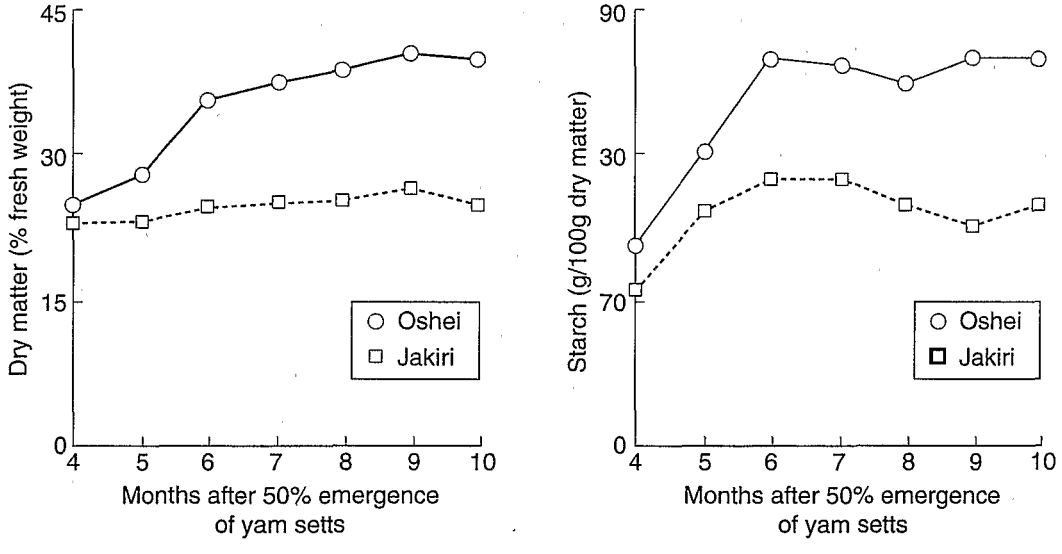
Statistical analysis

Data obtained from the chemical analyses were statistically analysed using BMDP (University of California, Los Angeles, USA) computer software. The statistical techniques used with the computer package are based on those described by Snedecor & Cochran (1980).

Results and discussion

Changes in the chemical composition during tuber growth

Throughout growth, Jakiri tubers had a lower dry matter content than those of Oshei (Figure 1). The maximum dry matter was reached in both cultivars, 9 months post-emergence being 40.4 and 26.4%, respectively, for Oshei and Jakiri tubers. This was judged to be the optimum time for harvesting. Increases in dry matter have also been reported during the growth of *Dioscorea alata* tubers (Sobulo, 1972a; Steele & Sammy, 1976). The starch content increased in both cultivars with age of the plant up to 6 months when peak values of 86.7 and 78.3 g/100 g were found for Oshei and Jakiri tubers, respectively. These peak starch levels decreased slightly to the eighth and ninth months, respectively. Ethanol-soluble sugars declined from 9.4 to 2.3 g/100 g in Oshei tubers but remained constant at over 6.0 g/100 g in Jakiri tubers (Table 1). Previous studies in Nigeria and Barbados also reported high sugar levels during the early stages of growth of *D. rotundata* tubers (Gooding, 1972; Ketiku & Oyenuga, 1973). Reducing sugar contents were found to be very high in both the yam cultivars studied during the early stages of growth. The sucrose content of Oshei tubers was high during



(Each point on the graphs at the different times represents the average values obtained from triplicate analyses)

Figure 1. Changes in dry matter and starch levels during growth of the yam setts.

Table 1. Changes in carbohydrate contents during growth of the yam tubers

	Months after 50% emergence of the planted yam setts						
	4	*5*	*6*	*7*	*8*	*9*	*10*
D. rotundata cv. Oshei							
Ethanol-soluble sugar	9.4^{c}	6.6^{b}	3.0^{a}	4.0^{a}	3.5^{a}	2.7^{a}	2.3^{a}
Reducing sugar	4.6^{c}	2.3^{a}	2.3^{a}	1.2^{a}	0.8^{a}	0.5^{a}	0.4^{a}
Sucrose	5.3^{cd}	4.6^{c}	0.5^{a}	3.1^{bc}	2.8^{bc}	2.2^{b}	1.6^{b}
Neutral detergent fibre	8.9^{c}	6.8^{b}	4.3^{a}	3.6^{a}	2.7^{a}	2.9^{a}	3.3^{a}
Acid detergent fibre	4.4^{b}	3.3^{ab}	2.6^{a}	2.7^{a}	2.5^{a}	2.1^{a}	2.3^{a}
D. dumetorum cv. Jakiri							
Ethanol-soluble sugar	6.1^{bc}	5.2^{ab}	4.8^{a}	5.8^{abc}	6.0^{bc}	6.6^{c}	6.8^{c}
Reducing sugar	3.2^{b}	1.5^{a}	0.9^{a}	0.8^{a}	0.8^{a}	1.0^{a}	1.0^{a}
Sucrose	3.6^{a}	3.7^{a}	3.4^{a}	3.1^{a}	4.2^{a}	5.4^{b}	5.5^{b}
Neutral detergent fibre	8.3^{c}	4.7^{ab}	4.2^{ab}	3.8^{a}	4.4^{ab}	4.9^{ab}	5.4^{b}
Acid detergent fibre	6.7^{b}	4.5^{a}	4.0^{a}	3.5^{a}	4.0^{a}	4.2^{a}	3.9^{a}

Mean values (g/100 g, on dry weight basis) of triplicate analysis. Values within a column with the same letter are not significantly different at the 5% level.

the early stages of growth but decreased with later dates of sampling. The trend in sucrose levels found in this study is similar to that reported for potato growth studies (Mazza *et al.*, 1983). Neutral and acid detergent fibre contents of Jakiri tubers were very high during the early

Table 2. Changes in crude protein and essential amino acid contents during growth of the yam tubers

	Months after 50% emergence of the planted yam setts						
	4	*5*	*6*	*7*	*8*	*9*	*10*
D. rotundata cv. Oshei							
Crude protein[a]($N \times 6.25$) (g/16 g nitrogen)	4.5	4.6	4.6	4.7	5.3	5.2	5.4
Isoleucine	nd	nd	4.1	4.2	3.7	3.4	3.3
Leucine	nd	nd	7.7	8.1	6.9	6.5	6.6
Lysine	nd	nd	4.8	5.6	4.5	4.6	4.5
Methionine + cysteine	nd	nd	3.4	3.3	3.0	3.2	3.1
Phenylalanine + tyrosine	nd	nd	7.5	8.6	6.9	7.5	8.0
Threonine	nd	nd	4.1	4.2	3.7	3.6	3.5
Tryptophan	nd	nd	1.0	0.9	0.8	1.2	0.7
Valine	nd	nd	4.3	4.9	4.1	4.2	4.1
Total amino acids[a]	nd	nd	4.3	4.7	4.5	4.4	4.4
D. dumetorum cv. Jakiri							
Crude protein[a] ($N \times 6.25$) (g/16 g nitrogen)	7.2	6.8	6.4	6.8	7.5	7.7	8.0
Isoleucine	nd	4.2	4.3	3.9	4.1	4.1	3.6
Leucine	nd	7.6	8.3	7.4	8.1	8.2	7.3
Lysine	nd	5.1	5.0	5.2	5.3	5.0	4.5
Methionine + cysteine	nd	2.8	3.0	2.8	3.1	2.7	2.7
Phenylalanine + tyrosine	nd	7.4	7.8	6.8	7.2	7.4	8.1
Threonine	nd	4.0	4.7	4.3	4.6	4.3	4.2
Tryptophan	nd	1.2	1.5	1.3	1.2	1.3	1.2
Valine	nd	5.1	5.8	5.4	5.8	5.7	4.9
Total amino acids[a]	nd	6.2	6.2	6.1	7.4	7.4	7.4

[a]This is g/100 g, on a dry weight basis. nd, not determined. Mean values of triplicate analyses.

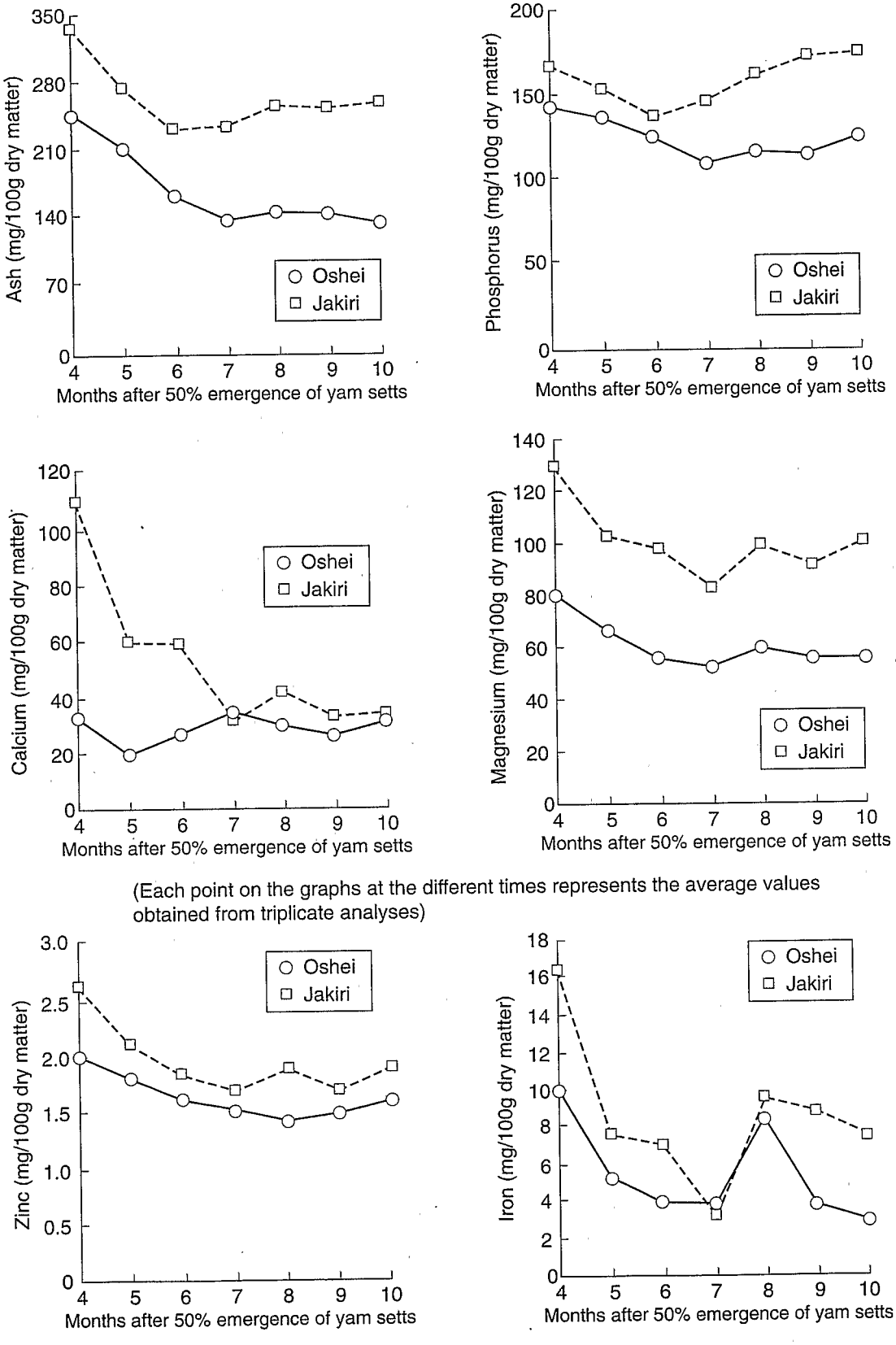


Figure 2. Ash and mineral levels during the growth of the yam setts.

stages of growth but reached lowest levels 7 months after there was 50% emergence of the planted yam setts. Earlier studies also reported that fibre contents were higher in immature yam tubers than when harvested mature (Trèche & Guion, 1979a; Brillouet *et al.*, 1981). In general, the fibre levels obtained for the yam cultivars studied decreased appreciably as the plants aged.

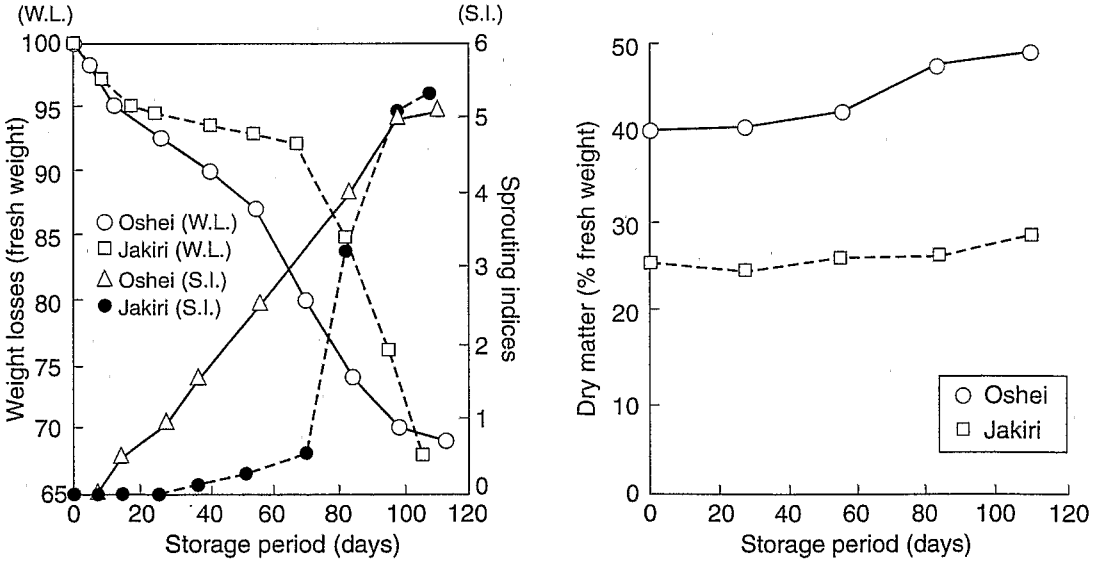
Mineral levels obtained during the growth studies are shown in Figure 2. Ash contents of the yam cultivars decreased between the fourth and seventh months of growth. This observation is similar to that reported during the growth of *D. alata* tubers (Steele & Sammy, 1976). Generally, mineral levels were higher in tubers harvested during the early stages of growth than at later periods of sampling. For most of the minerals estimated, the lowest levels were reached 7 months after planting and they stayed relatively constant in the later months of growth, except for phosphorus and iron.

The crude protein and total amino acid contents of Jakiri tubers were found to be higher than those of Oshei (Table 2). Crude protein values increased slightly to a maximum of 5.4 and 8.0 g/100 g, respectively, for Oshei and Jakiri tubers. Similar increases have been reported earlier for some tropical root and tuber crops (Trèche & Guion, 1979a). The essential and total amino acid levels did not vary much during tuber growth.

The results obtained from these growth studies indicate that the chemical composition of the two yam cultivars studied was affected by the age of the tubers at harvest. In view of the fact that the maximum accumulation of dry matter occurred in both cultivars 9 months after 50% emergence of the planted yam setts, this period can be considered as the optimum time for harvest.

Weight losses and changes in the chemical composition of mature tubers during storage

Tuber weight losses (expressed as a percentage of fresh weight) and sprouting indices obtained during storage under tropical ambient conditions are shown in Figure 3. Total weight losses were 31% for Oshei tubers and 35% for Jakiri after 110 days of storage. In this study, no incidence of decay was found during storage and sprouting occurred earlier in Oshei tubers (after 14 days) than in Jakiri (after 37 days). It was observed that as Oshei weight losses decreased during storage, there were increases in the sprouting indices. However, the weight losses of Jakiri tubers decreased slightly to the seventieth day of



(Each point on the graphs at the different times represents the average values obtained from triplicate analyses)

Figure 3. Tuber weight losses, sprouting indices and dry matter content during storage of the yam tubers.

Table 3. Changes in carbohydrate contents during storage of the yam tubers

	Storage under tropical ambient conditions (18–31°C, 62–100% RH) for the different periods (months)				
	0	*1*	*2*	*3*	*4*
D. rotundata cv. Oshei					
Starch	86.0[a]	85.7[a]	84.8[a]	84.5[a]	82.5[b]
Ethanol-soluble sugar	2.9[a]	2.9[a]	3.3[a]	3.6[a]	5.3[b]
Reducing sugar	0.6	0.9	0.9	0.8	0.7
Sucrose	2.3[b]	0.6[a]	0.5[a]	0.4[a]	2.7[b]
Neutral detergent fibre	2.8[a]	3.3[a]	4.0[ab]	4.9[bc]	6.2[c]
Acid detergent fibre	2.2[a]	2.5[a]	2.7[ab]	3.1[ab]	3.6[b]
D. dumetorum cv. Jakiri					
Starch	75.6[a]	71.1[b]	72.3[b]	73.0[ab]	73.6[ab]
Ethanol-soluble sugar	6.3[a]	8.0[b]	7.1[ab]	7.5[b]	7.5[b]
Reducing sugar	0.9[a]	1.6[c]	1.2[ab]	1.4[bc]	1.6[c]
Sucrose	4.8[a]	6.4[b]	5.5[ab]	5.8[ab]	5.7[ab]
Neutral detergent fibre	4.6[a]	4.2[a]	5.0[ab]	5.9[b]	7.3[c]
Acid detergent fibre	4.1[a]	4.1[a]	4.7[ab]	5.6[bc]	6.3[c]

Mean values (g/100 g, on dry weight basis) of triplicate analyses. Values within a column with the same letter are not significantly different at the 5% level.

Table 4. Changes in crude protein and the essential amino acid profiles during storage of the yam tubers

	Storage under tropical ambient conditions (18–31°C, 62–100% RH) for the different periods (months)				
	0	*1*	*2*	*3*	*4*
D. rotundata cv. Oshei					
Crude protein[a] ($N \times 6.25$) (g/16 g nitrogen)	5.3	6.2	5.6	5.5	5.7
Isoleucine	3.5	3.5	4.7	3.4	4.0
Leucine	6.6	6.8	7.5	6.6	7.6
Lysine	4.6	4.3	5.1	4.7	5.0
Methionine + cysteine	3.1	3.0	3.0	2.8	2.7
Phenylalanine + tyrosine	7.3	6.9	7.9	8.1	8.5
Threonine	3.6	3.5	4.1	3.4	3.8
Tryptophan	1.1	1.2	0.8	0.8	1.3
Valine	4.2	4.0	4.7	4.1	4.7
Total amino acids[a]	4.5	5.0	5.3	4.6	5.4
D. dumetorum cv. Jakiri					
Crude protein[a] ($N \times 6.25$) (g/16 g nitrogen)	7.6	9.0	7.5	8.2	6.9
Isoleucine	4.1	3.2	3.6	4.0	4.1
Leucine	8.1	6.8	7.5	8.6	8.6
Lysine	5.2	4.1	4.3	5.2	5.2
Methionine + cysteine	2.9	2.5	3.1	3.2	3.2
Phenylalanine + tyrosine	7.3	6.1	7.1	8.7	10.8
Threonine	4.5	4.0	4.4	5.0	5.0
Tryptophan	1.2	1.2	1.2	1.4	1.5
Valine	5.8	4.3	4.9	5.5	5.5
Total amino acids[a]	7.4	7.4	6.7	8.3	7.2

[a]This is g/100 g, on a dry weight basis. Mean values of triplicate analyses.

storage, then there was a rapid decrease in the later days of storage which corresponded to a marked increase in sprouting indices. The observed weight losses in the yam cultivars studied were due to sprouting and dehydration. The total weight losses found in this study are comparable to those reported for *D. rotundata* tubers during 3 months' storage in a barn (Mozie, 1981). During storage, dry matter levels increased from 39.9 to 48.5% in Oshei tubers but remained relatively constant at over 26.2% in Jakiri tubers.

Storage caused slight decreases in the starch contents of both the yam cultivars studied while marked increases in ethanol-soluble sugars were found only in Oshei tubers (Table 3). The decreases in starch (3.5–4.5 g/100 g) obtained in this study are very low when compared with values (9.8 g/100 g) reported for cassava roots stored for 7 days in field clamps (Booth *et al.*, 1976). The reducing sugar content was found to increase during storage only in Jakiri tubers. In both the yam cultivars studied, slight increases in neutral and acid detergent fibre contents were found during storage. However, earlier studies reported very high increases in fibre levels during storage of Jakiri tubers (Brillouet *et al.*, 1981; Trèche & Delpeuch, 1982; Sealy *et al.*, 1985). The increases in fibre levels were attributed to yam tuber 'hardening phenomenon' (thickening of cell wall parenchyma, extended cooking time, impaired cooked tuber texture and taste) which occurs a few hours after harvest. Storage did not cause any significant changes in the levels of crude protein and essential amino acids (Table 4). Similar findings have been reported for yam crude protein values during 2 months' storage in a barn (Mozie, 1984) and for total amino acid contents during storage under tropical ambient conditions (Kouassi *et al.*, 1988).

During storage under tropical conditions, marked changes were not observed in the mineral levels of the yam cultivars studied (Table 5). However, slight increases were found in the ash contents of both the yam cultivars. Storage also caused significant decreases in iron content but did not vary very much for calcium and zinc levels.

The results obtained in this study, as compared to those reported for cassava (Booth, 1976) and edible aroids (Agbor-Egbe & Rickard, 1990) indicate that the yam cultivars studied have a potential for long-term storage under tropical ambient conditions without causing highly significant changes in their chemical composition.

Table 5. Changes in ash and mineral composition levels during storage of the yam tubers

	Storage under tropical ambient conditions (18–31°C, 62–100% RH) for the different periods (months)				
	0	*1*	*2*	*3*	*4*
D. rotundata cv. Oshei					
Ash	141^{a}	169^{bc}	180^{c}	161^{b}	168^{b}
Phosphorus	114^{a}	129^{b}	134^{b}	140^{b}	131^{b}
Calcium	27	28	27	32	28
Magnesium	57^{a}	72^{b}	62^{a}	61^{a}	62^{a}
Iron	5.0^{b}	2.1^{a}	1.7^{a}	1.8^{a}	1.6^{a}
Zinc	1.4	1.6	1.6	1.6	1.5
D. dumetorum cv. Jakiri					
Ash	253^{a}	253^{a}	259^{a}	240^{a}	261^{b}
Phosphorus	166^{a}	186^{b}	170^{ab}	172^{ab}	172^{ab}
Calcium	37	36	33	34	36
Magnesium	95	103	100	97	96
Iron	9.1^{c}	5.5^{b}	4.8^{ab}	3.1^{a}	3.5^{a}
Zinc	1.8	1.8	1.6	1.7	1.7

Mean values (mg/100 g, on dry weight basis) of triplicate analyses. Values within a column with the same letter are not significantly different at the 5% level.

Conclusion

In this study, it was found that marked accumulations of dry matter and starch levels occurred in both cultivars 9 and 6 months post-emergence of the planted yam setts, respectively. However, the results obtained indicate that the optimum time for harvesting could be judged to be 9 months after planting. On the basis of qualitative and quantitative losses in food value, both yam cultivars showed relatively lower weight losses and in the nutrients estimated. These studies have shown that the two yam cultivars could provide the dietary requirements for human nutrition.

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