Physical and Chemical Changes in Traditionally Stored Yam Tubers (*Dioscorea rotundata* Poir and *Dioscorea cayenensis* Lam)

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Two yam types, white yam (*Dioscorea rotundata*) and yellow yam (*Dioscorea cayenensis*), were stored for 150 days in the traditional barn and evaluated for changes in physical, chemical, and sensory quality attributes in comparison to the fresh tubers. Losses of moisture, dry matter, crude protein, and ascorbic acid were observed while the total reducing sugars increased concomitantly during the first 120 days and thereafter changes in sprouting and rotting became apparent. The levels of polyphenolic and glycoalkaloid substances in the stored tubers increased and became concentrated at the head regions, which were attributed to their tendency toward discoloration. The improved taste of the cooked stored tuber compared to the fresh tubers was related to the preponderance of sugars in the stored tubers, masking the bitter effect of the residual polyphenol and glycoalkaloids. In order to avoid quality deterioration due to changes in the chemical constituents and nutrient value of the tubers, processors and small-scale farmers should not store the tubers in the barn for a period longer than 120 days.

The yam (genus *Dioscorea*) is an important crop of nutritional and economic significance in the tropical countries, particularly Nigeria, which accounts for 74.5% of the world's output.

The supply of yam, which is mainly for domestic consumption, falls short of demand due to heavy losses during transportation and distribution.

Yam varieties differ in their production requirements, storage characteristics, usage in recipes, and taste. Most yams are readily susceptible to mechanical injury during transportation, weight loss, and fungal decay during retail and distribution. However, yam-growing cultures especially in West Africa have developed traditional storage structures and systems for yam tubers. The basic principles involve keeping uninjured tubers in shaded barns, usually a raised platform, or tying the tubers singly to life poles. Free air circulation is essential for good storage (Coursey, 1967, 1968; Adesuyi, 1971; Adesuyi and Mackenzie, 1973).

Although improved scientific methods of yam storage have been demonstrated, such techniques as use of γ-radiation, biocides, and low temperatures (14–15 °C, RH 65–75%) have limited success for commercial application. These postharvest storage methods, which have been successfully applied to other horticultural crops, are technically complex and quite expensive for adoption by small-scale farmers who produce the bulk of the yam tubers. The conventional barn is popular in many rural communities. It is an effective method of yam storage in Nigeria and other West African countries (Coursey, 1967).

Curing of yam (*Dioscorea alata*) prior to storage under conditions similar to the environment in the typical barn has shown no advantage in comparison to other improved forms of storage (Gonzalez and Collazo de Rivera, 1972; Rivera et al., 1974, Rodriguez et al., 1980). Weight loss and fungal decay were similar for the cured and uncured yams. It is generally recognized that curing of yam increased the storage life (Been et al., 1977). Passam (1982) showed that curing facilitates drying-out and healing of wounds, as with most tropical root crops.

Differences in the storage conditions or treatment of yams may produce chemical changes that could affect the subsequent rate of sprouting of the tubers or the sensory qualities (Hanson, 1986). There are conflicting reports in the literature on the effect of the different storage systems and treatments on the chemical changes produced in stored yams. Adesuyi (1971) reported that white yam stored in the traditional barn for 6 months improved in taste compared to the freshly harvested yams. Rivera et al. (1974) found no changes in the taste of irradiated yam stored for 6 months. However, Rodriguez et al. (1980) reported decreased taste at the onset of sprouting in stored yams. Mozie (1983, 1984) observed decreased protein levels in white yam stored in the barn and increased concentration of total nitrogen in head and tail ends but did not relate these constituents to their sensory quality. Martin and Ruberte (1975) reported that stored yam tubers (*Dioscorea dumentorum*) showed increased levels of polyphenol and glycoalkaloids, associated with their increased discoloration and poor tastes.

Webster et al. (1984) isolated a number of polyphenolic compounds and alkaloids in yams (*Dioscorea hispida* and *Dioscorea bulbifera*), which were associated with their astringency and bitterness. Environmental conditions to which the tubers are exposed and mechanical injuries to the tubers have been reported to cause an increase in the chemical constituents implicated in causing the bitterness of improperly handled potatoes (Mondy et al., 1971). It is not unlikely that as storage organs these changes in the chemical constituents of the tubers are produced as a protective device against fungal attack due to the mechanical stress of the storage environment or wound healing following the mechanical injury or bruises to the tubers. The extent to which these changes in the chemical constituents influence the sensory qualities of the tubers has not been well-defined. However, it is believed that the processes of peeling, washing and soaking, and cooking reduce these chemical compounds in the yam and potato tubers to a tolerable level (Sinden et al., 1976; Telek et al., 1976; Salunkhe and Wu, 1979).

In some parts of Nigeria, some freshly harvested yam varieties are very bitter while others are reported to be toxic. When these yams are consumed, they produce the disorder described as "shake syndrome", which is not reported when their stored forms are consumed. The etiology of this disorder has not been established, but as a general precaution to avoid these symptoms local custom and belief in certain parts of Southern Nigeria stipulates that fresh yams should not be consumed until some celebrations and rituals have been performed. The period (30–40 days) for the celebration varies with different communities after harvesting of yams. Some form of

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storage of yam naturally occurs under this condition, and some chemical changes that probably affect the sensory qualities of the yam take place.

There are not many reports in the literature on the effects of the traditional barn storage methods in relation to the chemical constituents and their sensory qualities. This type of investigation is necessary in order to evaluate the merit of the storage technique.

MATERIALS AND METHODS

Yam and Storage Methods. Tubers of white yam (*Dioscorea rotundata* Poir) and yellow yam (*Dioscorea cayenensis* Lam) were obtained from the local market in Ile-Ife. These yam types are the most popular and widely cultivated yams in West Africa. Random samples of the wholesome tubers were selected and divided into three lots: Two lots were used for storage tests while the third lot was used as the control. The experiment started immediately after harvest (August–February). Sound and unbruised tubers were weighed and placed on a rack under a shade at ambient conditions (temperature 23–28 °C, RH 80 ± 5%) for 150 days. These conditions simulated the conventional barn and typified the method widely adopted on most farms and by vendors and middlemen dealing with yam in rural communities in Nigeria.

The second lot of tubers was cured by holding the tubers at 35 ± 1 °C for 3 days and a relative humidity of 90–95%. This condition was obtained by enclosing the tubers in a cabinet containing trays of water while the temperature was maintained at 35 ± 1 °C (Rodriguez et al., 1980). The cured tubers were weighed and kept on a laboratory bench in a room with free air circulation (temperature 23–26 °C, RH 75–85%). The storage area for both the cured and uncured tubers was screened off to prevent rodent attack. At a 30-day interval, the tubers were examined for weight changes, degree of sprouting or decay, and changes in chemical constituents. The susceptibility of the tubers to discoloration was evaluated by visual comparison test as described by Mondy et al. (1971) and organoleptic tests by taste panel procedure.

Chemical Analysis. The fresh and stored tubers were analyzed, in duplicate, for moisture, crude protein, starch, and sugar by the standard methods (AOAC, 1980). Total ascorbic acid was determined by 2,6-dichloroindophenol method with modification to precipitate the heavy metals using metaphosphoric acid (AOAC, 1980). Total polyphenol content in the tubers was determined, with tannic acid as the standard, by the method of Rosenblatt and Peluso (1941). Total glycoalkaloids in the tubers were determined by the method of Fritzpatrick and Osman (1974). Sections of the fresh and stored tubers were soaked in water, then steamed for periods up to 10 min, and later analyzed for total glycoalkaloid content. All determinations were made in triplicate.

Bitter compounds were evaluated as follows: Small portions (0.5 g) of the raw tubers were chewed by a number of tasters. Extracts from the tubers were also spotted onto strips of filter paper that were subsequently dried and tasted for bitterness. Bitter compounds in the edible portion of the tubers were extracted as follows: 25 g of the fresh or stored tuber sections (head, middle, tail ends) was macerated with 100 mL of diethyl ether for 10 min.

The slurry was centrifuged at temperature below 23 °C, and the clear supernatant extract was collected in a 250-mL flask. The sediments were washed back to the blender with 100 mL of methanol and reextracted. After a third extraction the pooled extracts were evaporated to 50 mL. Ethyl acetate (50 mL) was added to the aqueous fraction used for the chromatogram. The residue of the tuber after extraction was tested for bitterness.

The methanolic extract was spotted on a silica gel G coated plate (20 × 30 cm) that had been activated by heating at 110 °C for 30 min. The compounds were separated by an ascending method with a solvent mixture of acetic acid–benzene–hexane (1:1:3, v/v) and a solvent mixture of ethyl acetate–hexane (9:1).

The plates were air-dried and subsequently sprayed with 1% anisaldehyde in glacial acetic acid containing 2% concentrated sulfuric acid. The plates were then heated to 105 °C for 10 min and examined for spots in visible and ultraviolet light. The separated spots on the plates were removed with the silica gel and eluted with boiling methanol into small flasks. The methanol was reduced to 3 mL by heating in a water bath. Strips of filter paper were immersed in this solution and then dried and tasted for bitterness in comparison with the extract from the fresh tubers.

Another set of chromatograph plates was prepared, and the spots were identified by fuming the plates with either ammonia, formaldehyde, or vanillin for identification.

Sensory Evaluation. Samples of the fresh and stored tubers were peeled, washed with distilled water, sliced to 2-cm pieces, and then cooked to doneness. Cooking was done in the traditional manner by allowing the water to come to boil initially and then boiling the pieces to doneness. Doneness was judged by pressing a portion of the pieces between the fingers and with a fork.

At a 30-day interval, portions of the stored yams cooked to doneness were submitted to a 10-member taste panel for evaluation of the organoleptic qualities [taste, appearance, texture (mouthfeel)] using a multiple-comparison test. Sections of the fresh and stored yam were cooked and compared for differences in organoleptic qualities. Panelists were asked to score the product on a 7-point hedonic scale with 1 = dislike very much and 7 = like very much. The results were analyzed for significance by the multiple-range test.

RESULTS AND DISCUSSION

The changes in the physical characteristics and proximate composition of the stored tubers are presented in Table I. White yam showed a greater magnitude of loss in dry matter than the yellow yam. Significant reductions in the moisture and crude protein occurred gradually in the first 90 days of storage and thereafter declined slightly until the end of the experiment, 150 days. Although yam species differ in their storage characteristics, the curing treatment did not show any appreciable advantage in reducing weight losses in the two yam varieties investigated. The results of the curing treatments prior to storage varies depending on the storage environment, duration, yam cultivar, and the method of curing. Gonzales and Collazo de Rivera (1972) showed that cured Habanero yam (*D. rotundata*) stored for 3 months under controlled conditions showed lower weight loss and tuber spoilage than uncured tubers. The tubers not cured prior to storage showed greater degrees of rotting and woodiness especially at the head ends. These defects were more noticeable in the white yam than the yellow type. The cured tubers had thicker peels than the uncured ones, apparently due to the drying-out and wound healing on the surface, which protects the tubers from moisture loss.

Table II shows the changes in the levels of ascorbic acid, total glycoalkaloids, and polyphenols in the fresh and stored tubers. Generally, ascorbic acid level decreased during storage for the two yam varieties while total soluble carbohydrate increased slightly after 60 days of storage. The white yam showed a greater trend for changes in the

Table I. Proximate Composition and Physical Changes in the Fresh and Stored Yam Tubers[a]

	white yam (fresh) storage time, days						yellow yam (fresh) storage time, days					
	0	30	60	90	120	150	0	30	60	90	120	150
constituents												
moisture, %	77	76	75	74	73	71	79	77	75	75	74	74
dry matter, %	23	21	20	20	21	20	22	21	21	21	21	20
ether extr, %	0.20	0.19	0.18	0.17	0.17	0.16	0.40	0.35	0.3	0.3	0.29	0.28
crude protein (N × 6.25), %	1.2	1.0	1.0	1.0	0.8	0.6	1.4	1.2	1.0	1.0	1.0	0.8
starch, %	21.8	20.0	19.0	18.0	17.5	17.0	21.0	21.0	20.0	20.0	19.5	19.0
sugar, %	0.8	0.85	0.90	1.0	1.20	1.25	0.60	0.65	0.70	0.75	0.80	0.90
ash, mg/100 g	0.6	0.6	0.59	0.60	0.60	0.59	0.5	0.5	0.5	0.5	0.5	0.49
physical changes												
weight loss,[b] %	0	3	5.5	6.0	6.9	8.0	0	2	4	4.5	5	6
sprouting,[b] %	0	1	1	1.5	2.0	3.8	0	0	1	1	1	2
rotting,[b] %	0	2	2	2.1	3	3	0	0	2	2	2	2

[a] Data refer to the edible portion of the tubers not cured prior to storage. [b] Data refer to the proportion of change with respect to the original number of tubers stored.

Table II. Chemical Quality Changes in the Fresh and Stored Tubers[a]

	storage period, days											
	0 (fresh)		30		60		90		120		150	
constituents, mg/100 g	A	B	A	B	A	B	A	B	A	B	A	B
total polyphenols	0.60	0.50	0.65	0.55	0.75	0.60	0.8	6.5	0.89	0.65	0.95	0.70
total glycoalkaloid	16	20	20	22	25	28	30	35	40	42	54	50
ascorbic acid	11.5	13.0	10.4	11.2	10.0	10.8	8.6	9.0	8.2	8.0	8.0	7.5
degree of discoloration[b]	1	1	1	1	3	2	3	2	4	3	5	4

[a] Data in columns A and B refer to white yam and yellow yam, respectively. Analyses were based on the edible portion of the tubers. [b] Degree of discoloration of the cut surface was based on a 5-point scale where 1 = slightly discolored and 5 = very discolored.

Table III. Characteristics of Compounds Extracted from Stored Yams[a]

	color reaction[b]			bitterness values		taste			
						uncooked		cooked	
tuber section	short-wave UV	UV + NH_3	UV + HCHO	benzene–acetic acid–methanol (1:1:3, v/v)	ethyl-acetic acid–hexane (9:1, v/v)	A	B	A	B
head	lt yellow	brown	dk gray	0.86	0.77	very bitter	very bitter	moderately bitter	moderately bitter
middle	lt yellow	brown	gray	0.68	0.68	bitter	bitter	just sweet	fairly bitter
tail	black	brown	gray	0.52	0.51	slightly bitter	slightly bitter	slightly bitter	slightly bitter

[a] Data were based on the tubers stored for 150 days. The fresh tubers contained relatively low levels of polyphenols. Key: A = white yam (*D. Rotundata*); B = yellow yam. [b] The color bands showed some overlaps and were not too distinct.

ascorbic acid and total soluble carbohydrate than in the yellow yam regardless of the curing treatment. The levels of polyphenol and glycoalkaloids in the stored tubers increased compared to the fresh tubers, and these were correlated ($r = +0.85$) with the increased level of discoloration observed during the storage period. The discolorations were mainly confined to the head and tail ends of the tubers where the glycoalkaloids and polyphenols are predominantly concentrated. Similar distributions of polyphenol in stored potatoes have been reported (Mondy et al., 1971).

The level of glycoalkaloid increased significantly ($P < 0.05$) from 10–30 mg/100 g in the fresh tubers to 30–50 mg/100 g (expressed on fresh tuber weight basis) in the stored tubers, especially at the onset of sprouting (approximately 120 days) during the period of storage. Osman and Sinden (1977) and Leete and Pinder (1973) reported that stored potatoes at the onset of sprouting showed a sharp increase in the level of glycoalkaloids of the tubers. The emergent sprouts are normally broken off in order to extend the storage life of the tubers.

It is not possible from this experiment to ascertain the real factors responsible for the increased levels and localization of polyphenols and glycoalkaloids in the stored yam tubers although a number of factors have been suggested as the probable causes for the situation noted in potatoes and similar mechanisms might be at play since yams and potatoes are botanically similar.

The curing treatment prior to storage did not significantly affect the levels of the chemical constituents in the yam types. This observation is important because exposing the yams to sun in the field for a few days after harvest provided ideal conditions that are quite conducive to achieve a natural curing of the tubers during the peak of the harvest period, September–December in many parts of West Africa. Therefore, artificial methods of curing yams or prolonged exposure to the sun prior to storage as it is applied to some horticultural crops should be avoided in order to eliminate unnecessary cost and heat damage to yam tubers.

Table III shows the results of the investigations on the bitterness compounds of the fresh and stored tubers. A number of the bitterness compounds isolated indicated that these compounds are mainly polyphenolic in nature and other complex mixtures of other compounds that overlap on the chromatogram for the different sections of the yam tubers. These bitterness substances in yam have been attributed to the polyphenolic compounds (Webster et al., 1984). In general the stored yellow yam showed a greater concentration of bitterness compounds than the white yam. In both yam varieties the amounts of bitterness compounds increased with the length of storage in comparison with the fresh tubers and were mostly concentrated at the head section although a few overlaps within the sections were evident. However, the threshold levels at which the polyphenolic compounds exerted their

Table IV. Panel Scores for the Sensory Attributes of Stored Yam Tubers[a]

	storage time, days											
	0		30		60		90		120		150	
attributes	A	B	A	B	A	B	A	B	A	B	A	B
aroma	3.5	3.5	3.8	3.8	4.0	4.0	4.0	4.0	4.2	4.0	4.0	4.0
flavor	2.5	2.0	3.0	2.8	3.2	3.5	3.9	4.1	4.5	4.8	4.2	4.3
mouthfeel (texture)	2.0	2.0	2.5	2.5	3.0	2.8	3.5	3.0	4.0	4.0	4.5	4.5
acceptability	3.0	3.0	3.0	3.0	3.5	3.2	3.5	3.5	4.5	4.7	2.5	2.5

[a] Data represent the average of two determinations and are based on a 7-point scale where 1 = dislike very much and 7 = like very much. Key: A = fresh/white yam; B = fresh/yellow yam.

bitterness differed among the two stored yam types. The peeling, trimming, washing, soaking, and cooking treatment of the edible portions of the tubers effectively reduced the amount of bitter-tasting compounds in both the fresh and stored tubers. The tasters response to the level of bitterness were mixed; some sections of the fresh yam were slightly bitter but acceptable while sections from the yams stored for longer than 120 days tasted too bitter and were rejected. Generally the intensity of bitterness in tuber extract of the raw fresh yams was higher than in the cooked yams especially with the white yam. This probably suggest that the bitter principles may be water soluble and heat labile.

Sensory Evaluation of the Stored Tubers. Table IV shows the panel scores for the sensory quality of the fresh and stored yams. The curing treatment generally had no effect on the flavor scores for the yam types; however, the stored tubers were rated higher than the fresh tubers especially up to 120 days of storage. Thereafter the panelists indicated that the tubers were bitter and astringent, corresponding to the stage at which sprouting commenced and glycoalkaloid level increased sharply. Bitterness was specifically more pronounced for pieces from the head section than at other sections. Both the head and tail sections were rejected as unacceptable (lower scores) due to the pronounced bitterness and very nonmealy texture. The high levels of polyphenols and glycoalkaloids mainly concentrated at the distal ends in the yam tubers at the onset of sprouting beyond 120 days in storage might be related to the bitter taste observed at this sections of the tubers. Similar trends have been reported with potatoes (Mondy et al., 1971; Salunkhe and Wu, 1979) although it may be necessary to determine the threshold levels at which these bitterness constituents can determine the acceptability of the tubers. Telek et al. (1974) reported that a number of chemical constituents are involved in the perception of the taste of yam. The improved sensory quality attributes of the stored yam might be due to other chemical constituents. Mozie (1984) reported an increased level of metabolic activities, crude protein loss in white yams, stored in the barn. Apart from normal loss of moisture and dry matter, the stored yam showed increased levels of sugar, ascorbic acid, and reduced starch contents.

Generally the overall improved taste and mouthfeel qualities of the traditionally (barn) stored yam is confirmed in this work (Table IV). This may be attributed to the accumulation of total reducing sugars and low nitrogenous constituents over the concentration of the bitterness compounds. These chemical changes are probably related to the improved quality of the locally stored yam tubers.

The implications of these findings are that yam tubers for processing or marketing should not be stored in the barn longer than 120 days in order to avoid deterioration of the quality. Curing the tubers did not show any advantage in reducing weight loss since exposure to the sun can achieve the natural curing. Artificial methods of curing the tubers before storage in the barn might be avoided in order to avoid additional cost.

Registry No. Ascorbic acid, 50-81-7; starch, 9005-25-8.

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