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Dry matter, Free Sugar and Starch Changes in Tuber Regions of White Yam (Dioscorea rotundata Poir.), and the Effect of Storage Environment

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ABSTRACT

This study was conducted to determine the changes in dry matter (DM), free sugar (FS) and starch contents in the three yam *(D. rotundata*) tuber regions under two storage environmental conditions (natural light- yam barn, or and darkness). Three varieties of *D. rotundata* (alaako, Dodoro and Odo) were studied. The dry matter content of the Head region was the highest (28.6%), followed by the Middle (26.9%) and Tail (22.3%) regions. Change in dry matter content of the tuber is mainly due to rapid changes in the dry matter content of the Tail region over time. Storage environment significantly ($P \leq 0.05$) affected dry matter content of the three tuber regions at 8 and 16 weeks in storage (WIS). Head regions per variety were lower in dry matter when stored under Light than in the Dark at 8 WIS, while the reverse was the case for the Tail. This may relate to the release of endodormancy. By 16 WIS, when tubers stored under Light had well developed sprouts and those stored in the Dark only showed the first sign of sprouting, all Head regions had higher dry matter content under Light than in Dark storage. This may be due to the presence of sprouts. Storage environment did not significantly affect starch content at the various tuber regions. Head regions had higher percentage free sugar content under Light than Dark storage, and these effects were manifested between 8 and 16 WIS.

Indexing terms/Keywords

Dioscorea rotundata; tuber regions; dry matter; free sugar starch; dark storage; light storage.

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INTRODUCTION

White Guinea yam (*Dioscorea rotundata* Poir.) is an important staple in West and Central Africa (IITA, 1988). The tuber is eaten mainly for its high starch content, which constitutes about 60% - 70% of the tuber's dry matter content (%). Other nutrients which make up the dry matter include sugars, proteins, amino acids, minerals and vitamins (Osagie, 1992).

In West Africa, yams are planted between January and April and harvested (main harvest) at the onset of vine and leaf senescence in November or December, which coincides with the acquisition of maximum tuber weight and the onset of the dry season (Onwueme, 1975; Passam, 1982). These events are often considered to mark the onset of dormancy. During dormancy, the food quality of tubers are maintained due to low chemical and physiological activity while food value declines shapely with the onset of sprouting as a result of rapid breakdown of stored food. Therefore, dormancy is seen as an important adaptive trait, maintaining food quality in storage and ensuring that tubers germinate/sprout (release dormancy) at the start of the rains (Craufurd *et al.,* 2001). However, for yam plant breeders and farmers, dormancy is a barrier to rapid generation turnover in breeding programs and multiple production cycles per annum (Asiedu *et al.,* 1998). While much is known about the control of seed dormancy and bud dormancy in potato (*Solanum tuberosum*), the mechanism of control of yam tuber dormancy in *Dioscorea spp*. is still not well understood (Suttle, 1996; Craufurd *et al.,* 2001).

Following studies conducted after a main tuber harvest and on whole tubers, total dry matter content of tubers changed in a definite pattern. It increases in the first instance due to transpiration and surface evaporation, then it declines gradually during dormancy due to respiration at low metabolic rate, and then, rapidly during sprouting due to increased metabolic rate at the onset of sprouting. Similarly, starch, sugar and fat contents as well as enzyme type and content have been shown to change in a definite manner through dormancy and sprouting (Oyenuga, 1968; Ikediobi and Oti, 1983; Mozie, 1984b, 1987; Oluoha, 1988; Onayemi and Idowu, 1988; Achide *et al*., 1996; and Hariprakash and Nambisan, 1996). Many of these studies that relate the changes described above to dormancy, have assessed tuber that were stored in yam barns. Such studies of the dynamics of nutrients in tubers during storage have not only contributed towards the understanding of nutrient quality but may provide some understanding of the mechanism of tuber dormancy (Osagie. 1992; and Hariprakash and Nambisan, 1996).

Storage environment have been shown to affect the rate at which these changes occur (Coursey, 1961; Mozie, 1984[b]; 1988; Rivera *et al*., 1984; and Onayemi and Idowu, 1988), and dark storage is known to delay the timing of sprouting. However, the demonstration of horizontal physiological gradient along the tuber length drives the need to study changes in nutrient content at the various tuber regions. Both physiologically and morphologically the tuber has been divided into three regions: Head (Proximal), Middle and Tail (Distal) regions (Oluoha, 1988 and Onwueme, 1991). Among these regions the distribution and pattern of change in nutrients during storage (mostly under traditional barn) have been shown to vary considerably (Mozie, 1984 Hariprakash and Nambisan, 1996). Dry matter content has been reported to increase in the order: Tail < Middle < Head with the Tail region having the highest rate of increase during storage (Ferguson, 1980; Ologhobo, 1985 and Hariprakash and Nambisan, 1996). Starch content and change trends have also been shown to vary among tuber regions (Hariprakash and Nambisan, 1996). There is however, little information on free sugar changes at tuber regions. Further, the effect of different storage conditions the changes in dry matter, free sugar and starch contents is not well known. Also, it is unclear whether these changes may explain the effect of storage environment on the timing of sprouting. Therefore, this study sought to determine the effect of two storage conditions (Light and Dark storage) on changes in dry matter, starch and free sugar contents in the three tuber regions of white yam *D. rotundata*.

MATERIALS AND METHODS

The experimental site and materials

Three *D. rotundata* varieties were studied; 'Alaako', 'Dodoro' and 'Odo'. These varieties are commonly planted in the month of October of one year and harvested about September of the following year. The tubers were obtained from farmers' fields around Ibadan, Alaako from Alabata village, while Dodoro and Odo were from Abadina in the University of Ibadan, Ibadan. The tubers were harvested one month before the usual harvesting period by milking (removal of a large portion of the mature tuber while the foliage is still green and keeping a small portion of the head region still attached to the plant for further development into seed yam). This was done to ensure that the tubers were still developing and so, dormant.

Experimental Design and Tuber Storage

The experimental design was Randomized Complete Block arranged as split plots. Two storage environments (natural Light and Dark conditions) formed the main plots. Randomized and replicated three times. The Light environment was yam barn at the International Institute of Tropical Agriculture (IITA); Ibadan, Nigeria The barn is made up of horizontal wooden racks that are open but roofed with raffia palm leaves while the Dark environment was created by covering the horizontal wooden racks in the yam barn with brown jute sacs. The tuber regions and the peel and pulp of the regions constituted the sub and sub-sub sections plots. The experiment began in the month of August of August with the selection of 120 healthy tubers of various sizes for each of the three varieties used. The tubers were then placed in 12 wooden crates that were randomly and equally allocated to the two storage environments.

The night time mean relative humidity consistently remained high (>70%) throughout the duration of the study (Hamadina *et al*., in press). In contrast, the daytime %RH declined with time from the onset of the study in August to the end in December. The daytime relative humidity declined from magnitudes of >70% in August to 40-50% in December. The temperature profile of the storage environments (Hamadina *et al*., in press) show that, ambient temperatures fluctuated without discernible differences between storage environments before 8 WIS (August through September). After 8 WIS, mean temperature stabilized, clear differences between storage environments. Also, daytime temperatures were higher, and darkening the environment reduced daytime temperatures to the magnitudes of night time temperatures of the Light Environment.

Tuber Sampling Method

Sampling was done at the start of the experiment and monthly thereafter. On each sampling date, two tubers /variety were randomly picked from each replication of treatment combinations. These tubers were prepared by washing, and air-drying. Each pair of tubers per variety per replication was split longitudinally in halves. Halves of the different tubers in were then exchanged to form two new tubers denoted as pairs 1 and 2.

Dry Matter Determinations

Pair 1 was divided into three regions: Head, Middle and Tail. Each pair of regions was then shredded together. Duplicate 100 g samples per region were dried to constant weight (approx. 24hrs) at 100^0C in an air draft oven. The dry samples were allowed to cool in a desiccator after which samples were weighed for dry matter determination.

Starch and Free Sugar Determinations

Pair 2 was divided into three regions and then each pair of regions was peeled to a depth of about 1.5mm. A sample of about 50g pulp was dried to constant weight at $70\text{-}75^0$C. Dried samples were then ground to flour, in a laboratory mill (analytical mill A-10), sieved through a mesh sieve of 1mm and preserved in airtight packs made of polythene. The finely ground flour was then analyzed for starch and sugar contents.

Tissue analysis

Tissue analyses were carried out at the Biochemistry Laboratory of IITA, Ibadan, Nigeria. Duplicate 0.250g pulp flour samples were used for the analysis of free sugar and starch contents expressed as g/100g dry weight basis. Boiling ethanol (95% v/v) was added to the weighed sample, which was then vortexed and centrifuged at 2000 rpm for 10 minutes. The supernatant was decanted and then used for the quantitative analyses of free sugar (McGrady, 1970). The residue after decanting was hydrolysed with 7.5 ml perchloric acid into monosacharide sugars after standing for 1hr. The duplicate samples were then diluted with 17.5 ml of distilled water and filtered through Whatman #2 filter paper. Upon twice dilution with distilled water, 0.05ml aliquot was made up to 1ml with distilled water. Starch content was quantified colorimetrically using phenol and sulphuric acid. Sugars obtained after hydrolysis of the residue was converted to starch by multiplying by a factor 0.9, after correcting for moisture content. This method is a modification of the procedure described by McGrady, (1970) (IITA, 1998).

Data Analysis

The data collected were subjected to analysis of variance using Statistical Analytical System (SAS mixed model) statistical package (SAS, 1994) for dry matter data analysis while GENSTAT was used for starch and sugar data analysis. Least square means were separated by Standard Error of Differences.

RESULTS

Dry matter

At the commencement of the experiment, the distributions of DM amongst the yam tuber regions were 28.6%, 26.9%, and 22.3% for Head, Middle, and Tail regions respectively ($P \leq 0.001$). Although the varieties differed in dry matter content, with Alaako being higher in dry matter compared to Dodoro and Odo, dry matter content of the tuber regions followed the same trend as above. Except at 8 WIS, the same trend was observed throughout the experiment (Fig. 1). By 4 WIS, dry matter content increased in all regions by 11.3%, 8.4% and 13.4% in the Head, Middle, and Tail regions respectively. The dry matter content of the Tail region increased sharply by 31% at 8 WIS before it declined by 27% at 12 WIS. On the other hand the dry matter in the Head or Middle regions remained either almost constant or declined slightly until 20 WIS.

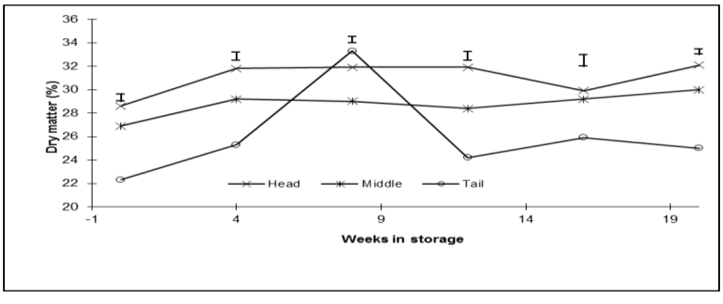

Fig. 1. Changes in mean dry matter content of the Head, Middle and Tail yam tuber regions. Vertical bars are S.E.D. values at P=.001

The interaction of storage environment and tuber regions at 8 WIS shows that, the Head regions of Dodoro and Odo varieties had a higher DM content under Dark storage while the Tail regions (particularly Odo) had a higher DM ($P \leq 0.05$) under Light storage (Table 1). In contrast, the trend in Alaako (the variety with the highest dry matter content in each region compared to Dodoro and Odo) showed that the Head region had a higher dry matter content under Light than Dark storage while the Tail region had higher dry matter content under Dark than Light storage. Thus, while the dry matter content in Middle region did not show any clear trend, the dry matter content of the Head and Tail regions differed with Dark or Light storage.

Table 1.The distribution of dry matter in tuber regions of three varieties of *D. rotundata* at eight weeks in storage.

Environments	Yam varieties								
	Alaako			Dodoro			Odo		
	Head	Middle	Tail	Head	Middle	Tail	Head	Middle	Tail
Dark	31.0	29.8	33.7	33.8	28.5	24.0	31.0	27.4	21.9
Light	34.0	31.2	27.0	30.6	29.4	24.5	29.0	26.6	24.3
SED*	1.26								

*Standard Error of Difference; $P \leq 0.05$

By 16 WIS, when shoot buds/sprouts were first observed only on the surface of the tubers stored under Light, the Head regions had significantly higher dry matter content under Light than Dark storage environment. In contrast, the Tail and Middle regions had higher dry matter under Dark than Light storage.

Table 2. Effect of storage environment on dry matter content of yam tuber regions at 16 weeks in storage

Environments	**Tuber Regions**		
	Head	**Middle**	**Tail**
Dark	28.5	29.3	27.1
Light	31.3	29.1	24.7
Mean	29.9	29.2	25.9
SED	1.33		

$P \leq 0.05$

Starch content and changes

Prior to storage, the mean starch content of the three varieties were: 72, 69 and 64 g/100g, dry weight basis, for Alaako, Dodoro and Odo respectively. Starch content at the tubers regions differed significantly ($p < 0.01$) in the order: Middle > Head > Tail (Figure 2). At 4 WIS, starch content of the Head and Middle region declined slightly while that in the Tail region increased slightly. However, the difference in the starch content of the Middle and Tail regions did not differ significantly. By 8 WIS, the Tail region had the lowest starch content while the starch content of the Head and Middle regions did not differ significantly. At 12 WIS, starch content did not differ across the regions, and the interaction of storage environment with variety and tuber regions ($P \leq 0.01$) showed no definite trend. At 16 WIS (when sprouting was observed in Light stored tubers) and beyond, starch content declined sharply in all tuber regions.

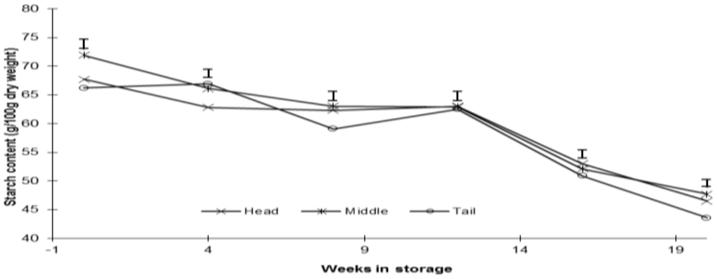

Fig. 2. Changes in starch content of the Head, Middle and Tail regions of yam tuber. $P \leq 0.05$ at 4 and 8 week

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Free sugar content and changes

The three varieties used in this study varied in free sugar contents (dry weight basis) at the start of the study. Odo had the highest free sugar content (4.89 g/100g) > Dodoro (4.56 g/100g) > Alaako (3.15g/100g) at P<0.05. Also, the interaction between variety and tuber region was significant (P≤ 0.001). In Alaako, which is least in sugar content, free sugar content in tuber regions followed the order Head > Tail > Middle (Table 3). This trend was observed throughout the study period except at 8 and 12 WIS. In contrast, in Dodoro and Odo, free sugar content followed the order Tail > Head > Middle, and this trend was observed throughout the study period.

Table 3. Free sugar changes in tuber regions of three *D. rotundata* varieties

VARIETY	REGION	Weeks in storage					
		0	4	8	12	16	20
Alaako	Head	3.41	2.64	3.1	2.75	2.65	2.69
	Middle	2.98	2.33	3.27	2.62	2.72	2.71
	Tail	3.06	2.44	3.64	3.1	2.7	2.24
Dodoro	Head	3.97	4.82	3.61	3.53	4.26	2.39
	Middle	3.79	3.9	3.66	3.16	3.78	2.51
	Tail	5.97	5.12	3.94	3.82	4.47	4.48
Odo	Head	4.68	4.3	3.55	3.78	3.51	4.55
	Middle	4.51	3.77	3.94	4.22	3.61	4.23
	Tail	5.48	4.84	4.51	4.31	5.57	5.85
S.E		0.35	0.29	0.33	0.29	0.35	0.29
S.E		0.31	0.31	0.34	0.31	0.38	0.3

At 4 WIS, tubers stored under Light had higher free sugar content (4.0 g/100 g) than those stored in the Dark (3.4 g/100 g). (P≤ 0.05). However, storage environment did not interact significantly with tuber regions except at 8 and 12 WIS (Table 4). At 8 and 12 WIS, free sugar content was higher (P< 0.05) in all tuber regions of Alaako and Dodoro tubers stored under Light than under Dark. In contrast, in Odo, the variety with the highest free sugar content, the Head regions had higher free content under Light than Dark storage, while those of the Middle and Tail showed no definite trend.

Table 4. Interaction effect of storage environments and varieties on free sugar contents of yam tuber regions during storage

Environment	Variety	Region	% sugar (g/100g dry weight basis) Time (weeks in storage)				
			4	8	12	16	20
Dark	Alaako	Head	2.72	2.79	2.55	2.68	2.37
		Middle	2.26	2.84	2.40	2.90	2.70
		Tail	2.72	3.66	2.43	2.37	2.19
	Dodoro	Head	4.15	3.32	3.25	4.72	2.32
		Middle	3.75	2.65	3.35	4.16	2.95
		Tail	5.07	3.35	3.53	4.98	3.61
	Odo	Head	4.05	2.97	3.09	3.38	4.18
		Middle	3.56	4.17	3.18	3.69	4.56
		Tail	4.92	5.02	4.36	6.23	5.41
Light	Alaako	Head	2.56	3.42	2.95	2.63	3.01
		Miiddle	2.41	3.70	2.83	2.54	2.72
		Tail	2.16	3.62	3.76	3.02	2.29
	Dodoro	Head	5.48	3.90	3.82	3.81	2.46
		Middle	4.05	4.67	2.97	3.41	2.07
		Tail	5.17	4.53	4.10	3.96	5.34
	Odo	Head	4.55	4.13	4.47	3.64	4.92
		Middle	3.98	3.7	5.25	3.54	3.90
		Tail	4.76	4.01	4.25	4.19	6.29
SED			ns	0.45	0.40	ns	ns

SED, when comparing means within environment use 0.46 and 0.41 for week 8 and 12 respectively

SED, when comparing means within environment*variety use 0.48 and 0.43 for week 8 and 12 respectively

SED, when comparing means within environment*region use 0.46 and 0.41 for week 8 and 12 respectively

P≤0.01

DISCUSSION

This study shows that when *D. rotundata* tubers are harvested just before natural vine senescence but after artificial induction of vine senescence, the Head region, which is the oldest region of the tuber and the most likely region from which sprouts emerge in intact tubers, contains the highest dry matter content. In contrast, the Tail region, which is the youngest and most active region during dormancy (Passam et al., 1978), contains the lowest dry matter content. This trend in the distribution of dry matter among the tuber regions is, similar to those reported in other studies of mature, tubers of *D. alata* and *D. rotundata* (Ferguson *et al*., 1980; Ologhobo, 1985). Also, compared to the other tuber regions the Tail region showed the highest rate of increase in dry matter attributable to the presence of high moisture content and thin epidermis, and hence, higher rate of transpiration and evaporation (Passam, *et al,* 1978). Hariprakash and Nambisan (1996) reported a 16% moisture loss from Tail region, compared with 9%, and 11% lost by the Head and Middle regions respectively for *D rotundata*.

The eight and sixteenth week in storage seem to be important stages in the ageing process of the *D. rotundata* tubers. At these dates, the tuber regions show strong response to Light or Dark storage with the Tail and Head regions showing opposite responses to the two storage conditions. In a moisture rich tuber, the Tail region gets higher dry matter content when stored under Light than Dark while the Head region gets higher dry matter content when stored in the Dark than Light. Ile, 2004, has also shown that crude protein content in Tail-peels is higher under Light than Dark storage. Further, free sugar content of tuber regions was higher when storage was in Light than Dark. Although starch content in the tuber regions of the tubers studied was not significantly affected by storage environment, the increase in starch content at 12 WIS may be due to the reconversion of sugars to starch. Reduction in free sugar content was also observed at 8 and 12 WIS in tuber regions stored under Dark environment. Though the mechanism of starch break down is not well understood, starch and sugar have been reported to exist in a dynamic equilibrium with conversions of sugars to starch occurring under stress conditions (Osagie 1992).

Thus, to encourage high activity in the Tail (particularly) and Head regions of post harvest tubers and hence slightly early sprouting date, tubers may be stored under light storage conditions.

CONCLUSION

This study has shown that the Tail and Head regions are the most active regions of the yam tuber. Also, dry matter and free sugar contents of Head and Tail regions vary with Dark and Light storage conditions.

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