African Journal of Biotechnology Vol. 11(17), pp. 3964-3975, 28 February, 2012
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.1292
ISSN 1684ï 5315 © 2012 Academic Journals

Full Length Research Paper

Phenotypic analysis of tuber yield- and maturity-related traits in white yam (*Dioscorea rotundata*)

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Accepted 15 September, 2011

Inadequate yield potential of available varieties and their long growth periods are two of the factors limiting yam (*Dioscorea* spp.) production. Identifying yield- and maturity-related traits and breeding for them will enhance production. Ten morphological/physiological traits: time of shoot emergence, time of tuber initiation, plant height, shoot dry weight, time of shoot senescence, tuber fresh weight (tuber yield), tuber number/plant, tuber parenchyma colour, tuber dry matter content and tuber dormancy period were assessed in eight accessions of *D. rotundata* (white Guinea yam) on the field in 2008 and 2009. Shoot dry weight and plant height were identified as the major tuber yield-related traits. Early field emergence and tuber initiation, short tuber dormancy period and low tuber dry matter content may also be related to tuber yield. High yielding accessions were low in tuber dry matter content. Moreover, early and late maturing accessions could be separated by time of attainment of uniform parenchyma colour within a tuber, length of tuber dormancy period and time of shoot senescence. Accessions were identified that may be used as parents for developing mapping populations for some of the traits assessed in the study.

Key words: *Dioscorea rotundata*, tuber maturity, tuber dormancy, dry matter content, yield related traits, senescence.

INTRODUCTION

Yams (*Dioscorea* species of family Dioscoreaceae) are important for food, medicine, income and socio-cultural events. They are a leading source of calories for over 300 million people in the tropics and subtropics (Degras, 1993). The crop is grown in Africa, Asia, parts of South America, as well as the Caribbean and the South Pacific islands. In West Africa, about 48 million tons of yams are produced annually on 4 million hectares of arable land. Out of the more than 600 species, 10 are generally cultivated as food: *D. alata*, *D. rotundata, D. cayenensis, D. bulbifera, D. esculenta, D. opposita-japonica, D. nummularia, D. pentaphylla, D. transversa* and *D. trifida* (Lebot, 2009). *D. rotundata* and *D. cayenensis*, (together also referred to as *D. cayenensis–rotundata* complex) are indigenous to Africa, and represent most of global yam production. They have the highest market value owing to the superior suitability of their tubers to the preferred food uses for the crop in West Africa.

High yield potential and early maturity are important characteristics for production. Cultivars that are high yielding and early maturing will enhance production, and may also permit double cropping within a year. This will enable food yam to be available in the market for most of the year. However, these traits are complex. Crop yield is determined by several related traits, and tuber maturity in yam is difficult to measure directly. In breeding for a complex trait, the identification of its components or related traits and breeding for them have been proposed as the means to enhance the trait (Donald, 1968; Sparnaaij and Bos, 1993). Reports on yield related traits in yams are scanty. Shoot weight and height (Akoroda, 1984), and leaf area duration (Lebot, 2009) have been reported to correlate positively with tuber yield.

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The plant growth and development period in *D. rotundata* varies from 8 to 10 months after planting (MAP). This long period slows down breeding and related research activities and also restricts the crop cycle to only one in the year. Furthermore, the changing climatic pattern necessitates the release of new varieties as older ones become less adaptable. For instance, long duration varieties may no longer be suitable in places where the rainy season has become relatively short and erratic. In addition, the lack of quantitative methods for determining maturity makes it difficult for a processor to establish the suitability of a batch of yam for processing and to determine optimum storage conditions (Osagie, 1992). A tuber that is not mature has a poor taste and does not store well. So far there is no clear morphological indicator to determine physiological maturity in yam. Various reports have considered tuber maturity as a reduction in metabolic activity in an environment no longer favorable for growth (Nilson, 1987), reduction in starch content (Ketiku and Oyenuga, 1973), dry matter accumulation (Okoli, 1980), total sugar content (Burton, 1978) and an increase in the accumulation of citric and malic acids in the tuber (Osagie, 1981). The senescence of the aerial apparatus coincides with the end of the process of suberization of the tuber surface, which begins in the tuberõs proximal region at the first stages of growth (Degras, 1993).

Generally, yams are considered to be mature when the foliage (leaves or vines) is fully senesced or dried (Okoli et al., 1984). However, this could be misleading as environmental factors, such as disease incidence, drought, or other stress conditions may lead to early senescence of foliage. It is therefore necessary to look for alternative indicators that may not be much influenced by the environment, if at all. A dramatic change in the pigmentation of leaves from green to dark green is used as an indicator by traditional farmers to identify early maturing yam varieties. However, Akinwande (2005) did not find such a link between tuber maturity and the colour indices of leaves and tubers. The objectives of our studies were to identify (i) traits that are related to tuber yield and tuber maturity in *D. rotundata*, and (ii) genotypes that are high yielding and/or early maturing.

MATERIALS AND METHODS

Plant preparation and experimental design

Eight accessions of *D. rotundata* comprising four breeding lines and four land-races were used in the study. The accessions were selected based on tuber maturity period and yield. The land races, Ehobia (late maturing), Amula (late maturing), Omi Efun (late maturing) and Akoko (early maturing), were bought from markets in Oyo North, Oyo State, Nigeria. The breeding lines (TDr 95/18949, TDr 99/02562, TDr 97/00960 and TDr 00/00403), medium-late maturing, were obtained from IITAõs Yam Breeding Program. For every accession, 220 tuber sets, each weighing 100 g were prepared, and buried in carbonized rice husks for sprouting. Fifty sprouted sets of each accession were transplanted on mounds at a spacing of 0.5 x 1 m in the field at the IITA Ibadan station during the second week of June in 2008, and replicated four times in a randomized complete block design. The sets obtained from head, middle and tail portions of a tuber were planted randomly for each accession. The experiment was repeated in 2009 at the same site but on another field (about 400 m from the 2008 field) using the same procedures and design except that planting was done during the third week of May. The plants were staked in both years.

Trait phenotyping

Data were collected on shoot emergence, time of tuber initiation, leaf colour, plant height, shoot dry weight, tuber fresh weight, tuber number/plant, tuber parenchyma colour, tuber dry matter content and tuber dormancy period in 2008. In 2009, leaf colour was not assessed, but data were collected on leaf (shoot) senescence in addition to the other traits assessed in 2008. Data were collected on shoot emergence from 10 days after planting (DAP) in 2008 and 20 DAP in 2009. Data on time of tuber initiation were collected from 50 DAP in both years. Data for the other traits were collected monthly from 3 to 6 MAP in 2008 and from 4 to 8 MAP in 2009 except tuber number per plant that was not collected at 3 MAP in 2008. More also, data were collected from all the 50 plants in each plot for shoot emergence and from 10 randomly selected plants of each plot for tuber initiation. While data for the other traits were collected from five plants from each plot at all sampling times, except for the sampling at 6 MAP in 2008 and 8 MAP in 2009, for which data were collected from three plants/plot because some plants were dead. The five plants were identified by selecting one out of every 10 plants along a row of 50 plants/plot. Plant height and shoot dry weight were not measured at the sampling at 6 MAP in 2008 and from 7 MAP in 2009 because the plants had all senesced. At every sampling time, except for shoot emergence and tuber initiation, all tubers/plant were first harvested and weighed. Data were collected as follows:

Shoot emergence- This was recorded as the number of days between the planting of a sprouted tuber sett and the emergence of a shoot above the ground.

Tuber initiation- The bases of the selected 10 plants/plot were exposed and inspected for the presence of new tubers every other day until tubers were observed for all the plants.

Leaf colour- The colour of the lower leaves (first 4 to 5 leaves) was determined using the Methuen Handbook of Colour (Kornerup and Wanscher, 1978).

Tuber number- The number of tubers/ plant were counted and recorded at 4, 5 and 6 MAP.

Tuber fresh weight- All tubers/plant were weighed after harvest.

Tuber colour (on the skin and parenchyma of head, middle and tail sections of the tuber) - This was determined using the Methuen Handbook of Colour (Kornerup and Wanscher, 1978). One tuber was split with a knife from head to tail and the colours of the head, middle and tail portions of the skin and parenchyma were recorded.

Tuber dry matter content- A representative sample of about 100 g (W1) prepared by thoroughly mixing sliced pieces of tubers was oven dried at 105°C for 48 h and weighed (W2). The percentage dry matter content was then calculated as (W2 / W1) ×100.

Plant height- After harvest, the length of the longest vine was measured with a tape and recorded.

Shoot dry weight- All the vines and leaves/plant were oven dried at 105°C for 48 h and weighed.

Leaf senescence- This was recorded as the number of days from planting to the date when 0 to 20, 20 to 30, 30 to 50, 50 to 80 and 80 to 100% of the leaf canopy had senesced. Data were collected from the plants that were assessed for tuber initiation. The assessment started at 5 MAP and continued every other day to 8 MAP.

Tuber dormancy period- Data were collected on tubers harvested from those plants that were assessed for tuber initiation. The tubers were dug out carefully with their corms intact, and were stored in open boxes at ambient temperature in the IITA yam barn at Ibadan. Data collection on the time of tuber sprouting started three weeks after harvest and continued every other day until 80 to 100% of all tubers had sprouted. A tuber was considered sprouted when it had a bud 3 mm long. The dormancy period was calculated as the number of days between sprouting and tuber harvest,

Data analysis

Two kinds of analysis were performed:

(1) Traits measured more than once (plant height, tuber fresh weight, shoot dry weight and tuber dry matter content) were analyzed considering their change across time and the residual terms were modeled using an autoregressive (order 1) model in a frame of repeated measures analysis;
(2) Traits measured only once (tuber initiation time, shoot emergence time and dormancy) were analyzed by a simple linear model. We used a Linear Mixed Model considering accessions, sampling times, and the interaction between accession and sampling time as fixed effects, and replication, the interaction between replication by accession and the effect of plants within accessions, as random effects. The least square means for fixed effects were calculated and a Tukey (or Tukey-Kramer) adjustment was used to make the pair comparisons. The MIXED PROCEDURE from the SAS statistical package was used to do the analyses. Multiple regression analysis was performed using tuber fresh weight (tfw) as dependent variable and all other traits as independent variables to quantify the effect and importance of each trait on the tfw variable.

Type IV sum of squares (SS) and partial regression coefficients were calculated to measure the effect of each trait after the effect of all others (including the replication and accession effects) was removed from the model. The Type IV SS were expressed as a percentage of the ñall regression traits sum of squaresò to get a relative measure of the contribution of each trait when entered at the last position in the model, that is, considering the possible correlation among traits.

RESULTS

The mean values of the traits except for tuber colour are shown in Table 1. The accessions were significantly ($p<0.05$) different for most of the traits in 2008 and 2009, but similar in tuber initiation time in both years and in plant height and tuber fresh weight in 2009. In 2008, Akoko was the shortest plant, while TDr 95/18949 had the highest tuber fresh weight. Plants within accessions were different ($p<0.05$) for shoot emergence, tuber initiation and dormancy period in both years, and for tuber fresh weight and time of shoot senescence in 2008 and 2009, respectively. Shoot emergence time, calculated from the time plants were transplanted on the field, was on average 19.9 days in 2008 and 26.3 days in 2009, which was earlier in the breeding lines than in the landraces, except TDr 97/00960 that emerged at similar time with the landraces in 2009.

Tuber fresh weight and shoot dry weight were higher in 2009 than in 2008 for all the accessions. The average tuber fresh weight was 499.4 g in 2008 and 1063 g in 2009, while that of shoot dry weight was 59.1 and 99.6 g in 2008 and 2009, respectively. The average shoot dry weight across the two years was highest in TDr 99/02562 and similar in the other accessions. In 2008, however, shoot dry weights of TDr 95/18949 and TDr 99/02562 were similar. The two-year average tuber fresh weight was highest in TDr 95/18949 (1096.0 g) and lowest in Ehobia (636.1 g), Amula (760.5 g) and Omi Efun (732.4 g). Tuber bulking was generally rapid in the first three to four months (following tuber initiation at about 53 days after transplanting) and slowed down afterwards (Table 2, Figure 1d and 2d). Tuber bulking was fastest in TDr 95/18944 than in the other accessions. Accessions with high tuber fresh weight (TDr 95/18949, TDr 97/00960 and TDr 99/02562) were low in tuber dry matter content, except Akoko that had high tuber fresh weight and high tuber dry matter content. Tuber dry matter content increased with growth period (Table 2 and Figure 1e). It was lowest at the 3- month harvest (16.7%) and highest at 8 months (35.5%), with an average of 24.7 in 2008 and 29.7% in 2009. Tuber dry matter content was highest in Ehobia, moderate in Akoko and Amula, and lowest in TDr 95/18949, TDr 97/00960 and TDr 99/02562.

There was no clear contrast in leaf colour at 3 months harvest from that of 4 or 5 months harvest in any of the accessions in 2008 (data not shown). In all the accessions, leaf colour was generally dark or dark green when tubers were harvested 3 or 5 months from time of planting. At 4 months harvest, leaf colour was grayish-green, dark-green, or deep-green across the accessions.

In general, there was no clear demarcation in tuber parenchyma colour of some of the accessions at any sampling time (Table 3).

Three colours were associated with tuber parenchyma; creamy, white and purple. Generally, tubers were white at the tail portion, creamy or white at the middle, and creamy at the head in most accessions, indicating an association of creamy colour with tuber maturity. All tuber portions (head, middle and tail) were creamy in TDr 95/18949 at 5, 6, 7 and 8 monthsôharvest; and in Amula at 7 and 8 months harvest. The head and middle portions were creamy in TDr 99/02562 at 6, 7 and 8 months harvest; in TDr 97/00960 and Ehobia at 7 and 8 months harvest. In TDr 00/00403, all tuber portions were creamy at 4 months harvest, and white at 6, 7 and 8 months harvest, while at 5 months the head and middle were creamy and the tail was white. In Omi efun and Akoko, the head was either purple or creamy at all harvest times, while the middle and tail were white in Omi efun at 7 and 8 months harvest and in Akoko at 6, 7 and 8 months

Table 1. Mean values of nine physiological traits assessed during growth stages of eight accessions of *D. rotundata* in 2008 and 2009.

***D. rotundata* accession**	**Shoot emergence (day)**			**Tuber initiation (day)**			**Number of tubers/plant**		
	2008	**2009**	**Combined**	**2008**	**2009**	**Combined**	**2008**	**2009**	**Combined**
Amula	22.2^{a}	28.5^{ab}	25.3^{ab}	51.6^{a}	50.9^{a}	51.2^{a}	1.7b	1.4^{ab}	1.6^{bc}
Akoko	22.0^{a}	26.9^{abc}	24.4^{abc}	52.5^{a}	53.6^{a}	53.0^{a}	1.3b	1.4^{ab}	1.4^{bc}
Ehobia	23.1^{a}	25.1^{bc}	24.1^{bc}	52.2^{a}	52.2^{a}	52.2^{a}	2.8a	1.7^{a}	2.3^{a}
Omi Efun	24.4^{a}	29.9^{a}	27.1^{a}	53.2^{a}	53.5^{a}	53.3^{a}	1.5b	1.2^{b}	1.3^{c}
TDr 00/00403	15.9^{b}	24.9^{bc}	20.4^{d}	52.1^{a}	53.1^{a}	52.6^{a}	1.6b	1.3^{ab}	1.5^{bc}
TDr 95/18949	14.4^{b}	24.9^{bc}	19.7^{d}	51.8^{a}	52.7^{a}	52.2^{a}	2.0ab	1.7^{a}	1.8^{ab}
TDr 97/00960	17.4^{b}	26.2^{abc}	21.8^{cd}	52.3^{a}	52.1^{a}	52.2^{a}	1.6b	1.5^{ab}	1.5^{bc}
TDr 99/02562	14.2^{b}	24.1^{c}	19.1^{d}	51.9^{a}	54^{a}	53.0^{a}	1.8b	1.6^{ab}	1.7^{bc}
Mean	19.9	26.3		52.2	52.7		1.8	1.5	
Average Se	0.73	0.90		0.67	0.86		0.18	0.09	
P>F (between accessions)	<.0001	0.002	<.0001	0.811	0.257	0.218	0.001	0.013	<.0001
P>F (within accession)	<.0001	<0.0001		<.0001	0.002		0.704	0.490	
P>F (years)			<.0001			0.156			<.0001
P>F (year*accession)			<.0001			0.717			0.014
P>F (months)							<.0001	0.339	<.0001
P>F (month*accession)							0.004	0.403	0.252

***D. rotundata* accession**	**Tuber fresh weight (g)/plant**			**Tuber dry matter content (%)**			**Plant height (cm)**		
	2008	**2009**	**Combined**	**2008**	**2009**	**Combined**	**2008**	**2009**	**Combined**
Amula	635^{b}	875^{a}	761^{b}	28.6^{ab}	29.6^{bc}	27.9^{b}	244^{a}	211^{a}	229^{a}
Akoko	401^{b}	1222^{a}	861^{ab}	28.1^{bc}	30.7^{b}	28.5^{b}	139^{b}	228^{a}	184^{a}
Ehobia	403^{b}	876^{a}	636^{b}	31.3^{a}	33.9^{a}	31.0^{a}	179^{ab}	190^{a}	185^{a}
Omi Efun	555^{b}	1003^{a}	732^{b}	27.8^{bc}	30.9^{b}	28.2^{b}	191^{ab}	213^{a}	200^{a}
TDr 00/00403	645^{b}	913^{a}	805^{ab}	26.8^{bc}	31.2^{b}	27.6^{bc}	197^{ab}	187^{a}	192^{a}
TDr 95/18949	947^{a}	1195^{a}	1096^{a}	22.8^{d}	27.1^{c}	23.9^{d}	203^{ab}	163^{a}	183^{a}
TDr 97/00960	577^{b}	1209^{a}	904^{ab}	25.4^{cd}	26.8^{c}	25.1^{d}	181^{ab}	191^{a}	186^{a}
TDr 99/02562	587^{b}	1224^{a}	884^{ab}	25.7^{c}	27.6^{c}	25.5^{cd}	226^{a}	241^{a}	233^{a}
Mean	499	1063		24.7	29.7		185	199.9	
Average Se	63.8	104.5		0.64	0.57		14.85	18.86	
P>F (between accessions)	<.0001	0.048	0.003	<.0001	<.0001	<.0001	0.003	0.114	0.024
P>F (within accession)	0.019	0.071		0.559	0.620		0.274	0.730	
P>F (years)			<.0001			0.436			0.269
P>F (year*accession)			0.005			0.051			0.002
P>F (months)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.316	0.272	0.957
P>F(month*accession)	0.003	0.086	0.077	0.106	0.054	0.005	0.589	0.414	0.979

***D. rotundata* accession**	**Shoot dry weight (g)/plant**			**Shoot senescence (days)**	**Tuber dormancy (days)**		
	2008	**2009**	**Combined**	**2009**	**2008**	**2009**	**Combined**
Amula	67.6^{abcd}	71.3^{b}	69.4^{b}	191.5^{b}	79.8^{a}	64.8^{ab}	72.3^{abc}
Akoko	33.8^{d}	94.3^{ab}	64.2^{b}	192.5^{b}	69.6^{ab}	54.7^{bc}	62.1^{cd}
Ehobia	45.9^{cd}	86.8^{b}	66.4^{b}	190.9^{b}	77.4^{a}	59.6^{abc}	68.2^{abc}
Omi Efun	58.6^{abcd}	94.7^{ab}	75.8^{b}	194.2^{ab}	71.6^{ab}	66.3^{ab}	69.4^{abc}
TDr 00/00403	67.9^{abc}	84.3^{b}	76.2^{b}	197.5^{a}	78.3^{a}	73.5^{a}	75.9^{ab}
TDr 95/18949	79.2^{ab}	85.3^{b}	82.4^{b}	190.2^{b}	55.3^{b}	48.4^{b}	51.9^{d}
TDr 97/00960	52.1^{bcd}	85.8^{b}	69.0^{b}	193.6^{ab}	73.9^{ab}	53.9^{bc}	63.9^{bcd}
TDr 99/02562	90.2^{a}	153.5^{a}	121.1	197.4^{a}	84.5^{a}	68.7	76.4^{a}
Mean	59.1	99.6		193.5	72.3	60.5	
Average Se	7.46	12.63		0.95	4.36	3.7	

Table 1.Contd

P>F (between accessions)	0.0003	0.007	0.0004	<.0001	0.005	<.0001	<.0001
P>F (within accession)	0.109	0.738		<.0001	<0.0001	<.0001	
P>F (years)			<.0001				<.0001
P>F (year*accession)			0.004				0.015
P>F (months)	0.002	0.015	0.001				
P>F (month*accession)	0.597	0.333	0.748				

Means followed by different letter within a column are significantly different ($p \leq 0.05$) in the Tukey's test.

harvest. The periods between the dates of transplanting sprouted sets and the senescence of the shoots of the established plants were measured only in 2009 (Table 1), and the average was 193.5 days (6.5 months). Shoot senescence was earliest in TDr 95/18949, Ehobia, Amula and Akoko, and late in TDr 99/02562 and TDr 00/00403. Senescence time in Omi-efun and TDr 97/00960 was not statistically different from early or late senescing accessions. In 2008, leaf senescence started during the fifth month after planting, but was observed only in some plants of Omi Efun, TDr 97/00960 and Amula. All the leaves were completely senesced at 6 and 8 months after planting in 2008 and 2009, respectively.

The tuber dormancy periods calculated from the day that tubers were harvested to the date of sprouting, was on average longer in 2008 (72.3 days) than in 2009 (60.5 days) (Table 1). Tubers for the dormancy experiment were harvested in December 2008 and January in 2009. The average tuber dormancy period across the two years was shorter in TDr 95/18949, TDr 97/00960 and Akoko than in the other accessions. There were significant ($p<0.001$) differences in trait values between sampling times of those traits that were assessed more than once (tuber number per plant, tuber fresh weight, tuber dry matter content, plant height and shoot dry weight), except for plant height that was similar at all sampling times in both years, and tuber number per plant in 2009 (Table 4, Figures 1 and 2). Accessions that differ in some of the traits are shown in Table 4, which may be used as parents in crossing to develop mapping populations for those traits.

Simple correlation analysis of nine of the 10 traits identified significant correlations among most of the traits (Table 5). Tuber yield (tuber fresh weight) correlated positively ($p \leq 0.01$) with shoot dry weight (2008 and 2009) and plant height (2008), but negatively with tuber dry matter content (2008), tuber dormancy period (2008 and 2009), time of shoot emergence (2008) and tuber initiation (2008). Shoot dry weight and plant height had a strong positive correlation in both years ($r = 0.78$ in 2008 and 0.62 in 2009). Shoot senescence time measured only in 2009 correlated ($p \leq 0.05$) with tuber dormancy period. When regression analysis was performed using tuber fresh weight as dependent variable and its correlated traits as independent variables, only shoot dry weight and plant height had a positive ($p<0.05$) effect on tuber fresh weight in 2008 and 2009, respectively (Table 6). Shoot dry weight accounted for 38.4% in total variation of tuber fresh weight, while plant height accounted for 10.0%. However, regression analysis did not identify any significant relationship between shoot senescence and the other traits (data not shown).

Data on rainfall and temperature were obtained from the IITA GIS unit. The average rainfall from May to November (months plant were grown on the field) was 164.67 mm in 2008 and 124.60 mm in 2009, while minimum and maximum temperatures were respectively 21.9 and 29.8°C in 2008 and 21.8 and 29.4°C in 2009.

DISCUSSION

Traits with direct effect on tuber fresh weight were identified as shoot dry weight and plant height. Although, the magnitude of the effect of these traits on tuber fresh weight varied with the year, that is, the effect of shoot dry weight was significant in 2008, while that of plant height was significant in 2009, the two traits had a strong positive correlation, indicating that either of them can be used to select plants for high tuber fresh yield. Previous study by other researchers had shown a strong positive relationship between tuber fresh weight and shoot dry weight (Akoroda, 1984), indicating that dense biomass/ canopy may be a morphological marker for selecting genotypes of *D. rotundata* for increased tuber yield. Our result showed that accessions that produced high shoot dry weight are likely to produce high tuber fresh weight, but other inherent factors may contribute to increased tuber fresh weight in *D. rotundata* (Sobulo, 1972; Suja et al., 2005). For instance, TDr 99/02562 had high tuber fresh weight and shoot dry weight, while TDr 97/00960 and Akoko had high tuber fresh weight, but relatively low shoot dry weight.

In larger populations it would be useful to estimate the harvest index and use it as a basis for comparison. Shoot emergence time, tuber initiation time, tuber dormancy period and tuber dry matter content may also be related to tuber yield, but they correlated negatively with tuber fresh weight as they influence the growth period of the plant. For instance, accession TDr 95/18949 which had high tuber fresh weight, broke dormancy early and produced shoots early, indicating that early establishment

Table 2. Mean values of physiological traits at different growth stages from time of planting of *D. rotundata*.

Sampling time	Tuber number per plant		Fresh tuber weight/plant		% dry matter content		Plant height		Shoot dry weight/plant	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
3 months			216.7 ± 25.0^{d}		16.7 ± 0.39^{d}		180.7 ± 7.18^{a}		69.9 ± 3.4^{a}	
4 months	2.3 ± 0.11^{a}	1.4 ± 0.06^{a}	565.1 ± 48.5^{b}	747.5 ± 59.2^{d}	23.6 ± 0.41^{c}	22.8 ± 0.39^{d}	200.5 ± 8.2^{a}	197.9 ± 9.6^{a}	69.6 ± 4.1^{a}	103.1 ± 5.6a
5 months	1.9 ± 0.08^{b}	1.5 ± 0.06^{a}	819.5 ± 46.9^{a}	1072.8 ± 59.2^{b}	27.9 ± 0.40^{b}	28.7 ± 0.39^{c}	190.0 ± 7.8^{a}	208.3 ± 9.6^{a}	54.3 ± 3.9^{b}	85.9 ± 5.5b
6 months	1.2 ± 0.12^{c}	1.5 ± 0.06^{a}	400.0 ± 51.0^{c}	1342.9 ± 59.2^{a}	29.7 ± 0.43^{a}	30.5 ± 0.39^{b}				
7 months		1.6 ± 0.06^{a}		1220.0 ± 59.2^{ab}		31.1 ± 0.39^{b}				
8 months		1.4 ± 0.08^{a}		940.2 ± 70.4^{c}		35.5 ± 0.43^{a}				

Means followed by different letter within a column are significantly different (p Ò0.05) in the Tukey test.

Table 3. Tuber parenchyma colour of eight accessions of *D. rotundata* assessed at different growth stages (sampling times in months after planting).

Sampling time	Tuber part	TDr 95/18949	TDr 99/02562	TDr 97/00960	TDr 00/00403	Ehobia	Amula	Omi Efun	Akoko
4 months	Head	Creamy	Creamy	Creamy	Creamy	Creamy	Purple-creamy	Purple	Creamy
	Middle	White	Creamy	Creamy	Creamy	Creamy	Creamy	White	Creamy
	Tail	White	Creamy	White	Creamy	White	White	White	White
5 months	Head	Creamy	Creamy	Creamy	Creamy	Purple	Creamy	Purple	Purple
	Middle	Creamy	Off-white	White	Creamy	White	White	Creamy	Off-white
	Tail	Creamy	Off-white	White	off-white	White	White	Purple	Off-white
6 months	Head	Creamy	Creamy	Creamy	Off-white	Purple-creamy	Purple-white	Creamy	Creamy
	Middle	Creamy	Creamy	Off-white	White	Creamy	White	Creamy	Off-white
	Tail	Creamy	Off-white	Off-white	White	White	White	Off-white	White
7 months	Head	Creamy	Creamy	Creamy	Off-white	Creamy	Purple-creamy	Purple-white	Creamy
	Middle	Creamy	Creamy	Creamy	White	Creamy	Creamy	White	Off-white
	Tail	Creamy	Off-white	White	White	White	Creamy	White	Off-white
8 months	Head	Creamy	Creamy	Creamy	Off-white	Creamy	Purple-creamy	Purple-white	Creamy
	Middle	Creamy	Creamy	Creamy	White	Creamy	Creamy	White	Off-white
	Tail	Creamy	Off-white	White	White	White	Creamy	White	Off-white

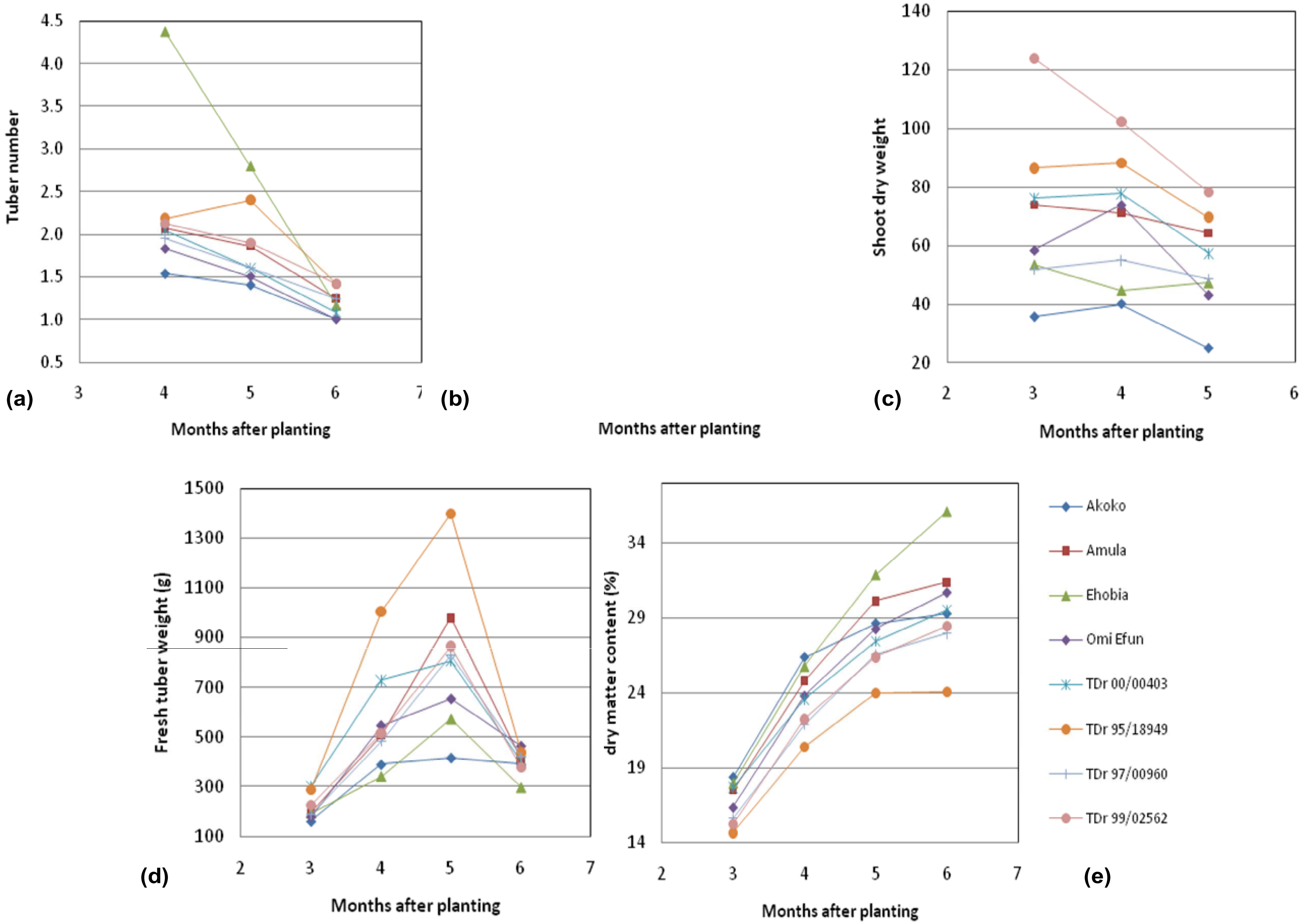

Figure 1. Tuber number (a), plant height (b), shoot dry weight (c), fresh tuber weight (d) and percent tuber dry matter (e) of *D. rotundata* accessions harvested at 3 to 6 months after planting in 2008.

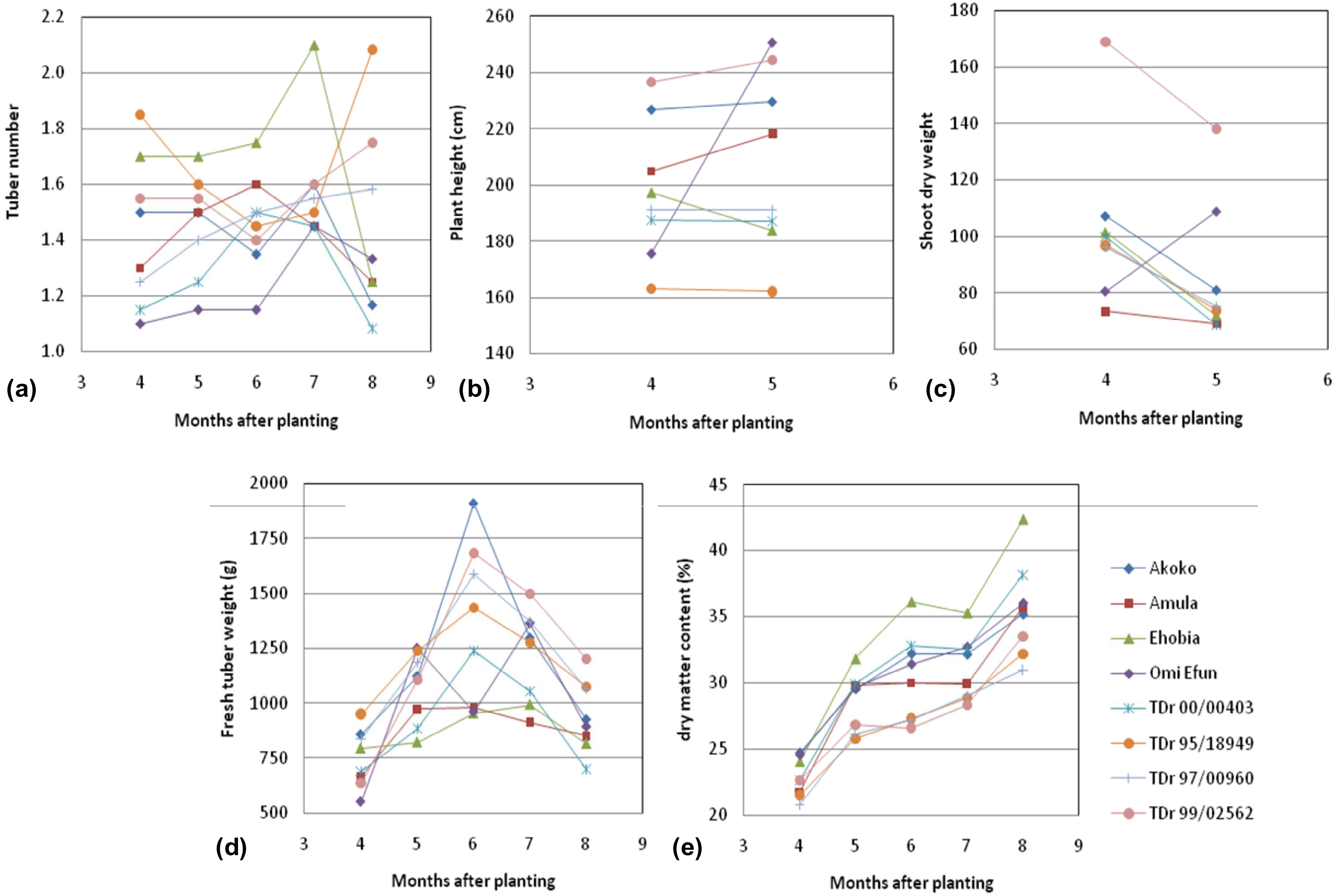

Figure 2. Tuber number (a), plant height (b), shoot dry weight (c), fresh tuber weight (d) and percent tuber dry matter (e) of *D. rotundata* accessions harvested at 4 to 8 months after planting in 2009.

Table 4. Potential mapping population parents of *D. rotundata* accessions with contrasting phenotypic expression of nine traits assessed in 2008 and 2009.

Trait	Status	
	Early	**Late**
Shoot emergence	TDr 95/18949 TDr 99/02562	Omi Efun Amula Akoko
Shoot senescence	TDr 95/18949 Ehobia Amula	TDr 00/00403 TDr 99/02562 Omi Efun
Tuber dormancy period	TDr 95/18949 Akoko TDr 97/00960	TDr 99/02562 TDr 00/00403 Amula
	Low	High
No. tubers per plant	Omi Efun Akoko	Ehobia TDr 95/18949 TDr 99/02562
Tuber fresh weight	Ehobia Omi Efun Amula	TDr 95/18949 TDr 97/00960 TDr 99/02562 Akoko
Shoot dry weight	Akoko Ehobia TDr 97/00960	TDr 99/02562
Tuber dry matter content	TDr 95/18949 TDr 97/00960 TDr 99/02562	Ehobia Akoko Amula

could be associated with increased tuber yield. Moreover, tubers of high fresh weight were generally low in dry matter content. For instance, tubers of Ehobia and Amula had low fresh weight but high dry matter content, while those of TDr 95/18949, TDr 99/02562 and TDr 97/00960 had high fresh weight but low dry matter content. The implication is that developing a cultivar for increased tuber yield based on fresh weight may be disadvantageous to those in tuber processing industries, for example, flour processors, who prefer accessions with high dry matter content. Contrarily, accession Akoko had high tuber fresh weight and also high tuber dry matter content, and may be a good candidate for flour processing industry, or a parent for developing a cultivar with combined ability for yield and dry matter production.

Tuber fresh weight for all the accessions were higher in 2009 than in 2008, which may have resulted from differences in time of planting and environmental conditions such as soil nutrient status, rainfall and temperature. Temperatures were similar in both years while the average rainfall was slightly higher in 2008 (164.67 mm) than in 2009 (124.60 mm). Planting was done earlier in 2009 (during May) than in 2008 (during June) and early planting of yams has been reported to increase tuber yield (Agbaje and Aluko, 2009). In contrast, late planting has been reported to reduce tuber yield due to shorter growth cycle and reduced tuber growth duration (Akoroda, 1993; Orkwor and Ekanakaye, 1998). Hence, variation in soil fertility in combination with early planting could be the basis for the yield difference, although soil nutrient status was not tested. The highest and lowest tuber yields over the two years were obtained from TDr 95/18949 (9.4 in 2008 and 11.9 t/ha in 2009) and Ehobia (4.0 in 2008 and 8.8 t/ha in 2009), respectively.

In yams, the separation of early maturing and late

Table 5. Coefficients of correlation among physiological traits in *D. rotundata* assessed in 2008 and 2009.

		N Tubers	tfw	dmc	pht	sdw	tubini	emer	dorm
	2008	-0.02							
tfw	2009	-0.37							
	combined	-0.16							
	2008	0.30*	-0.80**						
dmc	2009	0.18	-0.38						
	combined	0.25	-0.91**						
	2008	0.09	0.40**	-0.12					
pht	2009	-0.04	0.31	-0.07					
	combined	-0.13	-0.15	-0.11					
	2008	0.09	0.63**	-0.56**	0.78**				
sdw	2009	-0.27	0.72**	-0.29	0.62**				
	combine	0.02	0.31	-0.48	0.62				
	2008	-0.32*	-0.47**	0.19	-0.57**	-0.47**			
tubini	2009	-0.34	0.34	0.10	0.07	0.50*			
	combined	-0.39	0.02	0.02	-0.17	0.33			
	2008	0.04	-0.66**	0.79**	-0.27	-0.69**	0.50**		
emer	2009	-0.39	0.39	0.44	0.01	0.20	0.33		
	combined	-0.2	-0.66	0.67	-0.03	-0.61	-0.01		
	2008	0.05	-0.54**	0.51**	0.46**	0.17	-0.06	0.11	
dorm	2009	0.21	-0.77**	0.29	0.20	-0.26	-0.13	-0.42	
	combined	-0.16	-0.16	0.38	0.65	0.34	0.08	0.07	
sen	2009	-0.46	-0.09	-0.12	0.38	0.57	0.51	-0.37	0.73*

*: (p Ò0.05), **: (p Ò0.01). emer, Shoot emergence (days from planting); tubini, tuber initiation time (days from planting); N tubers, number of tubers per plant; tfw, tuber fresh weight per plant (g); dmc, tuber dry matter content (%); pht, plant height (cm); sdw, shoot dry weight per plant (g); sen, shoot senescence (days from planting); dorm, dormancy period (days from harvesting).

maturing accessions is not as easy as in other crops like cereals. Although a change in pigmentation of leaves, for example, green to dark green is used as an indicator by traditional farmers to determine maturity time in yam, it is not clear if the change in pigmentation will reflect physiological maturity. In our assessment, there was no clear contrast in leaf colour at all sampling times in all the accessions, indicating that colour indices of leaves do not change with plant age, and this is in support of what Akinwande (2005) had observed previously. It is generally believed that the proximal end (head) of a yam tuber matures earlier than the distal end (tail), and this reflects differences in colour of the head, middle and tail. Uniformity in tuber parenchyma colour, however, may be an indication of tuber maturity, if it happens during later growth stages of the crop. In accession TDr 95/18949, tuber parenchyma colours of head, middle and tail were creamy at 5, 6, 7 and 8 months after planting, indicating that this accession matured 5 months after transplanting. Shoot senescence was observed in TDr 95/18949 at about six months after planting, confirming that this accession is early maturing. However, no significant relationship was observed between time of shoot senescence and tuber colour. Time of shoot senescence correlated strongly and positively with tuber dormancy period. Late senescing accessions (TDr 00/00403 and TDr 99/02562) broke tuber dormancy late, while early senescing TDr 95/18949 broke tuber dormancy early, indicating that accessions of *D. rotundata* that broke dormancy early may be maturing early.

This however needs to be tested in a broader range of germplasm in the species, as other species like *D. cayenensis* that grow in the forest zone and are much later maturing generally have shorter dormancy com-

Table 6. Regression analysis to determine tuber yield related traits in *D. rotundata* assessed in 2008 and 2009.

Trait related to tfw	Estimate		Standard error		Pr > |t|		Contribution (%)	
	2008	2009	2008	2009	2008	2009	2008	2009
sdw	4.87	3.15	1.55	1.99	0.007	0.136	38.4	5.7
tubini	-16.77	-10.92	11.54	17.96	0.168	0.553	8.2	0.8
N tubers	30.46	-26.61	46.98	133.74	0.527	0.845	1.6	0.1
dmc	-18.38	-1.92	15.78	23.77	0.264	0.937	5.3	0.1
pht	-0.73	2.68	0.67	1.29	0.292	0.056	4.7	10.0
emer	-6.46	5.13	11.16	19.01	0.572	0.791	1.3	0.2
dorm	0.24	-7.56	1.91	4.69	0.901	0.129	0.1	6.0
tfw Mean	626.8	1054.4						
R-Square	0.9506	0.8953						
Coeff. Var.	11.22	11.49						

N tubers, Number of tubers per plant; tfw, tuber fresh weight per plant (g); dmc, tuber dry matter content (%); pht, plant height (cm); sdw, shoot dry weight per plant (g); tubini, tuber initiation time (days from planting); emer, shoot emergence (days from planting); dorm, dormancy period (days from harvesting.

pared to *D. rotundata* (Craufurd et al., 2001). The relationship between maturity and dormancy in yam tubers has also been the subject of earlier studies in *D. alata* (Passam et al., 1982).

The development of mapping population requires the crossing parents to be different in traits of interest in order to facilitate linkage mapping and segregation analysis (Young, 1994).

In this assessment, some accessions differ in most of the traits (Table 4) and they may be used as crossing parents for developing mapping populations for the traits. For instance, TDr 95/18949 and TDr 99/02562 are both high yielding but differ in time of shoot senescence and tuber dormancy period, and they could be used as parents to develop a mapping population for tuber maturity and dormancy if they differ in gender. TDr 95/18949 senesced late and had short tuber dormancy period, while TDr 99/02562 senesced early and had long tuber dormancy period.

Conclusion

Shoot dry weight and plant height were identified as major tuber yield-related traits in *D. rotundata*. Early field emergence and tuber initiation, short tuber dormancy period and low tuber dry matter content may also enhance tuber yield. Uniform tuber parenchyma colour at advanced growth stage, time of shoot senescence and tuber dormancy period were identified as maturity related traits. Accessions were identified that may be used as parents for developing mapping populations for some of the traits assessed in the study.

Our results, however, are based on a limited sample size (eight accessions), hence further analysis of a larger population may provide a better understanding of tuber yield and maturity related traits in white yam.

ACKNOWLEDGEMENTS

We thank Esther Ene Obaje, Patrick Ezighi, Oyeyemi Azeez, Toye Ayankami and Sunday Itebojie of the IITA yam Breeding Unit for helping with data collection.

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