Tuber maturity of white yam (*Dioscorea rotundata*)

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Abstract

Tuber maturity of yams (*Dioscorea* spp.) is a crucial factor in the production, marketing and consumption of the crop. A tuber that is not matured tastes poorly and does not store well. Tuber maturity, however, is difficult to measure directly, and the identification of related traits that distinguish early and late maturing accessions will be a useful tool in the genetic improvement of the crop. In this study, 10 morphological/physiological traits: time of shoot emergence, time of tuber initiation, leaf colour, plant height, shoot dry weight, tuber fresh weight, tuber number per plant, tuber colour (skin and parenchyma), tuber dry matter content and tuber dormancy period were assessed in eight accessions of *D. rotundata* during the 2008 yam growing season. Results show that attainment of stable tuber dry matter content and uniform parenchyma colour of the head, middle and tail portions of a tuber are indicators of physiological maturity in *D. rotundata*. Early and late maturing accessions could be separated by time of attainment of stable tuber dry matter content and uniform parenchyma colour within a tuber, rate of tuber bulking and length of tuber dormancy period. Early maturing accessions attain physiological maturity 5-6 months after planting while the late ones take longer. Tuber yield and tuber dry matter content correlated negatively, and tubers of high fresh weight were low in dry matter content. Regression analysis identified shoot dry weight and time of tuber initiation as major related traits to tuber fresh weight.

Keywords: *Dioscorea rotundata*; tuber maturity; tuber dormancy; dry matter content; yield related traits.

Introduction

Yams (*Dioscorea* spp) are widely cultivated throughout the humid and subhumid tropics in Africa, the Caribbean and the South Pacific Islands, with some production in the subtropics and temperate zone. Yams, of family Dioscoreaceae, are important staple food crops for over 300 million people in the tropics and subtropics. In West Africa, about 48 million tons of yams are produced annually on 4 million hectares of arable land. In this region, yams play key roles in food security and income generation, and are also integral to socio-cultural life of the people. 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). In West Africa, *D. rotundata* is the most commonly cultivated species.

One of the major constraints to yam improvement is its long growth cycle, or maturity period, which varies from six to more than eight months depending on the species and cultivar. This slows down yam breeding and related research activities, and also restricts the supply of the crop to only once per year. The development of early maturing cultivars may result in double cropping (producing yam more than once in a year), and this will promote increased production of the crop. Changing climatic pattern also necessitates 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 yams for processing and to determine optimum storage conditions. A tuber that is not matured tastes poorly and does not store well. Tuber maturity, however, is difficult to measure directly, and so far there is no clear indicator to determine physiological maturity in yam. Generally, yam is considered to be matured when the foliage (leaves or vines) is fully senesced (yellow or brown coloration). However, this could be misleading as environmental effect such as disease incidence, water or other stress conditions, may lead to early senescence of foliage. It is necessary to look for alternative indicators that may have little or no environmental influence. A change in pigmentation of leaves (e.g. green to dark green) is used as an indicator by traditional farmers to identify early maturing yam cultivars. However, previous research has shown that colour indices of leaves do not change with plant age (Akinwande 2005). The objectives of this research were to determine the state and time of

physiological maturity in *D. rotundata* yam and to identify traits that can distinguish early and late maturing accessions of this species.

Materials and methods

Plant preparation and experimental design

Eight accessions of *D. rotundata* including four breeding lines and four land races were used in the study. The land races, Ehobia, Amula, Omi Efun (all 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), all medium to late-maturing, were available from IITA's Yam Breeding Program. Two hundred and twenty tuber setts, each weighing 100g were prepared for every accession, and sprouted in carbonized rice husk. Fifty sprouted setts of each accession were transplanted in the field on 8th May 2008, and replicated four times in a randomized complete block design.

Trait phenotyping

Data were collected on shoot emergence, time of tuber initiation, leaf colour, plant height, shoot dry weight, tuber fresh weight, tuber number per plant, tuber colour (skin and parenchyma), tuber dry matter content and tuber dormancy period. Data collection on shoot emergence and time of tuber initiation started 10 and 50 days, respectively after planting. Data for the other traits were collected in sequence at 3, 4, 5 and 6 months after planting. Data were collected from all the plants (50/block/accession) for shoot emergence, and from five plants for all the other traits at all sampling times except for the sampling at 6 months for which data were collected from three plants because some plants were dead. The five plants were identified by selecting one out of every 10 plants along a row of 50 plants per block. Tuber number was not recorded at 3 months sampling, while plant height and shoot dry weight were not measured at 6 months sampling because the plants were all senesced at 6 months sampling time. At every sampling time, except for shoot emergence and tuber initiation, all tubers per plant were first harvested and weighed. Data were collected as follows:

Shoot emergence. This was recorded as the number of days between planting of sprouted tuber and the time the shoot emerged above the ground.

Tuber initiation. The bases of the selected clones were opened every other day until they all initiated tubers.

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

Tuber number. Number of tubers per plant counted and recorded. Tuber numbers were counted during 4, 5 and 6 months harvests.

Tuber fresh weight. All tubers per plant were weighed after harvest, and recorded as tuber fresh weight.

***Tuber colour* (skin and parenchyma of head, middle and tail).** This was determined using the Methuen Handbook of Colour (Kornerup and Wanscher 1978). One tuber was cut vertically with a knife from head to tail and colours of head, middle and tail portions 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 hours and weighed (W2). Per cent (%) dry matter content was calculated as (W2/W1) x 100.

Plant height. After harvest, length of the longest vine was measured with a tape rule and recorded. Plant height was not measured during 6 month harvest as the shoots were all dried out.

Shoot dry weight. All vines and leaves per plant were oven dried at 105°C for 48 hours and weighed.

Disease incidence. Incidence of yam mosaic virus, anthracnose and leaf blight were scored 40-45 days after transplanting, and at 3, 4 and 5 months harvesting times.

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

Data analysis

Two kinds of analysis were performed: (1) traits measured four times (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 one time (tuber initiation time, shoot emergence time and dormancy) were analyzed by a simple linear model. We used a Linear Mixed Model considering replications, accessions, sampling times, and the interaction between accession and sampling time as fixed effects, and the interaction between replication by clone 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 III sum of squares (SS) and partial regression coefficients were calculated to measure the effect of each trait after the effect of all other was removed from the model. The Type III SS were expressed as a percentage of the "all traits sum of squares" to get a relative measure of the contribution of each trait.

Results

The accessions were significantly ($p<0.01$) different for all the traits assessed except for tuber initiation time (Table 1) for which they were similar. The interaction between accession and time of sampling was only significant ($p<0.001$) for tuber number per plant and tuber fresh weight. Time of shoot emergence varied significantly ($p<0.001$) among accessions. The number of days a shoot took to emerge ranged from 10 to 61 days with an average of 19.9 days from time of planting (Table 1). Shoot emergence was early in TDr 99/02562 (14.2 days) and TDr 95/18949 (14.4 days), but late in Omi efun (24.4 days) and Ehobia (23.1 days). Generally, shoot emergence was earlier in breeding lines than in the land races. Time of tuber initiation was on average 52.2 days from time of planting, and was similar for all the accessions (Table 1).

Trait expression was significantly ($p<0.001$) different at each sampling time, except for plant height that was similar at 3, 4 and 5 months sampling time (Table 2), indicating that height measurement in *D. rotundata* would be ideal at three months after planting. Plant height varied significantly among the accessions and was on average highest in Amula (239 cm) and lowest in Akoko (144.7 cm) (Table 1). The accessions were significantly different in shoot dry weight at 3, 4 and 5 harvest times (Table 1). Comparing shoot dry weight at the first three harvests, it was lowest at 5 month harvest, and similar for third and fourth harvest (Table 2,). It was highest in TDr 99/02562 (101.5 g/plant) and lowest in Akoko (33.5 g/plant). The shoots were all dead by the time of the 6 month harvest.

Tuber number decreased with growth period (Table 2,), and was lowest at 6 month harvest. Some accessions, for instance, Ehobia produced more tubers during the early growth period, but tuber number was similar in all the accessions at 6 month harvest time. Tuber number increased from third to fourth month growth period in TDr 95/18949.

Fresh tuber weight increased from 3 months through to the fifth month after planting and decreased significantly afterwards (Table 2,). Fresh tuber weight of all accessions increased sharply from the third to the forth month after planting, and thereafter the increase slowed down in Akoko, TDr 00/00403 and Omi efun. Tuber bulking was fastest in TDr 95/18944 and TDr 00/00403 than in the other accessions. At 6 month harvest time, fresh tuber weight was highest in Omi efun (462.5 g), least in Ehobia (295.8 g) and similar in the other accessions. The average fresh tuber weight across sampling times was highest in TDr 95/18949 (781.80 g) and lowest in Akoko (340.23 g*).*

Table 1. Mean values of physiological traits during growth stages of eight accessions of *D. rotundata*. Means with the same letter within a column are not significantly different

Accession	Number of tubers/plant	Tuber fresh weight/plant (g)	Tuber dry matter content (%)	Plant height (cm)	Shoot dry weight/plant (g)	Tuber initiation (days from planting)	Shoot emergence (days from planting)	Dormancy period (days from harvesting)
Akoko	1.31±0.19 b	340.23±40.11 c	25.65±0.83 ab	144.67±13.13 c	33.53±7.16 d	52.44±0.69 a	21.99±0.75 a	69.48±4.33 ab
Amula	1.73±0.19 b	524.45±38.97 bc	25.95±0.81 ab	239.00±11.60 a	69.78±6.87 abc	51.58±0.65 a	22.18±0.72 a	79.85±4.48 a
Ehobia	2.78±0.18 a	350.61±38.46 c	27.93±0.80 a	174.50±11.37 bc	48.49±6.72 cd	52.22±0.67 a	23.13±0.73 a	77.45±4.49 a
Omi Efun	1.44±0.19 b	459.52±39.51 bc	24.79±0.82 ab	182.43±11.84 bc	58.53±6.97 bcd	53.17±0.66 a	24.39±0.73 a	71.84±4.46 ab
TDr 00/00403	1.58±0.18 b	559.26±38.21 b	24.55±0.80 abc	196.71±11.26 abc	70.39±6.67 abc	52.13±0.65 a	15.89±0.71 b	78.30±4.45 a
TDr 95/18949	2.00±0.18 ab	781.80±38.21 a	20.77±0.80 c	189.38±11.26 abc	81.49±6.67 ab	51.79±0.66 a	14.39±0.71 b	55.37±4.33 b
TDr 97/00960	1.60±0.18 b	479.82±38.21 bc	22.99±0.80 bc	170.99±11.26 bc	51.71±6.67 bcd	52.28±0.68 a	17.39±0.72 b	74.05±4.48 ab
TDr 99/02562	1.81±0.18 b	496.05±38.23 bc	23.06±0.80 bc	224.06±11.27 ab	101.54±6.66 a	51.99±0.66 a	14.17±0.71 b	84.52±4.30 a
Means	1.77±0.18.	499.38±38.74	24.66±0.81	185.38±11.62	59.13±6.80	52.23±0.67	19.91±0.72	72.34±4.42
P>F(comparison between accessions)	0.0005	<.0001	0.0001	0.0005	<.0001	0.8108	<.0001	0.0046
P>F(accession x time interaction)	0.001	<.0001	0.277	0.805	0.557			

Dry matter content increased significantly ($p<0.001$) with growth period (Table 2,). The increase was rapid from 3 to 5 months and slowed down afterwards. Dry matter content was similar at 5 and 6 months growth period for some accessions; for instance, it was 24% in TDr 95/18949 and 29% in Akoko at 5 and 6 months growth stages. At 6 months growth period, dry matter content continued to increase in Ehobia, Omi efun, TDr 99/02562 and TDr 00/00403, but started to decrease in Amula and TDr 97/00960. The average dry matter content was highest in Ehobia (27.93%) and lowest in TDr 95/18949 (20.77%) (Table 1).

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 (data not shown). In all the accessions, leaf colour was generally dark green at 3 months harvest, or dark or deep green at 5 months harvest. At 4 months harvest, leaf colour was greyishgreen or dark green or deep green across the accessions. Leaf senescence started during the fifth month after planting, but was observed only in few accessions. All the leaves were completely senesced at 6 months after planting.

In general, there was no clear demarcation in colour of some of the accessions at any sampling time. 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. At 6 months harvest time, tuber head was creamy in all the accessions, except in Ehobia, whose tubers appeared to be characteristically white across the three portions. The head, middle and tail portions were creamy in TDr 95/18949 and TDr 00/00403 at both 5 and 6 months harvest, and in Akoko at 6 month harvest. Contrarily, in TDr 99/02562, all the three portions were creamy at all sampling times, except at 6 month where only the head was creamy, while the middle and tail were white. Tuber skin colour was largely white in all accessions at 4 months sampling time, and brown or golden at 5 and 6 months sampling times, but was not distinguishable among accessions.

Tuber dormancy period measured as number of days from time of tuber harvesting to time of 80-100% tuber sprouting is shown in Table 1. Tuber sprouting time was significantly ($p <.0001$) different among the accessions, and was on average 72.3 days from time of harvest. It was early in TDr 95/18949 (55.4 days) and Akoko (79.5 days), and late in TDr 99/02562 (84 days) and Amula (80 days). When calculated from time of tuber initiation to time of sprouting, tuber dormancy period was similar (about 130 days) in all the accessions.

Simple correlation analysis of eight of the ten traits identified significant correlations among most of the traits (Table 3) e.g correlation was positive ($p<0.01$) between tuber yield (tuber fresh weight) and shoot dry weight ($r = 0.63$), but negative between the yield and tuber dry matter content ($r = -80$) . When regression analysis was performed using tuber fresh weight as dependent variable and the other traits as independent variables, shoot dry weight had positive($p<0.05$) effect on tuber fresh weight (contributing 38.72%), while tuber initiation had negative effect (contributing 20.95%) (Table 4).

Discussion

Tuber maturity

Results indicated that early and late maturing accessions can be distinguished based on speed and time of cessation of tuber bulking, time of attainment of stable tuber dry matter content, time of attainment of uniform tuber parenchyma colour of the head, middle and tail portions of a tuber, and length of tuber dormancy period. Tuber bulking was fastest in TDr 95/18949, while the period of bulking was shortest in Akoko. Fresh tuber weight increased from 3 months through to the fifth month after planting and decreased significantly afterwards (Table 2,), indicating that tuber bulking in *D. rotundata* generally terminates at five months after planting. Tuber dry matter content of TDr 95/18949 and Akoko appear to reach a stable stage at 5 months after planting, while in the other accessions dry matter content continued to increase after 6 months from planting. In other accessions, such as Ehobia, Omi efun, Amula and TDr 99/02562, dry matter content kept increasing even at 6 months growth period, suggesting that these accessions are late maturing. Assessment of dry matter content at later growth stages, for instance, at 7 or 8 months after planting, may have led to the determination of the growth stage at which those accessions attain stable tuber dry matter content levels, but the experiment was terminated 6 months after planting. As in the case with tuber bulking and tuber dry matter content, tuber parenchyma colours of the head, middle and tail portions were the same (creamy) at 5 and 6 months after planting in TDr 95/18949 and Akoko respectively, indicating that these two accessions are early maturing, and were physiologically matured 5 to 6 months after planting. In yams, the proximal end (head) of a tuber matures earlier than the distal end (tail), and this reflects differences in colour of the head, middle and tail. Although colour and

its intensity may vary among accessions, immature tuber potions are generally white in colour, hence the tail portion is mostly white compared to the other portions at all growth stages. Tuber heads of all the accessions were mostly creamy at all harvest times. Tuber parenchyma colour was generally creamy at 6 months harvest, which indicates that creamy colour of tuber parenchyma may be associated with maturity in *D. rotundata*. At the time of final harvest (6 months after planting), only the head portion was creamy, while the middle and tail were largely white in TDr 99/02562, Ehobia, Amula and Omi Efun, indicating that these accessions were late maturing and would require longer than 6 months to attain physiological maturity. However, uniformity in colour across a tuber was also observed during the early growth stages in TDr 99/02562, Omi efun and Ehobia, but this pattern changed during the advanced growth stages, ruling out tuber maturity at those early growth stages.

Tuber dormancy period measured as duration from time of harvest to time of tuber sprouting was significantly shorter in TDr 95/18949 and Akoko than in the other accessions (Table 1), indicating that early maturing accessions of *D. rotundata* may have shorter dormancy. In our investigation, tuber dormancy measured as number of days from time of harvest to time of 80-100% tuber sprouting was on average 73 days, and was short in TDr 95/18949 (55 days) and Akoko (70 days), and long in TDr 99/02562 (84 days) and Amula (80 days). This result is in agreement with findings of Craufurd et al (2001) who observed, based on dormancy assessment of 286 *D. rotundata* accessions grown in the field and stored in a yam barn, that the duration from harvesting to sprouting ranged from 60 to >110 d, with the greatest number of accessions sprouting between 70 and 80 d after harvest.

The rate of tuber bulking, dry matter content, tuber colour and tuber dormancy are traits that can only be measured after the crop is harvested or by destroying the tuber while the crop is still growing on the field. They are not visible traits that can be used to select early or late maturing crops from a field of growing crops. Further evaluation of these accessions based on time of leaf senescence is necessary to validate these results. Generally, yam is considered to be matured when the foliage (leaves or vines) is fully senesced (yellow or brown coloration). However, this could be misleading as environmental effect such as disease incidence, water or other stress conditions, may lead to early senescence of foliage. In this experiment, for instance, all the accessions were completely senesced 6 months after planting, but this time (December) coincided with the onset of dry season, and may not necessarily indicate physiological maturity of the accessions. A change in pigmentation of leaves (e.g. green to dark green) is used as an indicator by traditional farmers to identify early maturing yam cultivars. However, our results show that colour indices of leaves do not change with plant age, and this has been confirmed previously (Akinwande 2005).

Tuber yield related traits

Assessment of eight traits using simple correlation and regression analyses identified shoot dry weight and time of tuber initiation as major related traits of tuber fresh weight (tuber yield) in *D. rotundata*. The effect of shoot dry weight on tuber fresh weight was positive, while that of time of tuber initiation was negative, and the correlation between shoot dry weight and time of tuber initiation was negative. The positive correlation between shoot dry weight and tuber yield had been observed earlier (Lakshmi and Eswaiamma 1980). Tuber initiation in *D. rotundata* has been reported to occur from sprouting to 84 days after sprouting (Okezie et al., 1981; Njoku et al., 1984). The timing of tuber initiation and the duration of the period of tuber formation vary within and between species, and are affected also by environmental factors (Craufurd et al 2001). In this experiment the accessions initiated tubers at similar time, and the average tuber initiation time was 52 days from time of planting. The implication of the correlation among tuber fresh weight, shoot dry weight and tuber initiation time is that high yielding cultivars of *D. rotundata* may either produce dense foliage, or initiate tubers early. Our results show that TDr 95/18949, which tuber had the highest fresh weight was correspondingly one of the accessions that had the highest shoot dry weight. Conversely, accessions with the lowest tuber yield (Akoko and Ehobia) had the least shoot dry weight (Table 1).

Tuber yield and tuber dry matter content had a strong negative correlation, and tubers of high fresh weight were low in dry matter content. For instance, Ehobia with the least tuber fresh weight (350.6 g) had the highest dry matter content (27.9%), while TDr 95/18949 with the highest tuber fresh weight (781.8 g) had the lowest dry matter content (20.8%) (Table 1). The implication is that developing a cultivar for increased tuber yield based on fresh weight will be disadvantageous to those in tuber processing industries, e.g. flour processing, who prefer accessions with high dry matter content.

Peak yield values, expressed as tuber fresh weight were highest at 5 months after planting for all the accessions. This is in agreement with findings of Akinwande (2007), who obtained peak yields at 6 months after vine emergence. The decrease in tuber fresh weight at 6 months after planting could be as a result of tuber losses due to pests and diseases during tuber development. However, tuber fresh weight at 4, 5 and 6 months after harvest did not change in Akoko (about 400 g), indicating that this accession might have reached physiological maturity at 4 months after planting, and may be resistant to pests and diseases of yams.

Tuber number decreased with growth period (Table 2,), and was lowest at 6 month harvest, indicating that some tubers died before the 6 month harvest. Although some accessions, for instance, Ehobia produced more tubers during the early growth period, tuber number was similar in all the accessions at 6 month harvest time, which suggests that Ehobia may be prone to high tuber rot. An increase in tuber number from third to forth month growth period was observed in TDr 95/18949, indicating that this accession can form new tubers over an extended period of time.

Conclusions

Attainment of stable tuber dry matter content and uniform parenchyma colour of the head, middle and tail portions of a tuber are indicators of physiological maturity in *D. rotundata*. Early and late maturing accessions of *D. rotundata* may be separated by the rate of tuber bulking, time of attainment of stable tuber dry matter content and uniform parenchyma colour of the head, middle and tail portions of a tuber, and the length of tuber dormancy period. Among the eight traits assessed shoot dry weight and time of tuber initiation were identified as major related traits of tuber fresh weight in *D. rotundata*. Tuber yield and tuber dry matter content correlated negatively and high fresh weight tubers were low in dry matter content.

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Table 2. Mean values of physiological traits at different growth stages from time of planting of *D. rotundata*. Means with the same letter within a column are not significantly different

Sampling time after planting (months)	Number of tubers/plant	Tuber fresh weight/plant (g)	Tuber dry matter content (%)	Plant height (cm)	Shoot dry weight/plant (g)
3		216.93±25.53 d	16.68±0.39 d	180.69±7.18 a	69.98±3.43 a
4	2.26±0.09 a	564.07±26.61 b	23.59±0.40 c	199.88±7.21 a	69.15±3.57 a
5	1.88±0.09 b	814.88±24.56 a	27.89±0.38 b	190.08±6.65 a	54.17±3.30 b
6	1.19±0.11 c	400.00±31.44 c	29.67±0.47 a		
Means	1.78±0.10	498.97±27.04	24.46±0.41	190.22±7.01	64.43±3.43
P>F (comparison between time measures)	<.0001	<.0001	<.0001	0.1805	0.0007

Table 3. Coefficients of correlation among physiological traits in *D. rotundata* assessed in 2008

	Ntubers[†]	tfw	dm	ph	sdw	tubini	emer
tfw[‡]	-0.02ns						
dm	0.30*	-0.80**					
ph	0.09ns	0.40**	-0.12ns				
sdw	0.09ns	0.63**	-0.56**	0.78**			
tubini	-0.32*	-0.47**	0.19ns	-0.57**	-0.47**		
emer	0.04ns	-0.66**	0.79**	-0.27ns	-0.69**	0.50**	
dorm	0.05ns	-0.54**	0.51**	0.46**	0.17ns	-0.06ns	0.11ns

[†] ns: non significant, *: ($p<0.05$), **: ($p<0.01$)

[‡] Ntubers: Number of tubers per plant, tfw: Tuber fresh weight per plant (g), dm: Tuber dry matter content (%), ph: 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)

Table 4. Regression analysis to determine tuber yield related traits in *D. rotundata* assessed in 2008

tfw related traits	Regression Coefficients	Standard Error	t Value	Pr > |t|	contribution %
sdw	3.815	1.134	3.36	0.005	38.72
tubini	-20.862	8.435	-2.47	0.027	20.95
ntubers	43.22	38.182	1.13	0.277	4.39
dm	-7.205	8.487	-0.85	0.41	2.47
ph	-0.532	0.666	-0.8	0.438	2.19
emer	-7.659	7.807	-0.98	0.343	3.29
dorm	1.544	1.379	1.12	0.282	4.29
R-Square	Coeff Var	Root MSE	tfw Mean		
0.9422	9.51	47.55364	499.789		

Ntubers: Number of tubers per plant, tfw: Tuber fresh weight per plant (g), dm: Tuber dry matter content (%), ph: 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