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Distribution of dry matter and mineral nutrients in tubers of two cultivars of Dioscorea alata L.

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The distribution of dry matter, energy, N, P, Ca, K, Mg and crude protein were examined in the pulp and peel of two cultivars ('White Lisbon' and 'Oriental') of D. alata L. Positive physiological gradients in nutrient concentrations were observed. The concentrations of dry matter, energy, N, P, Ca, Mg and crude protein decreased from head to tail end of tubers; K was the only determinant to increase in concentration from head to tail end of tubers. The concentrations of K and Ca were higher while those of dry matter and N were lower in the peel than in the pulp. The pulp and peel of bulbils were higher in N, P and K and lower in Ca than the pulp and peel of whole tubers of similar size. Crude protein content on a dry weight basis decreased from head to tail end of tubers and was higher in the peel.

INTRODUCTION

The tubers of yams (Dioscorea spp.) are believed to be of stem origin and develop by the plagiotropic lobing of a degenerate rhizome (Burkill, 1960; Martin and Ortiz, 1962). The region of growth of the tuber is distal to the aerial stem or vine. The part of the tuber proximal to the vine is therefore older and thus physiologically more mature than the distal region.

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Physiological gradients have been demonstrated in tubers of the potato Macklon and DeKock, 1967; Johnston et al., 1968), and the cocoyam (Xanthosoma sagittifolium Schott) (Enyi, 1967). There is, however, little information on physiological gradients in yam tubers. Coursey (1967) noted that the head end of the tuber of yams is usually hard, woody and unpalatable. Miege (1957) found that the head and tail regions contain smaller starch grains than the middle region. Coursey et al. (1960) reported that the tail region of D. rotundata Poir. contains a markedly higher moisture content than the head end. Martin and Thompson (1971) examined the crude protein (N x 6.25) content of 40 yam cultivars belonging to five species, and found that crude protein content varied from 6.3 to 13.4 per cent on a dry weight basis. These authors reported crude protein values of 8.25 and 7.72 per cent from the unpeeled midsections of the D. alata L. cvs 'Farm Lisbon' ('White Lisbon') and 'Oriental', respectively. In the D. alata L. cv., 'Morado', it was found that crude protein content was highest in the upper (head) and inner portions of the tuber. The peel of the yam tuber consists of a corky bark and an immediately underlying cortex (Coursey, 1967). Oyenuga (1959) found that the peels of D. alata, D. rotundata, D. esculenta (Lour.) and D. cayenensis Lam. contain more crude and true protein, and thus nitrogen, than the rest of the tuber or pulp. Martin and Thompson (1971) also found a higher crude protein content in the peel of D. alata (cv. 'Morado').

It was the purpose of this study to determine the content and distribution of dry matter, energy and nutrients in the tuber of D. alata using cvs 'White Lisbon' and 'Oriental'.

MATERIALS AND METHODS

Three mature and dormant tubers weighing between 0.5 and 1.0 kg were selected from each cultivar. They were divided into head, middle, and tail sections. The sections were peeled with a sharp knife to a depth of about 2 mm. The portion so removed is hereafter called the peel. Samples of about 50 g were taken from the peeled portion (hereafter called the pulp). The peel from each section was taken as a sample. Samples from three small underground tubers and three bulbils (aerial tubers) of cv. 'White Lisbon', each weighing about 75 g, were similarly prepared. The peel from the small underground tubers and the bulbils were bulked as a single sample.

The samples were dried to a constant weight at 100°C and then ground. A sample of 100 mg of the ground material was digested with sulphuric acid and hydrogen peroxide. Total N was determined on this digest by micro-Kjeldahl distillation, and total P by the chlorostannous-molybdate method in a sulphuric acid system (Jackson, 1958). For K, Mg and Ca determinations, a sample of 500 mg of the ground material was ashed in a muffle furnace at 450°C for several hours and the residue dissolved in weak hydrochloric acid. Ca and Mg were determined by atomic absorption and K by flame photometry. Energy values were determined on the pulp of the head, middle and tail sections only; they were determined by bomb calorimetry.

RESULTS

The data presented in Table 1 show that very large differences exist among individual tubers for some determinations. The error variances for these determinations were high and significant variance ratios were not always recorded although definite trends were observed. The differences between tubers were sometimes higher than within tubers. Ca and P contents were the most variable determinants among tubers.

The distribution of dry matter, energy value and nutrients in the pulp and peel are presented in Tables 2 and 3, respectively. Dry matter percentage decreased from head end to tail end in the pulp of both cultivars. The head end had a significantly greater percentage dry matter than the middle and tail sections. There were small but insignificant differences between the cultivars for percentage dry matter in the pulp. The peel had a lower percentage dry matter and differences between the head and middle sections were not as marked as those in the pulp. Compared with 'Oriental', the various sections of the peel of 'White Lisbon' had a more uniform and lower percentage dry matter content.

Table 1. Dry matter, energy and nutrient contents of three individual tubers of 'White Lisbon' and 'Oriental' yams. Mean values of head, middle and tail sections expressed on a fresh weight basis

	'White Lisbon'			'Oriental'		
Pulp:						
Dry matter (%)	24.9	25.3	20.4	25.2	23.2	24.2
Energy (J/g)	3587	3818	3022	3755	3437	3541
N (mg/100 g)	283	448	227	420	256	360
P (mg/100 g)	35.3	38.4	28.3	49.5	12.4	28.3
K (mg/100 g)	312	317	384	356	165	280
Ca (mg/100 g)	9.5	34.9	15.4	13.7	32.5	27.6
Mg (mg/100 g)	23.0	24.6	18.7	16.9	16.6	16.7
Peel:						
Dry matter (%)	18.4	16.3	15.1	21.4	19.2	16.5
N (mg/100 g)	257	301	208	409	297	349
P (mg/100 g)	32.4	31.7	23.1	38.7	26.9	23.8
K (mg/100 g)	365	329	370	432	302	434
Ca (mg/100 g)	90.5	205.9	96.1	63.3	131.0	100.0
Mg (mg/100 g)	28.7	24.4	28.6	23.9	24.9	19.7

Table 2. Distribution of dry matter, energy and nutrients in the pulp of tubers of 'White Lisbon' and 'Oriental' yams (means of three tubers)

Cultivar	Section	Dry matter (%)	Energy (J/g)		Nutrient (mg/100 g fresh wt.)				
			Fresh wt.	Dry wt.	N	P	K	Ca	Mg
'White Lisbon'	Head	30.5	4584	14990	520	44.3	238	36.9	31.0
	Middle	20.3	2997	14831	251	28.5	277	14.3	22.3
	Tail	19.7	2846	14458	190	29.2	308	8.5	13.0
'Oriental'	Head	33.3	4981	14978	517	33.6	251	47.5	21.5
	Middle	21.3	3098	14538	271	27.0	286	17.8	17.0
	Tail	18.0	2654	14701	215	27.0	297	8.6	11.7
	SE	2.33	352	197	75	9.5	40	10.9	4.4
	CV(%)	16.9	17.2	2.2	39.7	51.4	25.1	32.5	39.2

Table 3. Distribution of dry matter and nutrients in the peel of tubers of 'White Lisbon' and 'Oriental' yams (means of three tubers)

Cultivar	Section	Dry matter (%)	Nutrient (mg/100 g fresh wt.)				
			N	P	K	Ca	Mg
'White Lisbon'	Head	16.5	316	30.9	323	167.4	30.5
	Middle	16.3	236	28.0	358	130.0	27.2
	Tail	16.9	215	28.3	383	95.2	24.0
'Oriental'	Head	20.7	412	35.1	364	106.7	25.2
	Middle	18.5	352	27.9	410	89.3	18.9
	Tail	18.6	312	26.4	394	98.3	23.5
	SE	1.44	34	4.5	38	33.6	2.5
	CV (%)	14.0	19.3	26.4	17.5	50.9	17.5

Like dry matter, the energy content of the fresh tuber decreased from head end to tail end (Table 2). When expressed on a dry weight basis the energy content was also highest in the head section but differences were not significant. Similar energy contents were recorded for both cultivars.

The contents of N, P, Ca and Mg decreased while the content of K increased from head to tail in the pulp and peel of both cultivars. N content of the pulp was 2.7 and 2.4 times higher in the head than in the tail sections of 'White Lisbon' and 'Oriental' respectively, indicating that a definite N gradient exists in the yam tubers studied. There was a similar N gradient in the peel but differences between sections were not as great. The gradient for P was not as marked as that observed for N, the P concentration in the pulp of the head section being only about 1.5 and 1.2 times higher than those in the tail sections of 'White Lisbon' and 'Oriental', respectively. Ca content had the most marked gradient along the tubers. In the pulp of 'White Lisbon' it was 4.3 times higher in the head than in the tail section and in 'Oriental' it was 5.5 times higher. The Ca content of the peel was very much higher than that of the pulp. The Ca content of the peel in the tail section of both cultivars was more than 11 times greater than in the pulp of the tail section in both cultivars; but in the head section the Ca content was only 4.2 and 2.2 times greater in the peel of 'White Lisbon' and 'Oriental', respectively. Mg content in the pulp of the head section of 'White Lisbon' was 2.4 times higher and in 'Oriental' was 1.8 times higher than the tail sections. In the peel the Mg gradients were not as marked. Similar Mg contents were recorded in the pulp and peel of head and middle sections in both cultivars, but in the tail section Mg content was much higher in the peel.

K was the only nutrient to increase in content from head end to tail end. In the pulp of 'White Lisbon' it was 1.3 times greater in the tail than in the head section and in 'Oriental' it was 1.2 times greater. The K content was higher in the peel than in the pulp and the gradient in the peel was similar to that described for the pulp.

The dry matter and chemical composition of bulbils and small tubers of 'White Lisbon' are given in Table 4. The dry matter content and chemical composition of the small tubers were very similar to those observed in the middle section of the larger 'White Lisbon' tubers. The pulp and peel of

Table 4. Mean dry matter and nutrient content in the pulp and peel of three small whole tubers and three bulbils of 'White Lisbon' yam

Tissue	Dry matter (%)	Nutrient (mg/100 g fresh wt.)				
		N	P	K	Ca	Mg
Small whole tubers:						
Pulp	21.9	282	26.5	281	19.8	17.0
Peel	17.8	283	19.4	365	148.3	23.9
Bulbils:						
Pulp	30.9	360	33.9	342	9.5	17.6
Peel	21.2	456	30.5	498	39.0	33.5

bulbils had higher N, P and K contents than small tubers. The greatest difference between bulbils and small tubers was in Ca content, which was very much lower in bulbils. Ca content in the pulp of small tubers was more than twice as high as in the pulp of bulbils and in the peel it was almost four times greater.

Crude protein contents were calculated from the N values and are presented in Table 5 on a fresh and dry weight basis. The trends for crude protein on a fresh weight basis are similar to those discussed for N above. On a dry weight basis the crude protein content of the pulp in the head section was 1.7 and 1.3 times greater than that of the tail section in 'White Lisbon' and 'Oriental' respectively. The peel had higher crude protein on a dry weight basis than the pulp in all three sections of both cultivars. Bulbils had a very high crude protein content on a dry weight basis in both the pulp and peel.

Table 5. Percentage crude protein content (N x 6.25) of the pulp and peel in head, middle and tail sections of tubers, and of whole small tubers and bulbils of yam cvs 'White Lisbon' and 'Oriental'

	'White Lisbon'		'Oriental'	
	Pulp	Peel	Pulp	Peel
	Dry weight basis			
Tuber section:				
Head	10.19	12.00	9.69	12.50
Middle	8.06	9.12	8.94	12.06
Tail	6.06	8.00	7.31	10.81
Small whole tubers	7.93	9.87	--	--
Bulbils	11.25	13.44	--	--
	Fresh weight basis			
Tuber section:				
Head	3.25	1.97	3.23	2.57
Middle	1.57	1.47	1.69	2.20
Tail	1.19	1.34	1.34	1.95
Small whole tubers	1.76	1.77	--	--
Bulbils	2.25	2.85	--	--

DISCUSSION

The higher dry matter content of the head section over middle and tail sections of tubers from both cultivars of _D. alata_ studied matches observations made by Coursey et al. (1960), who noted that the head end of tubers of _D. rotundata_ contained a lower moisture content.

The tail end of the tuber is the region of greatest growth during tuber development, and tissue in this region can be considered to be physiologically less mature than tissue from the head end. Lower dry matter content has been observed in the physiologically younger sections of the corm of the cocoyam (Enyi, 1967) and the tuber of the potato (Johnston et al., 1968). The difference in percentage dry matter between the mature and younger sections, however, appears to be greater for yams than for either cocoyam or the potato. Enyi (1967) observed a difference of seven per cent for cocoyams and Johnston et al. two per cent for the potato, whereas we found that the difference for 'White Lisbon' is about 11 per cent and for 'Oriental' about 15 per cent. This may also indicate that the yam tuber has greater physiological differences between mature and young sections than either the corm of the cocoyam or the tuber of the potato.

The results indicate that definite nutrient gradients exist in the tuber for the five nutrients determined. The content of N, P, Ca and Mg decreased from head to tail whereas K content appears to be highest in the tail section. Setts taken from the head section thus have a greater reserve of N and P which are important for root and shoot development in the early stages of growth. Furthermore, the higher dry matter and energy contents indicate a greater potential for the supply of carbohydrates from setts of the head section for the development of the young plant.

The higher concentration of K in the tail section is interesting from the point of view of K as a nutrient for mobilizing assimilates. Fujise and Tsuno (1967) demonstrated that high levels of K in the young tubers of sweet potato are necessary for good yields. These two workers put forward the hypothesis that K acts to increase the K_2ON ratio in the tuber. This leads to an increase in the water content of the tuber, a faster respiratory rate and increased relative growth rate. The outcome is speedier translocation of photosynthates from the leaves. In the tail section of the yam tuber high K and low N ensure a high K/N ratio. Also, in this section the moisture content is higher. These factors could be related to the mobilization of assimilates into the tail section which is the region of growth of the tuber. In the cocoyam where the region of growth is the top of the corm (proximal to the leaves), the data of Enyi (1967) indicate that the K/N ratio decreases from the youngest to the oldest section (Table 6). The data of Johnston et al. (1968) indicate that the K/N ratio decreases from bud to stem end in the

Table 6. Effect of age of sections on the K/N ratios and percentage moisture content in the tubers of yam and potato and the corm of cocoyam

Section	Yam*				Cocoyam+		Potato‡	
	'White Lisbon'		'Oriental'					
	K/N	Moisture content	K/N	Moisture content	K/N	Moisture content	K/N	Moisture content
Oldest	0.46	69.5	0.48	66.7	1.31	80.0	0.90	77.8
Youngest	1.62	80.3	1.38	82.0	1.35	87.2	1.16	79.8

* Data from the pulp of the two cultivars of _D. alata_ studied herein.
+ From Enyi (1967).
‡ From Johnston et al. (1968).

potato tuber. Macklon and DeKock (1967) found no gradient for nitrate in the potato but observed that K was much higher in the bud end. This can be interpreted to mean that in the potato the K/nitrate ratio was higher in the bud end which is the region of growth of the tuber during the early stages of tuber development and physiologically the youngest section. Moisture content was also higher in the youngest section of both the cocoyam corm and the potato tuber (Table 6). There thus seems to be a common pattern in the tubers or corms of these root crops with high K/N ratios occurring in the youngest section; this pattern lends support to the suggestion of Fujise and Tsuno (1967) that a high K/N ratio may help in the movement of assimilates to a developing area.

The value of 8.25 per cent crude protein (on a dry weight basis) reported by Martin and Thompson (1971) for the unpeeled sections of 'White Lisbon' tubers in Puerto Rico compares favorably with the 8.06 per cent we found in the middle section of peeled 'White Lisbon' tubers. The peel, which constitutes only a very small part of the tuber, has a higher crude protein content (dry weight basis) and the value of 8.06 per cent would have been slightly higher had the middle section not been peeled. The crude protein content of 8.94 per cent (dry weight basis) in 'Oriental' was, however, higher than the value of 7.72 per cent reported by Martin and Thompson (1971). The crude protein content (dry weight basis) in tubers was higher in the peel and decreased from head to tail and confirms indications noted by Martin and Thompson (1971) in tubers of D. alata cv. 'Morado'. The high crude protein content of bulbils suggests that where they are produced in large quantities they may be considered for use in livestock rations.

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