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Micromorphological and Chemical Characterization of Starches in *Dioscorea rotundata* L. (White Yam)

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Abstract

Starches isolated from twenty samples of *Dioscorea rotundata* L. (*Dioscoreaceae*) comprising ten local and hybrid cultivars each, were studied using micromorphological and chemical techniques. There is a marked polymorphism of granule shapes in all the samples, while the dimensions are more clear-cut, with granules exhibiting sizes >40 µm accounting for 42.2% and 12% in local and hybrid cultivars, respectively. Solubility and swelling power are characteristic in the cultivars and follow similar increase patterns along the temperature gradient under investigation. However, the swelling power was relatively higher in the hybrid, than in the local cultivars, that suggest the chemical properties of *D. rotundata* starches are less affected by granule micromorphology, but more by the molecular and associative forces, which are intrinsic in the particular cultivar. The intergrading nature of granule morphology makes it an unsuitable attribute for discrimination among the cultivars. Therefore, solubility and swelling power, in combination with granule dimensions, may provide a secure technique for yam cultivar diagnosis, to be used in quality control and assurances, as well as in forensics. 'Okun', 'Sasanbula', 'Efuru' and 'TDr97/00940' cultivars, which show lower solubility values could be important to diabetics and other health-conscious individuals while, 'Kokumo', 'Odo', 'Amula', 'Amuo', 'TDr98/01230', 'TDr95/18544', 'TDr95/9177', 'TDr8902565', 'TDr98/01217' cultivars which display higher solubility and swelling power may be important for dietary improvement and uses in pharmaceutical formulations.

Keywords: *Dioscorea rotundata* L., granule, micromorphology, solubility, swelling, diagnosis

Introduction

Starch is the chief reserve carbohydrate of plants and it is therefore one of the most widely distributed substances in the vegetable kingdom. It has been reported that the starch content of yam tubers ranges from 50-90% in dry weight, with some varieties having higher values (Kay, 1973; Gebre-Mariam and Schmidt, 1998). The physico-chemical properties of starches of yams have been studied by certain specialists (Rasper and Coursey, 1967; Beleia *et al*., 1990; Farthat *et al.*, 1999) in West Africa; Gebre-Mariam (1999) in Ethiopia and Riley *et al.* (2006) in Jamaica.

Use of yam starch granular structure for diagnostic purposes has been suggested by many references (Rao and Beri, 1955; Ayensu and Coursey, 1972). Starch grain analysis is a potentially valuable technique in archeology because starch grains occur in plants in a wide variety of forms, can be diagnostic to genus and sometimes species level, and can survive in a variety of depositional environments (Cortella and Pochettino, 1994). Indeed, grains from the taro genus *Colocasia* have been identified in residues on stone tools of early Holocene age and Late Pleistocene Age (Denham *et al*., 2003; Dickau *et al.*, 2006). Presently, yams are listed among the most common sources of industrial starch (Alexander, 1996), but there is little or no information to enhance their industrial uses, to improve functional properties of food products, as thickener and binder, as filling material and encapsulating agent (Guilbot and Mercier, 1985). The increased requirements for starches in different applications, such as functional and healthier food, or applications in pharmaceuticals have thus forced a steady development of new starch types and the crucial need to understand the properties of the existing ones (Oguntona, 1994).

The study was conducted to provide information on the physico-chemical properties of the starches of *D. rotundata* local and hybrid cultivars with a view to improving their utilization.

Materials and methods

The samples comprised ten local cultivars randomly collected from central Bodija yam market in Ibadan and ten hybidal cultivars of improved lines provided by the International Institute of Tropical Agriculture (IITA), Ibadan. For starch isolation, the method of Schoch and Maywald (1968) was employed with modifications, following Adebayo and Itiola (1998). The yam sample, weighing 250 g was milled with distilled water and sieved through a 75 µm-mesh sieve. The soluble impurities were removed by repeated washings and settlings in water till the wash water was clear. The resultant starches were dried and stored in sealed containers.

In order to study granule morphology, the starch specimen contained on a pinhead was suspended in a drop of distilled water and iodine-KI on microscope slide. The stained granules were observed under a Carl Zeiss light microscope fitted with camera. Photomicrographs were taken and the dimensions, in micron, of the longest axis of 100 granules per sample were recorded. Swelling power and solubility were determined over a temperature range of 60-80°C following the method of Ma *et al.* (1987).

Results and discussion

The diversity of shapes and sizes of starch granules in *D. rotundata* is shown in Fig. 1a-20a and Fig. 1b-20b, respec-

Tab. 1. Starches granule sizes of *D. rotundata* as reported by different workers

Source of information	Yam species	Cultivar	Granule size (range/mean in μm)
Rasper and Coursey (1967)	*D. rotundata*		10-70
	D. alata		10-70
	D. dumetorum		1-5
Jane *et al.* (1994)	Yellow yam		10-30x20-50
	White yam (*D. rotundata*)		10-30x20-50
	Water yam (*D. alata*)		10-36x25-40
	Bitter yam (*D. dumetorum*)		3-5
	Cassava		5-20
	Potato		12-60x15-75
Riley *et al.* (2006)	*D. alata*	'Sweet yam'	25.16
		'White yam'	27.33
		'Renta yam'	28.01
		'Moonshine'	23.74
		'Darknight'	22.89
		'Barbados'	27.65
		'Purple/white'	27.70
		'Calabash'	27.80
Shore Drogba Alex and Amanin n'Guessan Georges (2007)	*D. prachensilis*		8.5-56.5
	D .hirtiflora		11.6-37.0
	D .burkilliana		12.0-90.0
	D. bulbifera tubercule		8.50-52.0
	D. bulbifera bulbilli		13.5-52.0
	D. dumetorum		0.83-6.70
	D. mimutiflora		11.5-75.0
Current study	*D. rotundata* (Local cultivars)	'Okun'	10-30
		Modakeke	15-48
		'Kokumo'	38-48
		'Efuru'	15-44
		'Sasanbula'	28-46
		'Odo'	30-44
		'Amula'	22-33
		'Aimo'	10-42
		'Akoko'	20-56
		'Gbongi'	10-42
	D. rotundata (Hybrid cultivars)	'TDr95/19156'	20-33
		'TDr95/19158'	15-38
		'TDr95/18544'	10-36
		'TDr95/19177'	10-29
		'TDr97/02568'	30-33
		'TDr97/01217'	20-40
		'TDr98/00718'	20-36
		'TDr97/00925'	20-40
		'TDr97/00940'	15-42
		'TDr98/01230'	10-51

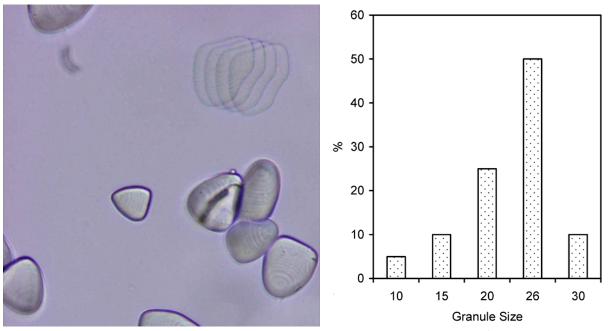

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Fig. 1. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Okun' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Okun'

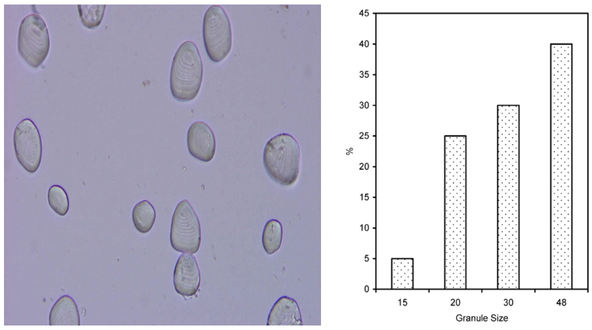

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Fig. 2. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Modakeke' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Modakeke'

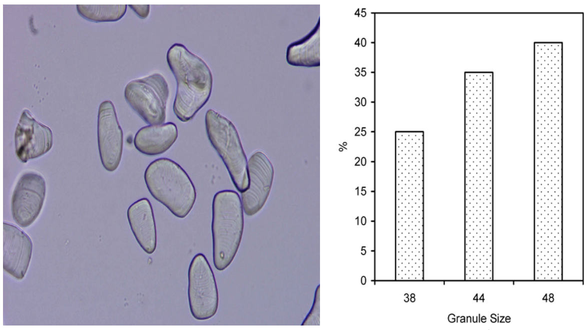

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Fig. 3. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Kokumo' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Kokumo'

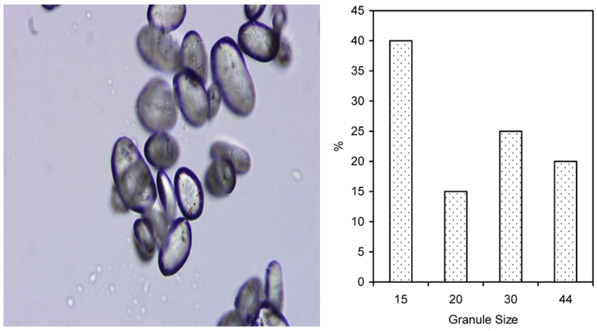

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Fig. 4. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Efurru' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Efurru'

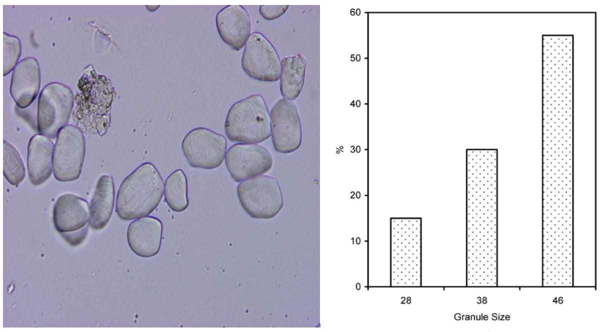

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Fig. 5. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Sasanbula' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Sasanbula'

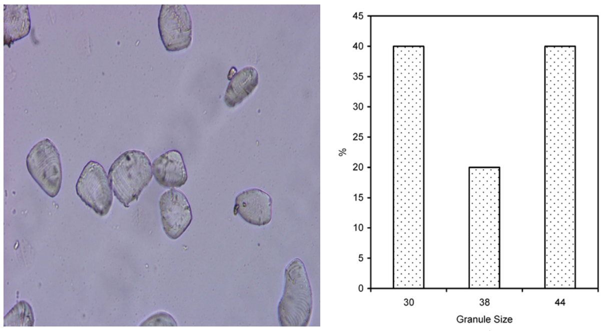

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Fig. 6. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Odo' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Odo'

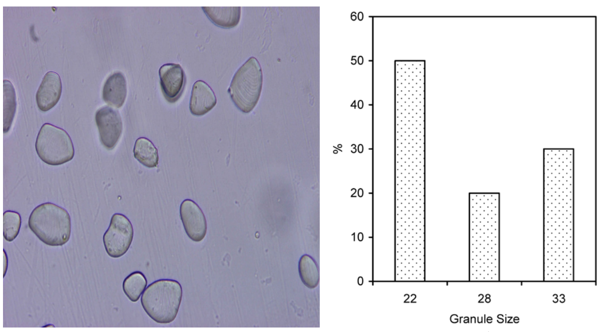

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Fig. 7. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Amula' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Amula'

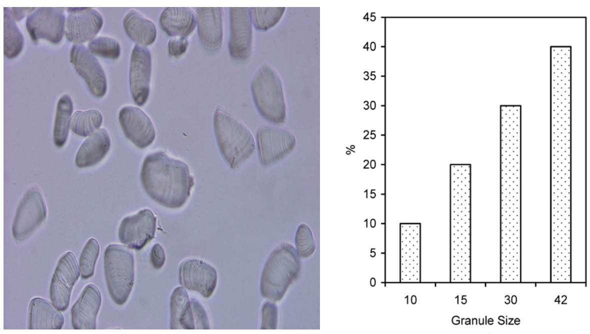

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Fig. 8. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Aimo' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Aimo'

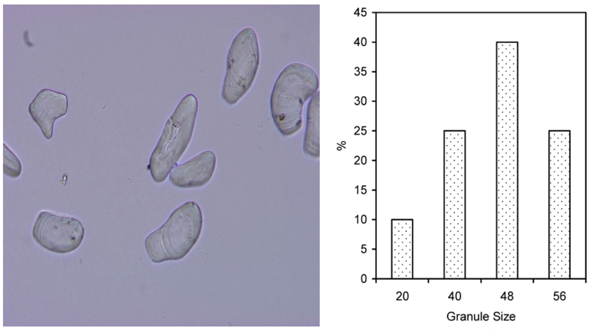

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Fig. 9. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Akoko' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Akoko'

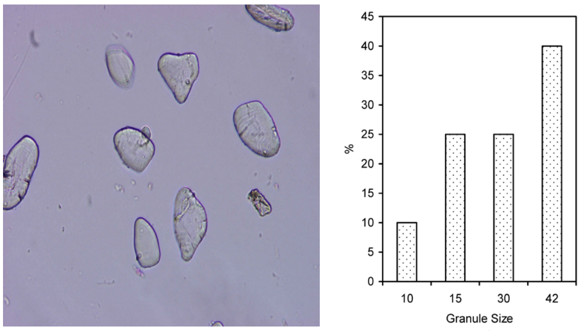

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Fig. 10. (a)-Micromorphology granules of *D. rotundata* local cultivars 'Gbongi' (x20); (b)-Distribution of granule sizes of *D. rotundata* local cultivars 'Gbongi'

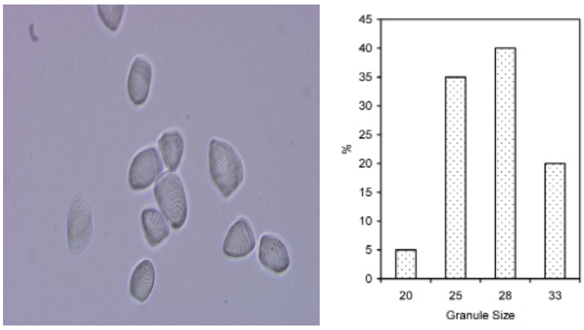

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Fig. 11. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr95/19156' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr95/19156'

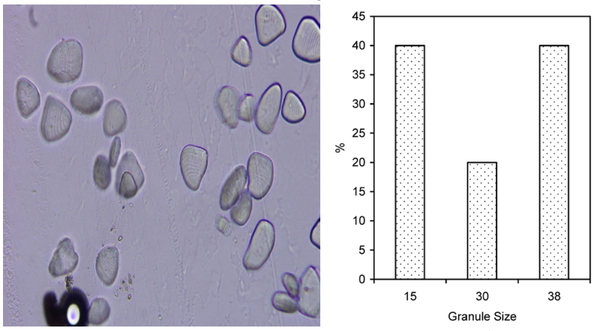

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Fig. 12. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr95/19158' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr95/19158'

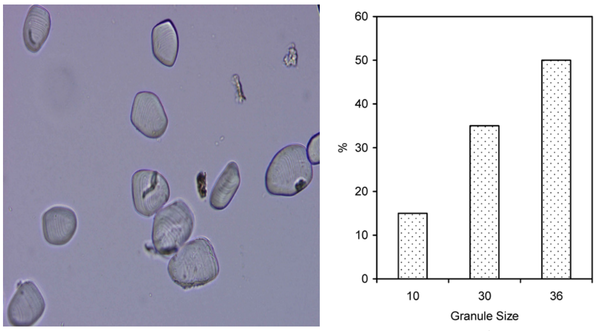

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Fig. 13. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr95/18544' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr95/18544'

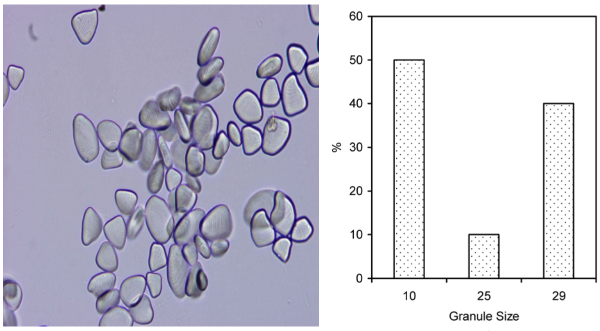

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Fig. 14. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr95/19177' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr95/19177'

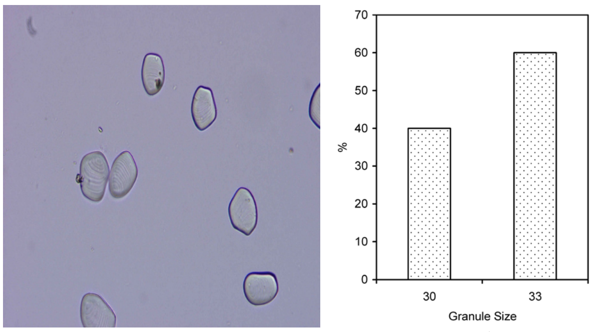

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Fig. 15. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr97/02568' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr97/02568'

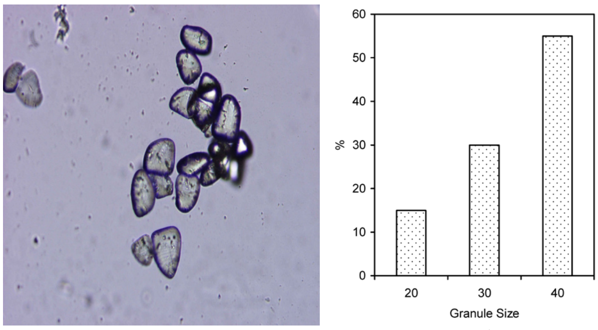

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Fig. 16. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr97/01217' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr97/01217'

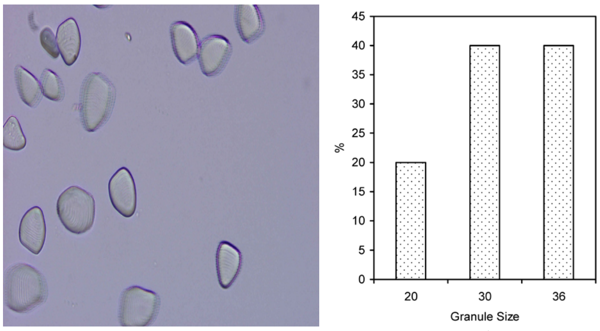

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Fig. 17. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr98/00718' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr98/00718'

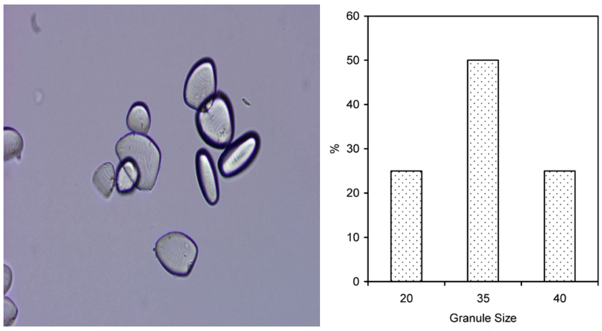

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Fig. 18. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr97/00925' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr97/00925'

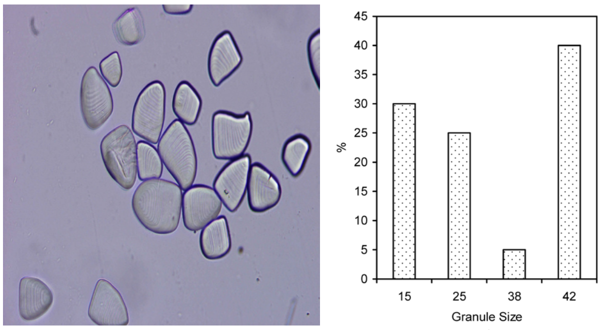

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Fig. 19. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr97/00940' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr97/00940'

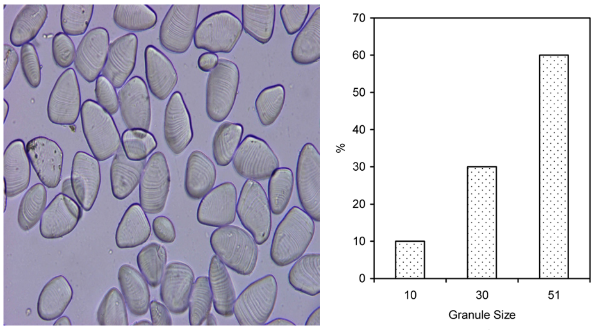

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Fig. 20. (a)-Micromorphology granules of *D. rotundata* hybrid cultivars 'TDr98/01230' (x20); (b)-Distribution of granule sizes of *D. rotundata* hybrid cultivars 'TDr98/01230'

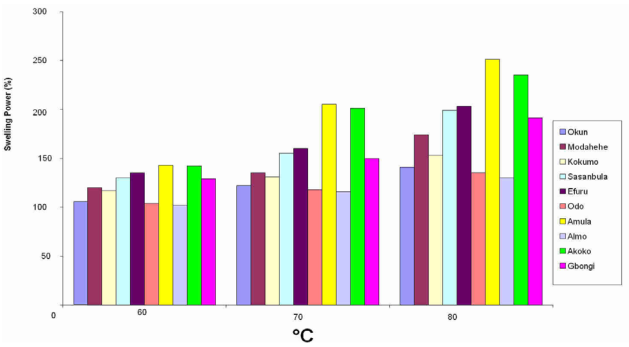

Fig. 21. Effect of temperature increases in on the swelling power of the yam starches (local cultivars)

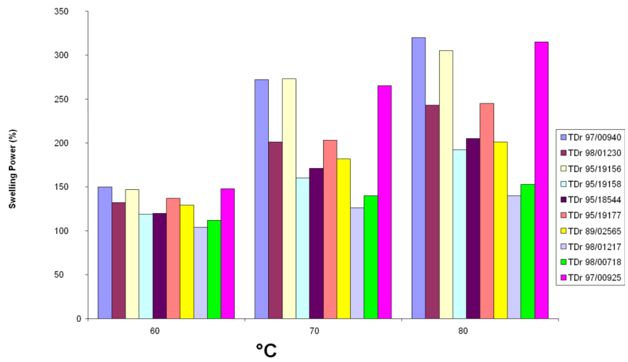

Fig. 22. Effect of increases in temperature on the swelling power of the yam starches (hybrid cultivars)

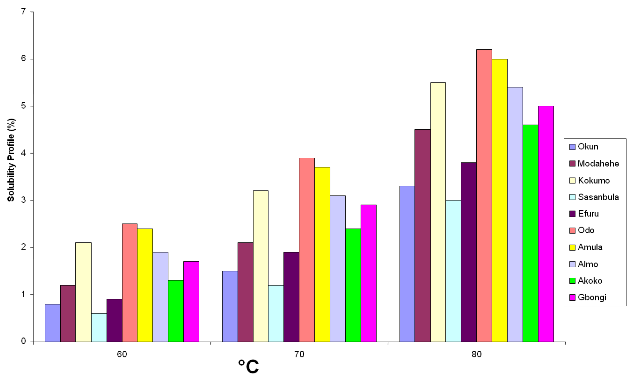

Fig. 23. Effect of temperature on the solubility of the yam starches (local cultivars)

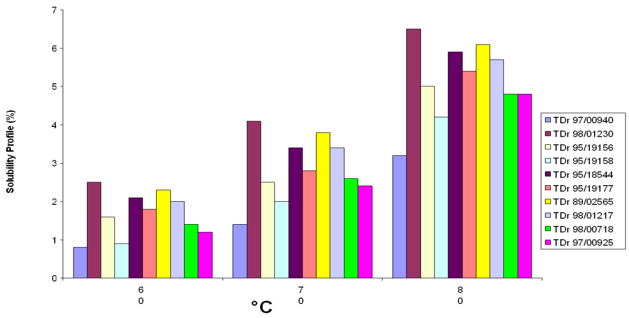

Fig. 24. Effect of increases in temperature on the solubility of the yam starches (hybrid cultivars)

tively. Broadly, the solubility and swelling power of starch granules in both local cultivars (land races) and hybrid lines follow a similar increase pattern with temperature increasing from 60 to 80°C, as shown in Fig. 2-5. However, each cultivar responds to the prevailing temperatures differently, suggesting the existence of molecular differences in these intraspecific entities. Riley *et al.* (2006) reported that both solubility and swelling power of *Dioscorea alata* cultivars in Jamaica varied significantly ($P<0.005$) and increase with increases in temperature.

The shapes of granules are as diverse as their sizes (Fig. 1a-20a). Shapes range from reniform/orbicular/irregular in 'Akoko', 'Kokumo' and 'Aimo'; oval/cordate in 'Gbongi' and 'Okun' to polyhedral/rounded/oval in 'Odo' and 'Sasanbula'; oval/circular in 'Amula' and 'Efuru' and being oval/ellipsoidal/rounded in 'Modakeke'. The granular morphology of the hybrid cultivars are also heterogeneous, consisting of different shapes in each line: 'TDr98/00718', 'TDr95/18544' (conical/oval/spherical); 'TDr97/02568', (flattened/spherical); 'TDr97/00925' (oval/cordate); 'TDr97/00940', 'TDr95/19158' and 'TDr95/19156'; (spherical/conical/irregular); 'TDr98/01230', 'TDr95/19177' and 'TDr98/01217' (conical/oval/irregular/elliptic).

Among the local cultivars, granule sizes above 40 µm represent 40% but constitute 12% in the hybrid cultivars, suggesting the tendency of the local cultivars to contain larger granules than the hyrbridal cultivars. It also implies that we encounter granules >40 um four times more in the local cultivars than in the hybrid cultivars. Granular sizes of yam species reported by various workers are in broad agreement compared with the results obtained in this study, as shown in Tab. 1. Cluskey *et al.* (1980) reported an inverse relationship between the size of starch granules and apparent amylose content of amylomaize starches; starches with lower amylose content were more digestible than those with higher amylose content. This then suggests that, in this study, the hybrid cultivars which tend to have smaller granules and (possibly) more amylose content would be less digestible than the local cultivars which tend to have larger granule sizes and less amylose content. Many researchers have suggested that as the amylose content increases, the irregularity of the starch granule shape increases, as well (Banks *et al.,* 1974; Gallant and Buchet, 1986). Many works have reported that amylose acts both as diluents and inhibitor of swelling (Tester and Karkalas, 1990; Zeleznak and Hoseney, 1997). The average size of amylase extender starch granules was smaller than that of normal starch (Boyer *et al.,* 1976; Cluskey *et al.,* 1980).

Riley *et al.* (2006) reported type B form of starch granules with high amylose and low digestibility in *D. alata* from Jamaca. However, the results of this study differ from the trend reported from earlier works (Banks *et al.,* 1974; Gallant and Buchet, 1986). Both the local and hybrid cultivars have similar solubility patterns in spite of the marked granular size differences, which tends to support previous reports that there is no direct correlation between granule diameter and amylose content (Franco *et al.*, 1988). Again, all the cultivars which attained 250% swelling power are hybrid lines whereas all the local cultivars were located below this phenon line, thereby further suggesting incongruence between granule size and starch chemical properties. Other works also reported that the physicochemical properties of yam starches such as granule size and morphology, amylose content, crystal form, gelatinization and pasting behaviour) depended strongly on the yam variety (Noda *et al.*, 1992). Solubility, though different from cultivar to cultivar, is relatively, consistently higher for 'Kokumo', 'Odo', 'Amula', 'Amuo', 'TDr98/01230', 'TDr95/18544', 'TDr95/9177', 'TDr8902565' and 'TDr98/0121' while it is lower for 'Okun', 'Sasanbula', 'Efuru' and 'TDr97/00940' (Fig. 23-24).

The low swelling power of starch granules shown by some of the yam cultivars (Fig. 21-22), may be the result of an extensive and strongly bonded micellular structure, thereby making them resistant to swelling (Lorenz, 1990; Gallant *et al.*, 1982). Since low swelling power suggests tight granule structure while high swelling power suggests loose granule structure (Leach *et al.,* 1959), the cultivars which show high swelling power would suggest loose structure in their granules while 'Aimo' with the lowest swelling power in all temperatures suggests tight architecture of the granule. Consequently, 'Kokumo', 'Odo', 'Amula', 'Amuo', 'TDr98/01230', 'TDr95/18544', 'TDr95/9177', 'TDr8902565', 'TDr98/01217' which have higher solubility values should be considered for industrial use. On the other hand, 'Okun', 'Sasanbula', 'Efuru' and 'TDr97/00940' may be considered for dietary improvement

Conclusions

Starch granular sizes of *D. rotundata* in Nigeria is in broad agreement with the figures reported for other places but observed incongruence was observed with previous findings concerning granule size and solubility, as well as and swelling powers. There is a suggestion that the chemical properties of *D. rotundata* starch depends less on granule dimensions and more on molecular and associative forces, intrinsic to the cultivar, that is, the physico-chemical properties of *D. rotundata* starches are controlled more by the internal mechanism of the granules than by their dimensions and shapes. While the granule dimensions intergrade and shapes are polymorphic, solubility and swelling power are unique parameters and may, in combination with granule dimensions, provide a secure technique for yam cultivar diagnosis, for use in quality control and assurances as well as in forensics. The cultivars which showed lowsolubility could be of significance to diabetics and other health conscious individuals. The cultivars which display high solubility will be relevant in dietary improvement and may be used in the processing of pharmaceutical formulations as absorbents, especially where the Active Pharmaceutical Ingredient (API) is in a liquid state

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