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Flow behaviour of yams grown in Papua New Guinea

(Ciri kelikatan buburan daripada keladi yang ditanam di Papua New Guinea)

P. A. Sopade*

Key words: yam, flour, rheology, shear-thinning, power-law model

Abstract

Dioscorea rotundata Poir. is a recently introduced yam in Papua New Guinea (PNG). Its rheological behaviour was studied as well as that of *D. alata* and *D. esculenta*. A rotational viscometer at speeds 0.5–100 rev/min was used and 4% slurries of the yam flours at temperatures 25–75 °C were studied. Results were presented as shear stress-shear rate data, which were modelled with the power-law equation. The equation adequately described (r = 0.9898–0.9998) the rheological behaviour and the power-law indices were: *D. alata*, 0.67 ± 0.057; *D. esculenta*, 0.42 ± 0.093; *D. rotundata*, 0.34 ± 0.045 indicating pseudoplastic behaviour as the viscosity was essentially (CV = 3–11%) time-independent. The temperature dependence of the consistency index (viscous nature) was analysed using the Arrhenius equation and the correlation coefficients were between 0.9722 and 0.9946. The *D. rotundata* slurry was the least sensitive to temperature changes. The significance of the rheological information for the success of the introduced yam in the PNG food chain is highlighted.

Abstrak

Dioscorea rotundata ialah sejenis keladi yang baru diperkenalkan di Papua New Guinea (PNG). Ciri kelikatannya telah dikaji, begitu juga dengan *D. alata* dan *D. esculenta*. Viskometer yang berputar pada kelajuan 0.5–100 putaran/min digunakan dan 4% buburan keladi pada suhu 25–75 °C dikaji. Keputusan dibentangkan dalam bentuk data 'shear stress-shear rate' yang dimodelkan dengan persamaan 'power-law'. Persamaan lengkap menerangkan ciri-ciri kelikatan (r = 0.9898–0.9998) dan indeks 'power-law' bagi *D. alata* 0.67 ± 0.057, *D. esculenta* 0.42 ± 0.093 dan *D. rotundata* 0.34 ± 0.045 menunjukkan ciri-ciri pseudoplastik, manakala kelikatan (CV = 3–11%) tidak bergantung pada masa. Indeks kelikatan yang bergantung pada suhu dianalisis menggunakan persamaan Arrhenius dan korelasi koefisiennya antara 0.9722 dan 0.9996. Buburan *D. rotundata* amat kurang peka terhadap perubahan suhu. Kepentingan maklumat tentang kelikatan bagi kejayaan keladi yang baru diperkenalkan dalam rantaian makanan di PNG diberi penekanan.

*Food Technology, Department of Applied Sciences, University of Technology, PMB, Lae, Papua New Guinea.
Author's full name: Peter Adeoye Sopade

Fax: 6754734558, E-mail: pade_sopade@hotmail.com

Introduction

White yam, *Dioscorea rotundata* Poir., is amongst the four most widely cultivated species of the yam family with the most superior characteristics (Kay 1987). It dominates the global yam production. It is, however, of minor importance in the Pacific islands (Bradbury and Holloway 1988) compared to *D. alata* and *D. esculenta*. Yams are the third root crop in Papua New Guinea (PNG) judging from the FAO (1993) figures, which put taro and sweet potato in front. Recently, *D. rotundata* is being introduced in PNG to add variety to the yam group in the country.

The assimilation and acceptability of the new yam species will be dependent on its properties in comparison to the existing yam species. The physico-chemical, functional and sensory properties of the new yam have been studied (Sopade et al. 1999) but rheological characteristics are also important. Although Sopade et al. (1999) reported the hot and cold paste viscosities of the new yam species, the relationship between shear stress and shear rate, which determines the flow behaviour, will add to the knowledge of the food potential of the yam. The uses to which rheological information are put in the food industry and, consequently their significance, have been discussed (Muller 1973; Rao and Anantheswaran 1982; Shoemaker et al. 1992). These underline the need to obtain experimental data in this direction as a way of enriching the database for the white yam grown in PNG. Also, the global importance of *D. rotundata* demands a complete information on its food properties and its rheological characterisation in relation to those of *D. alata* and *D. esculenta* will be a good addition.

Materials and methods

The yam samples were obtained from the storage barn of the PNG National Agricultural Research Institute at Bubia, PNG. They were identified as *D. alata, Takua Yavu*; *D. esculenta, Glame*; and *D. rotundata, TDr 90-1-1*. The tubers were peeled (Crypto Peerless Ltd., Birmingham B9 4UA, UK), sliced (AB Halde Maskiner, Sweden), dried (APV Mitchell Dryers Ltd., Carlie CA2 5OU, UK) at 40 °C for about 45 h and ground.

A 4% slurry of the yam flour was left to stand for about 30 min in order to rehydrate prior to boiling and simmering (for 5 min) before cooling. The lost water due to evaporation (110–130 g) was added into the cooled slurry, which was thoroughly mixed before the viscosity was determined. Viscosity was measured on duplicate samples at controlled temperature (25–75 °C) using a rotational viscometer (Brookfield Engineering Laboratories Inc., Stoughton, MA, USA) model RVDV-I+ version 4.1. Duplicate readings were taken per sample at 3 min intervals after 3 min rotation at each of the speeds (0.5, 1, 2, 5, 10, 20, 50, 100 rev/min) and 3 min rest after each reading (Sopade and Kassum, 1992). Appropriate spindles (numbers 1–3) were used to give readings between 10 and 100 on the scale. A 600 mL beaker (8.5 cm, diameter, 12.5 cm high) was used for all the measurements with the viscometer guard leg on. Enough samples were used to cover the immersion groove on each spindle shaft. All the measurements were carried out immediately after the yam slurries were prepared and did not vary substantially with time up to 1 hr. A typical measurement at 10 rev/min and 30 °C gave coefficients of variation (CV) from 3–11%.

The empirical data (% scale - rotational speed) obtained were converted into shear stress - shear rate data using the procedures of Mitschka (1982). The average shear stress (τ, N/m^2) was calculated as:

$$\text{Shear stress} = a \times \%\ \text{scale reading on the viscometer} \quad [1]$$

where a = constant and are 0.035, 0.119 and 0.279 respectively for spindle numbers 1, 2 and 3 used. Pairs of shear stress and rotational speed (rev/min) for each spindle were plotted on a log-log scale and the slope of the straight line (correlation coefficient = 0.9898–0.9999) was equal to the flow index (n) of the slurry. The average shear rate (γ/s) for each of the spindle speeds was then calculated as:

Shear rate = b(n) x rotational speed in rev/min [2]

where b(n) = conversion factor for a particular flow index and ranges from 0.334 to 0.885 from extrapolation.

Results and discussion

Figure 1, *Figure 2* and *Figure 3* show the relationship between shear stress and shear rate for the yam slurries. Irrespective of the temperature, shear stress increases with the rate of shear to describe a non-Newtonian behaviour. Flow behaviour of food systems have been modelled by using many equations (Rao and Anantheswaran 1982; Ofoli et al. 1987; Cheng 1990) and the power-law equation (Eqn.[3]) has proved to be the most widely used:

$$\tau = K\gamma^{n} \qquad [3]$$

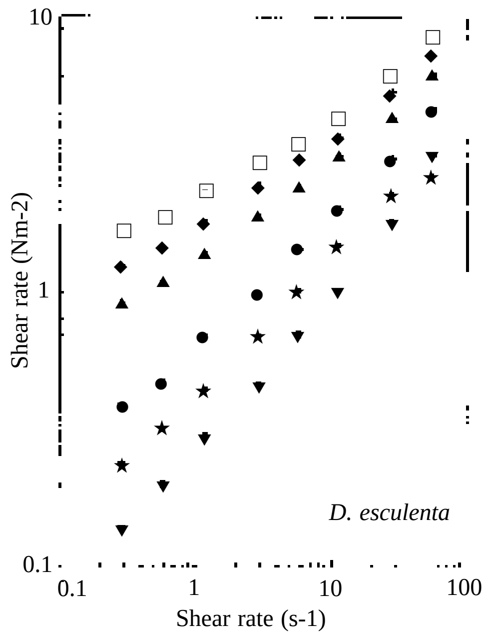

Figure 2. Relationship between shear stress and shear rate for ***D. esculenta*** *slurries*

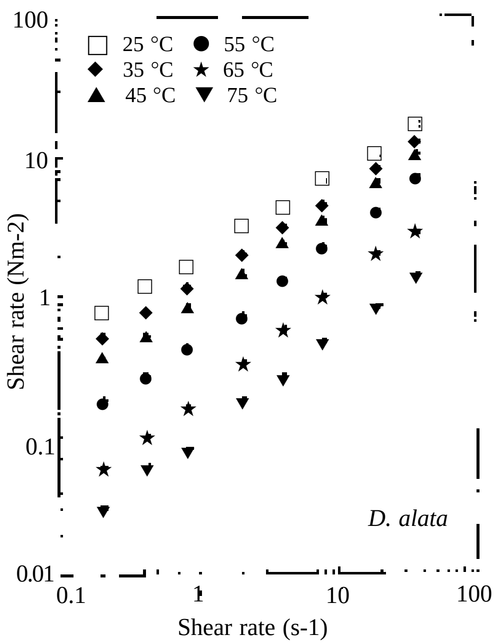

Figure 1. Relationship between shear stress and shear rate for ***D. alata*** *slurries*

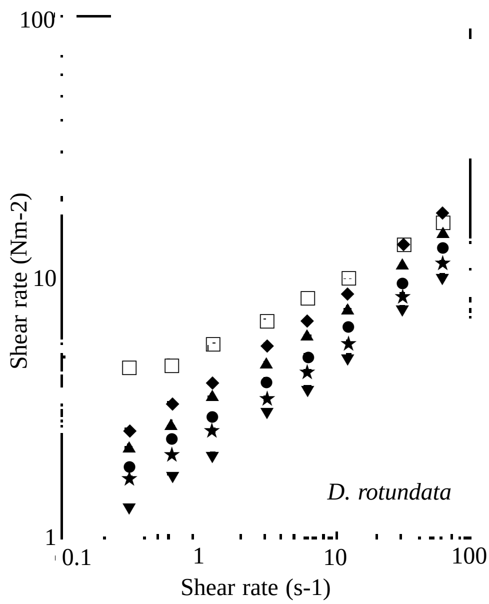

Figure 3. Relationship between shear stress and shear rate for ***D. rotundata*** *slurries*

Table 1. Rheological parameters of the yam slurry[a]

Yam	Temperature (°C)	n	n_e	K	K_e	r	r_e	E_a (MJ/mol/K)
D. alata	75	0.70	0.70	0.10	0.05	0.9987	–0.9924	
	65	0.76	0.77	0.20	0.11	0.9998	–0.9992	
	55	0.71	0.72	0.50	0.24	0.9981	–0.9841	50.3
	45	0.65	0.67	0.94	0.41	0.9996	–0.9966	(0.9722)[b]
	35	0.61	0.64	1.28	0.51	0.9997	–0.9967	
	25	0.60	0.63	1.80	0.70	0.9985	–0.9950	
		0.67 ± 0.057[c]	0.69 ± 0.048					
D. esculenta	75	0.57	0.57	0.31	0.10	0.9976	–0.9958	
	65	0.48	0.53	0.45	0.13	0.9980	–0.9938	
	55	0.48	0.50	0.67	0.18	0.9979	–0.9961	34.6
	45	0.36	0.39	1.30	0.25	0.9969	–0.9973	(0.9818)
	35	0.34	0.37	1.69	0.32	0.9959	–0.9981	
	25	0.30	0.34	2.05	0.35	0.9927	–0.9988	
		0.42 ± 0.093	0.45 ± 0.088					
D. rotundata	75	0.38	0.42	2.04	0.44	0.9982	–0.9991	
	65	0.35	0.35	2.50	0.49	0.9964	–0.9989	
	55	0.35	0.36	2.84	0.57	0.9972	–0.9986	15.1
	45	0.35	0.35	3.35	0.71	0.9980	–0.9994	(0.9946)
	35	0.35	0.35	3.85	0.80	0.9980	–0.9994	
	25	0.24	0.24	5.14	0.78	0.9898	–0.9989	
		0.34± 0.045	0.35± 0.052					

E_a = Activation energy
[a]Parameters with subscript e were obtained from the empirical viscosity-rotational speed (/revs) data and r = correlation coefficient.
[b]Figures in brackets are r-values from the Arrhenius analysis.
[c]Values are means ± standard deviations.

where K = consistency index and n is also referred to as the power-law index. The consistency index is a measure of the viscous nature of the food and can be used to identify the sensitivity of the food to temperature changes (Sopade and Filibus 1995). The power-law index defines the rheological class of the food and *Table 1* shows these parameters.

The power-law model suitably describes the non-Newtonian behaviour of the yam slurries as the correlation coefficients vary from 0.9898 to 0.9998. From the power-law index, which is less than unity, and because of the relatively constant viscosity irrespective of the time of shearing, the yam slurries exhibited time-independent shear-thinning or pseudoplastic behaviour. Rha (1975) describes shear-thinning as resulting from an increased alignment of constituent molecules when shear rate increases and most food systems exhibit this behaviour. Generally, the power-law index was temperature-independent and this is in line with published studies (Sopade and Kassum 1992; Sopade and Filibus 1995; Sopade and Koyama, 1999) on other food systems. From the mean n-values, *D. rotundata* was the most pseudoplastic while *D. alata* was the least.

Rather than calculate the viscosity functions, our previous studies (Sopade et al. 1993; Abubakar and Sopade 1993; Abubakar et al. 1997) used the empirical viscosity - rotational speed to calculate the power-law index. Applying this approach to the present data gave n-values (n_e) that are essentially the same as those from the shear stress-shear rate data *(Table 1)* but the consistency indices (K_e) are different.

As expected, with or without the viscosity functions, temperature affected the K-values and the viscous nature of the slurries also varies with the yam cultivar. Generally, the *D. rotundata* slurry was the most viscous at all the temperatures. Possibly in comparison with other yam species, Faboya and Asagbra (1990) have observed the highly viscous nature of *D. rotundata*, which is probably why it is the most preferred yam (Onwueme and Charles 1994) for the preparation of pounded yam in West Africa. Also, the difference (Kay 1987) in the size of the starch granule (*D. alata*, 5–50 µm; *D. esculenta*, 1–15 µm; *D. rotundata*, 10–70 µm) with *D. rotundata* having the biggest granule might be a factor in the viscous pattern.

The influence of temperature on the consistency index was investigated using the Arrhenius equation (Eqn.[4]):

$$K = K_o \exp (- E_a/R T) \qquad [4]$$

where E_a = activation energy, K_o = consistency index at a reference temperature ($T = \infty$), R = universal gas constant (= 8.318 kJ/moL/K) and T = absolute temperature (K). The activation energy was used as a measure of the temperature sensitivity of the slurries and *D. alata* slurry was the most sensitive *(Table 1)* while *D. rotundata* showed the least sensitivity.

Conclusion

The *D. rotundata* Poir. yam introduced in Papua New Guinea exhibited identical rheological behaviour as the *D. alata* and *D. esculenta*, which have been in the country's food system for many years; PNG is regarded as one of the centres of origin of *D. esculenta*. However, the slurry of *D. rotundata* was more viscous, it thinned more and showed the least sensitivity to temperature changes in comparison to the other two. Consumers of yams in the country, particularly in the slurry form, will have to use less of the solids of the new yam in order to obtain the same viscosity as they are accustomed to. Yams play a role in many traditional foods of the people and it should be stressed that slight modifications are required if the *D. rotundata* are to be the substitutes. But the modifications will not be such as to prevent the ready and easy assimilation of the introduced species in the food pattern.

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