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Density and viscosity of cold flour pastes of cassava (*Manihot esculenta* Grantz), sweet potato (*Ipomoea batatas* L. Lam) and white yam (*Dioscorea rotundata* Poir) tubers as affected by concentration and particle size

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Abstract

The effect of tuber type, paste concentration and flour particle size on the density and viscosity of cold pastes were investigated. The first set of samples were pastes of 5%–50% (w/w, db) of 180 μm flour particles. The second were 10% (w/w, db) pastes of varying size (75–500 μm) of flour particles. Results showed that both the density and viscosity of sweet potato (SP) were highest and significantly different ($P < 0.05$) from those of cassava (CS) and white yam (WY). The density and viscosity correlated directly ($r > 0.95$) and significantly ($P_r < 0.005$) with concentration and inversely ($r < -0.75$) and significantly ($P_r \geq 0.005$) with particle size. Analysis of variance (ANOVA) indicated that the influence of tuber type was significant ($P < 0.01$). The density and viscosity for the 40% paste were not significantly different from those of 35% and 45% pastes ($P < 0.05$). The viscosity and density of the 75 μm sample were significantly higher than those of any sample with larger particle size. These observations showed that tuber type, concentration and particle size are all crucial factors determining the density and viscosity of tuber flour pastes. The experiment has shown that when high concentrations of SP flour with $\leq$ 180 μm particle size are incorporated in foods, large changes in viscosity and density would be obtained.

Keywords: Tropical tuber flours; Cold pastes; Density; Viscosity; Concentration; Particle size

1. Introduction

Tropical root and stem tuber crops are commonly converted into flours (Coursey, 1983; Ihekoronye and Ngoddy, 1985; Kordylas, 1990; Chandra, 1991) to preserve them. These fours are used in food systems as ingredients and/or processing aids. For example, as dough conditioners in bread manufacture, stabilizers in ice cream and thickeners in soups (Jarmai and Montford, 1968; Martin and Ruberte, 1975; Ciacco and D'Appolonia, 1978; Martin et al., 1983; Hahn, 1989; Silva, 1990).

The functional characteristics of the flours could depend on, among other factors, the type of tuber as well as the handling history — i.e., treatment prior to flour extraction, type and condition of solvent, concentration and particle size distribution. The majority of reported work has involved the physico-chemical properties of the native tuber starches (Leach et al., 1959; Kawabata et al., 1984; Faboya and Asagbra, 1990; Rickard, 1991; Asaoka et al., 1992), rather than the flour itself, with the exception of the recent report on the physico-chemical properties of cocoyam flour by Iwuoha and Kalu (1995). There is a need to analyse the rheological and other physical properties of tropical tuber flours since these are frequently incorporated in the preparation of a diverse range of tropical foods.

The objectives of this work, which is one of a series of studies, were: (1) to extract whole, native flours from the tubers of cassava, sweet potato and white yam; and (2) to measure the bulk density and apparent dynamic viscosity of their cold pastes as a function of both concentration and particle size.

2. Experimental

2.1. Materials

Mature tubers of cassava, CS (*Manihot esculenta* Crantz),

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sweet potato, SP (*Ipomoea batatas* L. Lam), and white yam, WY (*Dioscorea rotundata* Poir) obtained from a local cottage farm were used.

2.2. Methods

2.2.1. Flour extraction

Tubers of CS were peeled while those of SP and WY were pared down, washed, cut into 2.5 to 5 mm thick chips, dried at 50°C for 24 h in an oven, milled into powder in a Kenwood Portable Mill and filtered through a 1 mm sieve. Each test tuber flour was hermetically sealed in glass jars prior to analysis.

2.2.2. Particle size variation test

The bulk flour from each tuber type was separated into particle sizes of 75, 125, 150, 180, 250, 375 and 500 μm by using a standard Tyler Sieve Series. Samples of 10% (w/w, dmb) flour pastes were prepared from each particle size and each tuber type for analysis.

2.2.3. The effect of concentration

Using the 180 μm particle size flour, duplicate pastes were prepared in distilled water at room temperature (28 ± 2°C) and left to stand for 1 h. Concentrations were 5, 10, 15, 20, 25, 30, 40, 45 and 50% (w/w, dmb).

2.2.4. Chemical and physical analyses

The moisture content of flour samples was determined according to the A.O.A.C. (1990) method. Flour was dried at 105°C for 3 h.

The cold pastes were subjected to both density and viscosity analysis. A hydrometer was inserted into each of the test pastes, the reading taken and the density recorded in kg m^{-3}. The procedure reported by Iwuoha and Kalu (1995) was used to determine viscosity. Spindle number 4 was used at a constant rotational velocity of 60 rev min^{-1} in a model LVF Synchro-lectric Viscometer (Brookfield Engineering Labs Inc., Stoughton, MS, USA). The dial reading was recorded while the spindle was immersed in the test paste for 60 s. The viscosity was expressed in mPa s, obtained by multiplying the dial value by 100, a factor supplied by the manufacturer.

2.3. Statistical analyses of data

2.3.1. Correlation analysis

The data from chemical and physical measurements concerning the three tuber types for varying flour particle size and paste concentration were subjected to correlation analyses. Flour particle size and paste concentration were paired with density and viscosity, respectively, for each tuber type and the correlation coefficients obtained.

2.4. Analysis of variance

Two sets of two-way analysis of variance (ANOVA) were carried out. The mean values of density and viscosity were assessed as functions of tuber type (three types) and cold-paste concentration (10 concentrations), which statistically fitted into a 3 × 10 factorial design. In the second set, the two parameters were also treated as functions of tuber (three types) and flour particle size (seven sizes) which fitted into a 3 × 7 factorial design. The appropriate reduced sum of squares, the mean squares and variance ratios were evaluated according to the standard procedures described by Steel and Torrie (1980).

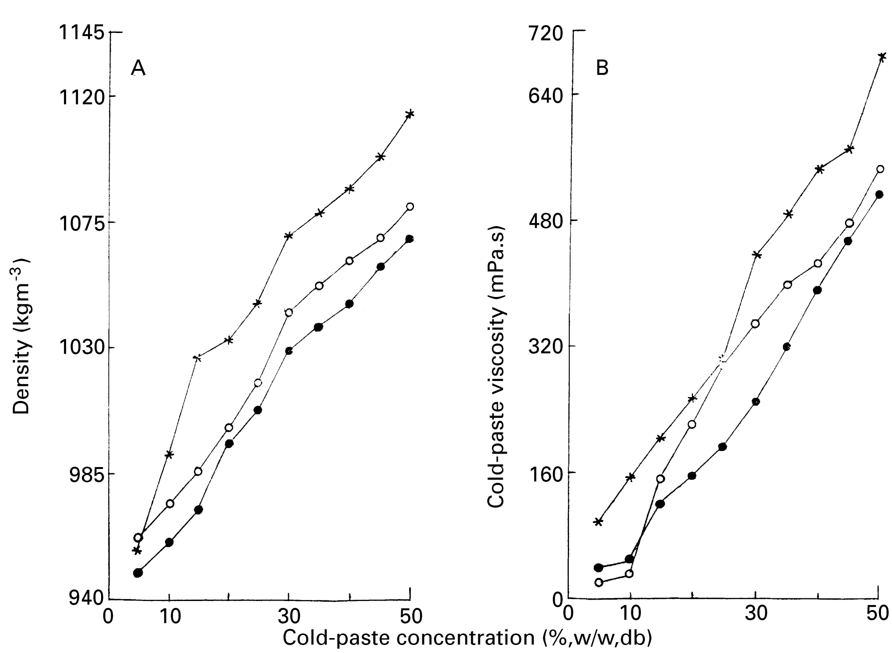

Fig. 1. Effect of cold-paste concentration on density (A) and cold-paste viscosity (B) for cassava (○), sweet potato (∗) and white yam (●) tuber flours.

Table 1
Correlation coefficients and their levels of significance for concentration (CPC) and particle size (FPS) with density (BMD) and visocisity for (CPV) CS, SP and WY

Tuber type	Variable–parameter	Correlation coefficient, r	Quality of fit, r^2	Level of sig for r, P_r
Cassava, CS	CPC–BMD	0.9916	0.9833	0.005
	CPC–CPV	0.9902	0.9804	0.005
	FPS–BMD	− 0.8564	0.7335	0.010
	FPS–CPV	− 0.7662	0.5871	0.025
Sweet potato, SP	CPC–BMD	0.9758	0.9523	0.005
	CPC–CPV	0.9929	0.9859	0.005
	FPS–BMD	− 0.8233	0.6778	0.025
	FPS–CPV	− 0.8953	0.8015	0.005
White yam, WY	CPC–BMD	0.9932	0.9865	0.005
	CPC–CPV	0.9913	0.9827	0.005
	FPS–BMD	− 0.9066	0.8219	0.005
	FPS–CPV	− 0.8059	0.6494	0.025

Sig = Significance; CPC = cold-paste concentration (%); FPS = flour particle size (μm); BMD = density (kg m^{-3}); CPV = cold-paste viscosity (mPa s).

Fisher's multicomparison test was used to determine significant differences among factors/mean values of variables (tuber type, cold-paste concentration and flour particle size).

3. Results and discussion

3.1. Effects of cold-paste concentration (CPC)

The data on density and cold-paste viscosity as functions of tuber type (TT) and concentration (CPC) are illustrated in Fig. 1(a) (density) and Fig. 1(b) (viscosity). The density was an approximately linear function of concentration, with the values for sweet potato being the highest. Results of correlation analyses showed that the coefficient r was very nearly $+1$ and highly significant also ($P_r < 0.005$, Table 1). Similar results (r and P_r) were obtained for viscosity. The technological implications of these very high correlation coefficient (r) and quality of fit (r^2) values are that the food processor may manipulate the end quality of his product formulae by pre-determined manipulation of the concentration of the paste/slurry under test. This assertion is clearly indicative that both tuber type and concentration play a crucial role in influencing the density and viscosity of cold, tuber flour paste. Elsewhere, results have shown that viscosity is a function of starch paste concentration at 30°C for cassava and potato (Kawabata et al., 1984).

The relatively higher viscosity of SP might be caused by the higher content and leaching of the amylose fraction of the starchy system (Galliard and Bowler, 1987).

The analysis of variance (ANOVA) results showed that the effects of TT and CPC were highly significant ($P < 0.001$) for both density and viscosity (Table 2). Further, data from the Fisher's test, to separate the tuber type means, showed significant differences between WY (high), CS (higher) and SP (highest) in both density and viscosity ($P < 0.05$, Table 3). Technically, a processor can use these data as preliminary indices to choose among tropical tubers and their flours on the basis of density and cold-paste viscosity.

On the concentration means (Table 4), for both parameters, the 40% paste means were statistically equivalent to those of 35% and 45% pastes ($P < 0.05$).

Table 2
Two-way analysis of variance (ANOVA) for density and viscosity as affected by tuber type and concentration

Source of variation	Degree of freedom	Sum of squares for the parameters	
		Density, BMD (kg m^{-3})	Cold-paste viscosity, CPV (mPa s)
Tuber type, TT	2	7298.61*	79406.60*
Cold-paste concentration, CPC	9	52624.13*	887896.13*
Residual	18	848.99	16104.07
Total	29	60771.73	983406.80

*Significant at $P < 0.001$ level of confidence.

Table 3
Mean ANOVA sources for density and viscosity as affected by tube type*

Property	Tuber types			LSD**
	Cassava, CS	Sweet potato, SP	White yam, WY	
Bulk mass density, BMD (kg m^{-3})	1024.89 ± 42.18[a]	1050.15 ± 48.88[b]	1012.69 ± 42.11[c]	6.45
Cold-paste viscosity, CPV (mPa s)	290.90 ± 181.89[a]	373.60 ± 198.10[b]	249.90 ± 167.68[c]	28.10

*These are values calculated over 10 various concentration levels for each of the tubers (Fig. 1(a) and Fig. 1(b)) using 180 μm flour particles.
**Least significant difference computed at 5% level of confidence.
[a–c]Uncommon superscripts along row indicate statistically significant differences ($P < 0.05$).

Table 4
Mean ANOVA scores for density and viscosity as affected by concentration*

Concentration (%, w/w, db)	Property	
	Density (kg m^{-3})	Cold-paste viscosity (mPa s)
5	956.67 ± 6.63^{h}	53.00 ± 40.36^{h}
10	975.90 ± 15.78^{g}	78.33 ± 65.29^{h}
15	995.13 ± 28.06^{f}	158.33 ± 43.11^{g}
20	1009.87 ± 19.78^{c}	210.00 ± 48.77^{f}
25	1023.43 ± 19.76^{d}	263.33 ± 62.07^{e}
30	1047.37 ± 20.75^{c}	343.67 ± 93.04^{d}
35	1056.38 ± 20.41^{bc}	403.33 ± 86.12^{a}
40	1064.57 ± 20.69^{b}	453.33 ± 78.65^{ab}
45	1075.69 ± 20.27^{ba}	503.67 ± 56.09^{b}
50	1087.43 ± 22.93^{a}	581.00 ± 91.48^{c}
LSD**	11.78	51.31

*Values are means calculated on three tuber flours of 180 μm size particles.
**Least significant difference at 5% level of confidence.
[a–h]Uncommon superscripts among columns indicate significant differences ($P < 0.05$).

3.2. Effect of flour particle size (FPS)

Results of the influence of FPS on density (Fig. 2(a)) viscosity (Fig. 2(b)) for the three test tubers indicated inverse relationships. Their correlation coefficient, r, ranged from -0.07 to -0.91 and at various levels of confidence (P_r: 0.005–0.025, Table 1). Finer FPS were observed to cause much higher viscosity and density than the coarser ones (Fig. 2). The larger surface area of the finer particles will result in more rapid leaching of the soluble components and this will alter the properties of the continuous phase.

These variations in the density and viscosity of the cold medium owing to tuber type and flour particle size were significant at different levels of confidence (Table 5). However, there was no significant difference between the mean

Table 5
Two-way ANOVA for density and viscosity as affected by tuber type and particle size

Source of variation	Degree of freedom	Sum of squares for the parameters	
		Density, BMD (kg m^{-3})	Cold-paste viscosity, CPV (mPa s)
Tuber type, TT	2	19 627.43*	22 951.87*
Flour particle size, FPS	6	143 300.42***	270 834.60***
Residual	12	16 921.29	11159.54
Total	20	179 849.15	34 946.02

*Significant at $P < 0.01$ level.
**Significant at $P < 0.005$ level.
***Significant at $P < 0.001$ level.

values for CS and WY, while SP was higher for both parameters (Table 6). The 75 μm sample showed statistically higher and different density and viscosity when particle size was considered (Table 7). Technically and economically, SP and flour samples with the smallest particle size tested have shown the greatest potential to be used to control or influence food formulae.

4. Conclusions

The effect of particle size and concentration on the textural quality of cold flour pastes of some tropical tubers have been studied. Density and apparent viscosity were measured as preliminary indices of texture. The type of tuber, flour particle size and cold-paste concentration have been found to influence, very significantly, the density and viscosity of the paste, and hence the textural quality of the carbohydrate-containing food system. Reduction in flour particle size and increase in cold-paste concentration

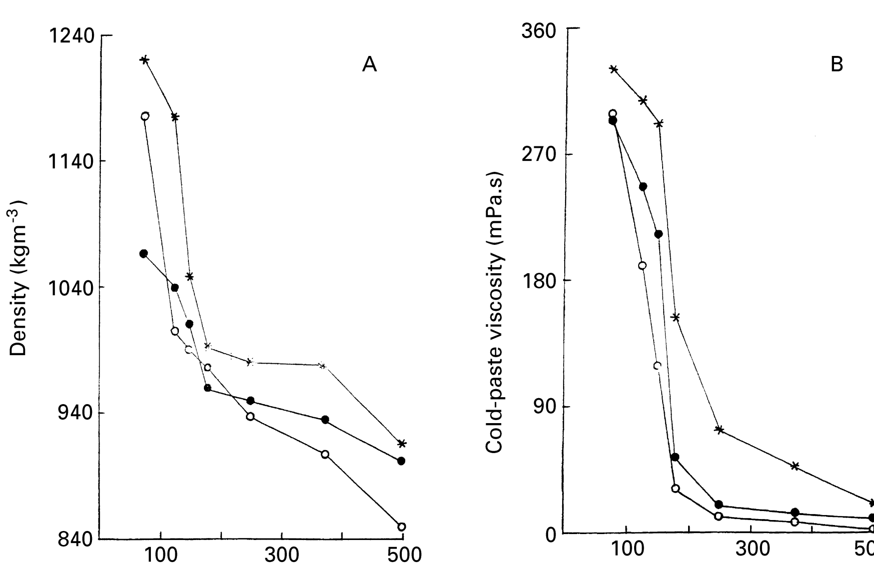

Fig. 2. Effect of flour particle size on the density (A) and cold-paste viscosity (B) for cassava (○), sweet potato (*) and white yam (●) tubers.

Table 6
Mean ANOVA sources for density, BMD (kg m^{-3}) and cold-paste viscosity, CPV (mPa s) as affected by tuber type, TT*

Property	Tuber type, TT			LSD**
	Cassava, CS	Sweet potato, SP	White yam, WY	
BMD	977.15 ± 102.81[a]	1044.19 ± 112.03[b]	981.77 ± 59.85[c]	43.74
CPV	95.02 ± 114.94[a]	174.41 ± 133.92[b]	120.91 ± 125.91[c]	35.52

*These are values calculated over seven various flour particle sizes for each of the tubers (Fig. 2(a) and Fig. 2(b)) using 10% (w/w, db) paste.
**Least significant difference computed at 5% level of confidence.
[a,b]Uncommon superscripts within a row indicate significant differences ($P < 0.05$).

Table 7
Mean ANOVA scores for density and viscosity as affected by flour particle size (FPS)*

FPS (μm)	Property	
	Density, BMD (kg m^{-3})	Cold-paste viscosity, CPV (mPa s)
75	1154.84 ± 78.70[d]	309.00 ± 18.25[h]
125	1072.97 ± 89.34[c]	248.80 ± 57.93[b]
150	1016.83 ± 28.87[ac]	208.67 ± 86.58[b]
180	975.90 ± 15.78[a]	78.33 ± 65.29[c]
250	956.45 ± 21.71[a]	33.77 ± 33.28[cd]
375	940.68 ± 35.62[ab]	21.98 ± 20.70[d]
500	889.58 ± 35.74[b]	10.27 ± 8.49[d]
LSD**	66.81	54.26

*Values are means calculated on three tuber flours of 10% (w/w, db) paste.
**Least significant difference.
[a–d]Uncommon superscripts among columns indicate significant differences ($P < 0.05$).

caused a large increase in the textural indices of the test slurries.

In this respect, it has been established through a series of studies that incorporating 10% (w/w, dmb) of 75 μm sweet potato flour will improve the bulkiness and/or consistency of a food system tremendously.

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