Flow Properties of Chinese Yam Pulp and its Serum

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This study was conducted to investigate the flow behaviors of Chinese yam pulp and its serum with a concentric cylinder viscometer.

Both pulp and serum showed a power law fluid behavior at shear rates ranging from 0.1–20 s⁻¹. Activation energy of the serum was 1182 cal/mol. In addition, serum showed a time dependency, and marked shear decay was observed at shear rates of more than 1.02 s⁻¹.

In recent years, the production of Chinese yam (*Dioscorea opposita* Thunb. cv. Nagaimo) greatly increased in the Tokachi district. In 1989, 15 000 tons of Chinese yam were harvested from this area, which amounted to 10% of the total production in Japan.

TANOUE *et al.*¹⁾²⁾ determined the compositions of viscous polysaccharide of yams (Jinennjo, Yamatoimo and Icho-imo). HIRONAKA *et al.*³⁾ purified the mucilage of Chinese yam using sodium dodecylsulfate (SDS) and found that it is composed mainly of mannan. However, little is known about the flow properties of Chinese yam. This study was conducted to investigate the flow behaviors of Chinese yam pulp and its serum with a concentric cylinder viscometer.

1. Materials and Methods

(1) Materials

Chinese yams were harvested from a farmer's field in Obihiro on Nov. 10, 1990 and stored at

5°C, 95% r.h. before analysis.

(2) Preparation of pulp and its serum solutions

Yam tubers were washed, peeled and diced into approximately 1 cm cubes. The diced yams (200 g) were homogenized in a blender (Model MK-K-3, Matsushita Denki Sangyo Co., Osaka). The homogenate (yam pulp) was centrifuged at 2 860 × g for 15 min. The yam pulp and supernatant were used to determine viscosity.

(3) Measurement of viscosity

Viscosities of the pulp and serum were measured at temperatures ranging from 20°C to 92°C using a B type viscometer (Model B8L, Tokyo Keiki Co., Tokyo). All measurements were performed in duplicate.

2. Results and Discussion

(1) Flow properties of the pulp and its serum

Apparent viscosity, by analogy to Newtonian fluids, is defined as the ratio of shear stress to shear rate. For power-law fluids without yield stress⁴⁾, the apparent viscosity η_a (Pa. s) is given by

$$\eta_a = \tau / \dot{\gamma} = K \dot{\gamma}^n / \dot{\gamma} = K \dot{\gamma}^{n-1} \quad (1)$$

Where τ is shear stress (Pa), $\dot{\gamma}$ is shear rate (s⁻¹), K is consistency index (Pa. sⁿ), and n is flow behavior index (-). For a power-law fluid without yield stress, a double logarithmic plot of apparent viscosity against shear rate yields a straight line.

Experimental results for the pulp and its serum of Chinese yams were plotted on logarithmic coordinates in Figs. 1a and 1b, respectively. The straight lines indicate that these samples are the power-law fluids.

The fluid characteristics of some food suspensions have been determined. BREKKE and MYERS⁵⁾ found that guava purees and concentrates were characterized by a power-law fluid model. Other purees and concentrates were shown to be non-Newtonian fluids^{6)~8)} with power law flow characteristics. VITALI and RAO⁹⁾ found that the low-pulp concentrated orange juice were shear-thinning fluids with negligible magnitudes of yield stress.

HARPER and EL SAHRIGI⁴⁾ showed that con-

Fig. 1 Log apparent viscosity (η_a) vs Log shear rate ($\dot{\gamma}$) data of Chinese yam pulp (a) and its serum (b) at six temperatures

centrated tomato serum (65° Brix) was a shear thinning fluid, and reported that the non-Newtonian behavior of concentrated fruits serums can be attributed to the presence of high molecular-weight solutes such as pectins^{10,11)}. Moreover, RAO and PALOMINO⁸⁾ showed that the serum samples were shear-thinning and mildly non-Newtonian due to the presence of dissolved pectins, and that the consistency index of the sauce was higher than that of the serum, again due to suspended matter.

HOLDSWORTH¹²⁾ suggested two explanations for the shear-thinning behavior of fluid food solutions: One is that the increasing shear rate progressively disentangles the arrangement of long-chain molecules and helps to overcome the intermolecular resistance to flow. The second explanation was based on the behavior of highly solvated molecules or particles present in the dispersed material; thus it was considered that solvated layers may be progres-

sively removed with increasing shear rate causing a reduction in the effective size of particles and hence, a reduction in apparent viscosity.

The shear-thinning behavior exhibited by the Chinese yam serum could be attributed basically to the presence of the mucilage which was found to consist mainly of the polysaccharide, mannan³⁾. Thus, the increasing rate of shear could have progressively disentangled the arrangement of the long-chain molecule which helped to overcome the intermolecular resistance to flow. On the other hand, the shear-thinning behavior exhibited by the Chinese yam pulp could be due to the presence of the mucilage and dispersed particles. So, in addition to the behavior of mucilage under increasing shear rate, it is considered that solvated layers of the dispersed particles may be progressively removed causing a reduction in the effective size of particles and hence, a reduction in apparent viscosity¹²⁾. A related explanation was given by FISHER and LINDSLEY¹³⁾ for the behavior of starch pastes. As the mixture is sheared, the particles are deformed and oriented to some extent in the direction of flow. Some of the liquid associated with the particles may be separated resulting in smaller particles, reduced interaction in shearing, and hence, a decrease in resistance to shear. As the rate of shear increases, the extent of such change in particle size becomes greater and the apparent viscosity falls off.

(2) Temperature dependency

Fig. 2 shows Arrhenius plot for the serum solution at shear rate of 4.08 s^{-1} . Apparent

Fig. 2 Apparent viscosity (η_a) vs the inverse of temperature of the serum

Fig. 3 Decrease in apparent viscosity (η_a) of the serum at four shear rates ($\bigcirc$: 0.1 s^{-1} , $\triangle$: 1.02 s^{-1} , $\square$: 10.2 s^{-1} , $\times$: 20.4 s^{-1}) at 20°C

viscosity decreased with temperatures. The activation energy was estimated to be 1182 cal/mol.

The decrease in apparent viscosity of the serum solution with increase in temperature could be due to the structural breakdown of its polysaccharide component or the dissolution of other particles. In a related study, LANG and RHA¹⁴⁾ reported that in egg white, the decrease in viscosity with increasing temperature reflects its decreased resistance to structural breakdown as a result of the weakening of secondary bonds and associations at higher temperatures. In starch, heat increases vibration of the intermolecular bonds allowing increased penetration and absorption of water with consequent release of soluble matter and lowering of viscosity (BECHTIL and FISHER¹⁵⁾).

(3) Time dependency

Fig. 3 shows thinning of serum solution with shearing time at 20°C . At shearing rates higher than 0.10 s^{-1} , the marked shear decay occurred.

LANG and RHA¹⁴⁾ observed such decay for the thick egg white at the constant shear rate of 34.2 s^{-1} and postulated that structural rearrangement or breakdown occur in egg white under the shearing forces corresponding to the constant shear rate used. The same explanation could hold for the shearing decay observed in the Chinese yam serum. However, further study will be needed to elucidate its structure.

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ナガイモの流動特性

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ナガイモのすりおろし液および粘稠液の流動特性を回転粘度計を用いて研究した。その結果、すりおろし液および粘稠液の流動特性は、せん断速度の $0.1 \sim 20 \text{ s}^{-1}$ の範囲内において、指数法則流体モデルで良く表すことができた。粘稠液の活性化エネルギーは、1182 cal/mol となった。さらに、粘稠液はせん断時間依存性を示し、著しい粘性低下が 1.02 s^{-1} 以上のせん断速度でみられた。