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Chemical composition and some physical properties of a water-soluble gum in taro (*Colocasia esculenta*)

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A high-purity (98%), water-soluble gum was extracted from taro corms (*Colocasia esculenta*) with a low-temperature extraction (4°C) and purification procedure. The major fraction of the gum had a peak molecular weight greater than one million Daltons, with two shoulder peaks at 850 000 Daltons and 100,000 Daltons. In the acid hydrolysates of the taro gum, D-galactose was identified by HPLC to be the main constituent (61·6%), followed by D-glucose (19·7%) and D-arabinose (16·2%). Small quantities of galacturonic acid and protein were also found in the gum. The gum is very soluble in water. The viscosity behavior indicates that the gum is mainly a neutral carbohydrate polymer, probably highly branched. The viscosity was comparable to gum arabic at 2% concentration, but increased drastically at 4% concentration. Neither pH nor ionic strength of the gum solution had significant effect on its viscosity.

INTRODUCTION

Taro (*Colocasia esculenta*) is a root crop grown in most tropical areas including Hawaii. Cooked taro paste, or 'poi' in Hawaiian, has been the major staple food of native Hawaiian people (Moy & Nip, 1983). The slimy texture of taro corns and taro products like poi has long been attributed to the presence of water-soluble gum, or mucilage in earlier literature (Allen & Allen, 1933; Moy *et al.*, 1977; Crabtree & Baldry, 1982). However, the identity and properties of the taro gum have received only limited attention. Amin (1955) reported that the taro mucilage contained mainly D-galactose but little was known about the rest of its composition. Gaind *et al.* (1968, 1969) studied the emulsifying and binding properties of a crude taro gum. The purity of the gum was not known. More recently, El-Mahdy and El-Sebaiy (1984) reported a preliminary study on the viscosities and molecular weight profiles of several mucilages including taro gum. Glucose was identified as the major sugar constituent in the taro gum, along with smaller fractions of galactose and fructose. The hot-water extraction these authors used, however, would conceivably extract some starch fragments along with gum thus yielding erroneously high amount of glucose in its hydrolysate. The protein content in their gum fraction was determined as approximately 5%. It was not clear if the protein was an integral part of the taro gum.

This study was designed to provide further information on the chemical composition, water solubility and rheological properties of a purified taro gum. This study is part of a broader effort in understanding the functional properties of taro gum in poi and other taro-based food products.

MATERIALS AND METHODS

Extraction of taro gum

Fresh taro corms (Lehua variety) were peeled, cut into one-inch diameter cubes, and blended with refrigerated 4°C water in a commercial Waring blender. After blending for 1 min, the mixture was quickly filtered through a 200-mesh Tyler sieve. The filtrate was clarified in a refrigerated centrifuge at 13 000*g* for 10 min with the temperature set at 4°C. The supernatant was decanted into a separate container. Three volumes of 95% ethyl alcohol were added to one volume of the supernatant to precipitate the gum fraction. The mixture was centrifuged at 10 000*g* and 4°C for 10 min. The sediment was washed with 95% ethyl alcohol and acetone three times for each. The washed material

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was dried in an oven at 40°C to a constant weight before being pulverized with mortar and pestle to pass 200 mesh. This powder is referred to as the crude taro gum.

A separate batch of the crude taro gum was prepared with the extraction temperature set at 70°C instead of 4°C to imitate a previously reported extraction procedure (El-Mahdy & El-Sebaiy, 1984). The material was prepared to evaluate the effect of extraction temperature on gum purity.

Purification of gum

A 5% gum dispersion was made by mixing an appropriate amount of the crude taro gum in refrigerated 4°C distilled water. Trichloroacetic acid (TCA) was added to the dispersion to achieve 4% of the mixture. The mixture was stirred for 5 min and then centrifuged at 10 000*g* and 4°C for 10 min. Again the supernatant was decanted to a separate container. Three volumes of 95% ethyl alcohol were added to one volume of the supernatant to re-precipitate taro gum. The gum fraction was collected by centrifugation at 10 000*g* and 4°C for 10 min. The precipitate was repeatedly washed with 95% ethyl alcohol and acetone to pH 5·5. The purified gum was dried and pulverized as described for making crude taro gum powder.

Purity of the gum sample was determined using the enzyme-gravimetric method described by Mongeau and Brassard (1990) for soluble dietary fiber. The moisture content was determined at 70°C in a vacuum oven.

Molecular size distribution

An Econo-column (2·6 cm × 80 cm, Bio-Rad Laboratories, Richmond, CA) packed with Sepharose CL-2B gel was used to analyze the molecular size distribution of the purified taro gum. The column was developed in the ascending mode. A sample solution of 5 ml containing approximately 15 mg of the gum was injected into the column. Glucose was added as a marker. The eluant was an alkaline-sodium salt aqueous solution of 1 mM sodium hydroxide and 25 mM sodium chloride with a flow rate of 30 ml/h. Fractions of 4·8 ml each were collected and analyzed for total carbohydrate by anthrone-sulfuric reagent with an AutoAnalyzer (Bran + Lubbe, Elmsford, NY). Iodine was used to detect the presence of any residual starch in gum fractions. Molecular sizes of the gum were determined following the method provided by Pharmacia (1985). The procedure was repeated twice. Pullulans (Shodex P-82, Waters Associates, Milford, MA) were used to establish a standard curve.

Infra-red spectra

Crude and purified taro gums were ground separately with potassium bromide into fine powder. An appropriate amount of the powder was pressed into a crystal window. The infra-red spectrum was recorded on a Fourier transform infrared spectrometer (Nicolet Analytical Instruments, Madison, WI).

Acid hydrolysis of gum

A two-step acid hydrolysis treatment was used to break taro gum into simple sugars (Voragen *et al.*, 1982). In the primary hydrolysis, a 20 mg/ml gum dispersion prepared in 80% sulfuric acid was flushed with nitrogen for 3 min then sealed with a rubber stopper. The hydrolysis proceeded immediately at 25°C for 17 h with continuous agitation. After the first hydrolysis, the hydrolysate was diluted with distilled water to 20% of sulfuric acid, flushed with nitrogen and sealed. The secondary hydrolysis proceeded at 100°C for 3 h. The hydrolysate was then neutralized with saturated barium hydroxide. Barium sulfate, the residue formed from neutralization, was removed from the aqueous portion by centrifugation and washed twice with distilled, deionized water. The supernatant and washings collected after centrifugation were combined and freeze-dried. The dried matters were redissolved in distilled water to yield a concentration of 10 mg/ml and then filtered through a 0·45 μm membrane for HPLC analyses.

HPLC analyses of hydrolysates

The chromatography used to analyze sugars in gum hydrolysates was performed with a SP8800 programmable isocratic solvent delivery unit (Spectra-Physics, San Jose, CA) fitted with a Rheodyne 7125 loop injector, and a RID-6A refractive index detector (Shimadzu Scientific, Columbia, MD) or a variable wavelength UV detector (Spectra 100, Spectra-Physics). Chromatograms were recorded and peak areas were analyzed using a digital integrator (Shimadzu CR601). There were two column systems used. For neutral sugar analysis, the calcium-fixed Sugar Pak I column (Waters Associates) was developed by a mobile phase of 0·1 mM calcium disodium EDTA in water at a flow rate of 0·3 ml/min. The column temperature was maintained at 90°C in a closed water bath. The refractive index detector was used. For the analysis of acidic sugars, the ligand-exchange Polypore H column (Applied Biosystems, Foster City, CA) was developed isocratically with a mobile phase of 5 mM sulfuric acid in water at a flow rate of 0·45 ml/min. The UV detector was set at a wavelength of 214 nm. Identities of the HPLC peaks were determined by their retention times and internal standards. The average recovery of simple sugars added to the gum hydrolysates was 95%, with a coefficient of variability ranging from 3 to 6%.

Measurement of water solubility and sorption isotherms

The water solubility of taro gum was determined using a procedure reported by Schoch (1964). Approximately 1 g (weighed to 0·1 g) of the purified taro gum was dispersed in 30 ml of distilled and deionized water with

a mixer at 25°C for 15 min. The dispersion was then centrifuged at 5000*g* for 10 min and at 10 000*g* for another 10 min. Twenty millilitres of the supernatant was dried at 105°C in a pre-dried/pre-weighed (Wg) glass dish until a constant weight (W_s) was obtained. Duplicate samples were measured. The solubility was calculated as:

$$\text{Solubility (mg/ml)} = (W_s - W\text{g}) \text{ mg/10 ml}$$

The sorption isotherm of the taro gum was established using the static-desiccator method (Iglesias & Chirife, 1982). Each desiccator contained a saturated salt solution to maintain a specific water activity. The water activities and salts were 0·11 (LiCi), 0·23 (KAc, potassium acetate), 0·43 (K_2CO_3), 0·71 (SrCl), 0·84 (KCl), and 0·97 (K_2SO_4). The desiccators were kept at 25°C, Triplicate samples were weighed in pre-dried/pre-weighed aluminium dishes and equilibrated in desiccators for at least 4 h or until an equilibrium weight (Weq) was reached, as indicated by a stable humidity reading on a humidity meter (Hygrometer model HTAB-176, Abbeon Cal, Inc., Santa Barbara, CA) inside the desiccator. The sample dry weights (W_d) were measured by vacuum drying at 60°C for 16 h to constant weights. The equilibrium percentage moisture content at a specific water activity was calculated as:

$$\%\text{ Moisture content} = [(W\text{eq} - W_d)/W_d] \times 100$$

The sorption isotherm was obtained by plotting the equilibrium percentage moisture content against its water activity. A commercial corn starch was used as a reference material for comparing taro gum with another polysaccharide material in terms of sorption isotherm.

Viscosity measurement

The viscosity of gum solutions was determined using a Brookfield LVTDV-II viscometer (Brookfield Engineering Lab., Stoughton, MA) with an UL adapter or a small sample adapter fitted with a SC4-18/13R spindle at a specified shear rate and temperature. The temperature was controlled by using an Isotemp refrigerated circulator (Model 910, Fisher Scientific, Pittsburgh, PA). The pH of the gum solution was controlled by the sodium phosphate dibasic/citric acid buffer (0·5 M). The ionic strength was standardized using sodium chloride in solution.

Data analysis

Replicate determinations of chemical components, water solubility, equilibrium moisture contents, and viscosities were averaged to obtain a single datum point for each measurement. Differences in averages were analyzed for statistical significance using either the Student's *t*-test or Duncan's multiple range test. Statistical analyses were conducted using the STAT-PAK software program (Northwest Analytical Inc., Portland, OR).

RESULTS AND DISCUSSION

Extraction and purification

In order to obtain a high-purity gum from a starch-rich material like taro corms, it is essential to maintain a low extraction temperature. If water-soluble starch fragments, such as oligosaccharides and the gelatinized starch, are extracted along with the gum, it would be very difficult to remove the contaminants due to their many similarities with the gum. The presence of starch fragments in gums would yield misleading sugar profiles of the gum hydrolysate. As shown in Table 1, glucose was the major sugar component in high-temperature (70°C) extracted samples, but galactose was the major sugar component in low-temperature (4°C) extracted samples. The difference in carbohydrate compositions can be mainly attributed to the presence of starch components in the gum after purification, which was proved by the positive iodine test in these samples. Therefore, we believe that the carbohydrate composition in the 4°C extracted gum in which galactose is the major component better represented the intrinsic taro gum. This material was used in the remaining tests to characterize the properties of taro gum.

All neutral sugar components, including galactose and glucose, were also previously identified in taro gum (Amin, 1956; Abdel-Akher *et al.*, 1972; El-Mahdy & El-Sebaiy, 1984). The weight percentages of these sugars differed greatly in the literature which can be attributed to the differences in the taro variety and extraction conditions. A small percentage of galacturonic acid in taro gum was first reported by Amin (1956). Later studies did not confirm this finding. We positively identified this acidic sugar in purified taro gum by HPLC with the Polypore-H column.

After treating gum fractions with TCA to remove unconjugated protein, the remaining protein content in purified gum was 2·1% less than the 4·56% reported by El-Mahdy and El-Sebaiy (1984). This residual amount of protein was determined with both the Lowry's method and an amino acid analyzer. Further purification of the gum fraction with repeated TCA precipitation did not further reduce the protein content. The presence of protein in taro gum can also be illustrated by the FTIR spectra in Fig. 1. The strong absorbances of two ester carbonyl stretches at 1550 cm^{-1} and 1650 cm^{-1}

Table 1. Effect of extraction temperature on the composition of the taro gum after purification

Composition (% dry weight)	Extraction temperature	
	4°C	70°C
Glucose	19·7 (± 1·8)	59·6 (± 2·1)
Galactose	61·6 (± 2·3)	26·7 (± 1·9)
Arabinose	16·2 (± 1·1)	5·1 (± 0·8)
Galacturonic acid	0·5 (± 0·1)	0·2 (± 0·1)
Protein[a]	2·1 (± 0·2)	5·4 (± 1·1)
Iodine test (starch)	Negative	Positive

[a] Based on test results of Lowry's method.

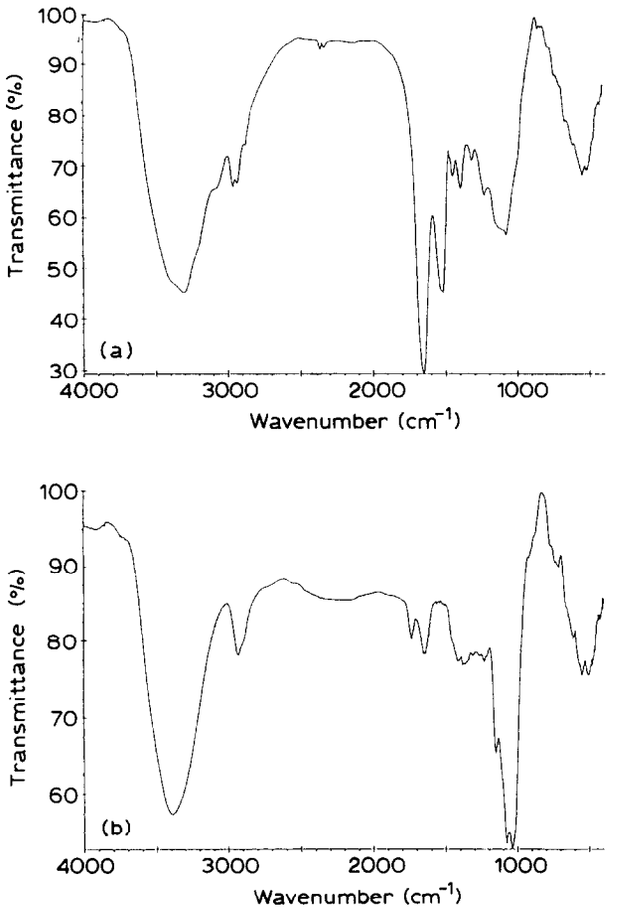

Fig. 1. Infra-red spectra of a crude taro gum (a) and a purified taro gum (b) in KBr windows.

indicated a high protein content in the crude taro gum. These absorbances were greatly reduced but still existed in the purified gum. The slight shifts of major absorption bands in the purified gum from those in the crude gum also indicated the presence of proteins. In the mean time the C–O stretch (1150–1000 cm^{-1}) mostly from the carbohydrate structures, became stronger

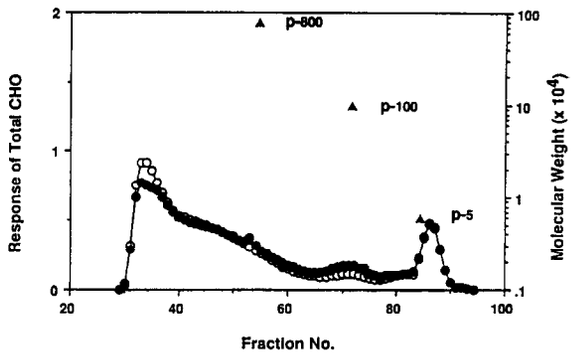

Fig. 2. Molecular size distribution of purified taro gum determined with a CL-2B gel column eluted with 1 mM NaOH/0·25 mM NaCl at a flow rate of 30 ml/h and collected at 4·8 ml each fraction. Eluants were monitored with anthrone/H_2SO_4 reagent for total carbohydrate and iodine reagent for residual starch. Open and closed circles represent two separately prepared gum samples. Filled triangles represent pullulan standards: p-800, MW-85·3 × 10^4; p-100, MW-10·0 × 10^4; p-5, MW-0·58 × 10^4.

in the purified gum, indicating taro gum is mainly a carbohydrate compound.

Molecular size distribution

Molecular size distribution chromatograms of the purified taro gum show two distinctive fractions. In separately prepared gum samples (Fig. 2), both the major fractions had a peak molecular weight greater than one million Daltons and two shoulder peaks at approximately 850 000 Daltons and 100 000 Daltons, respectively. Both the second fractions had a peak molecular weight at 5 000 Daltons. There were no peaks in the chromatograms monitored by the iodine test indicating the absence of starch in the purified taro gum extracted at 4°C. Due to the type of molecular sieve gel (Sephadex G-100, 40-120 U) used in the previous report (El-Mahdy & El-Sebaiy, 1984), the authors could

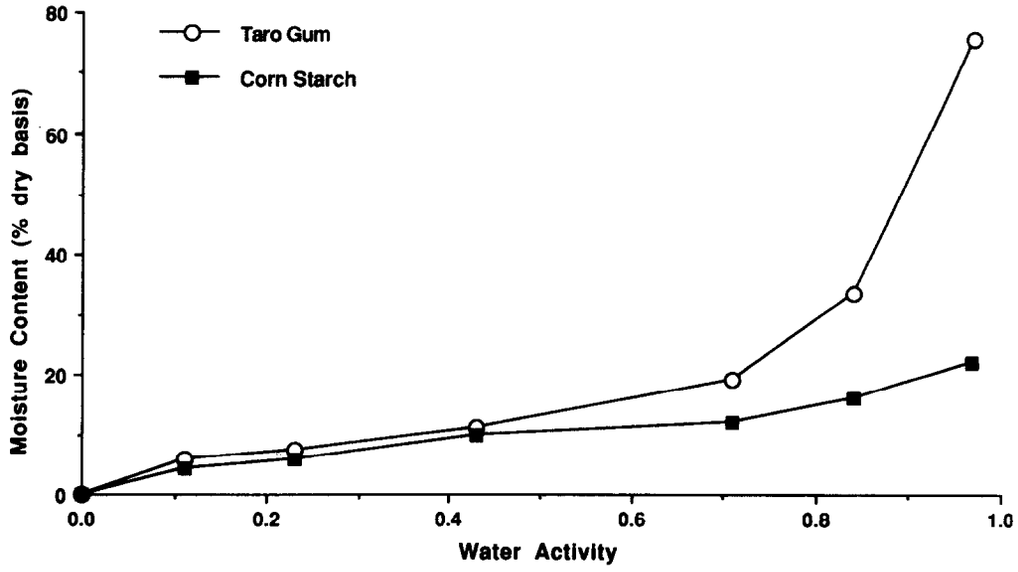

Fig. 3. Moisture sorption isotherms of taro gum and corn starch at 25°C. Method: static-desiccator (saturated salt solutions). All standard errors of moisture contents were less than 2%.

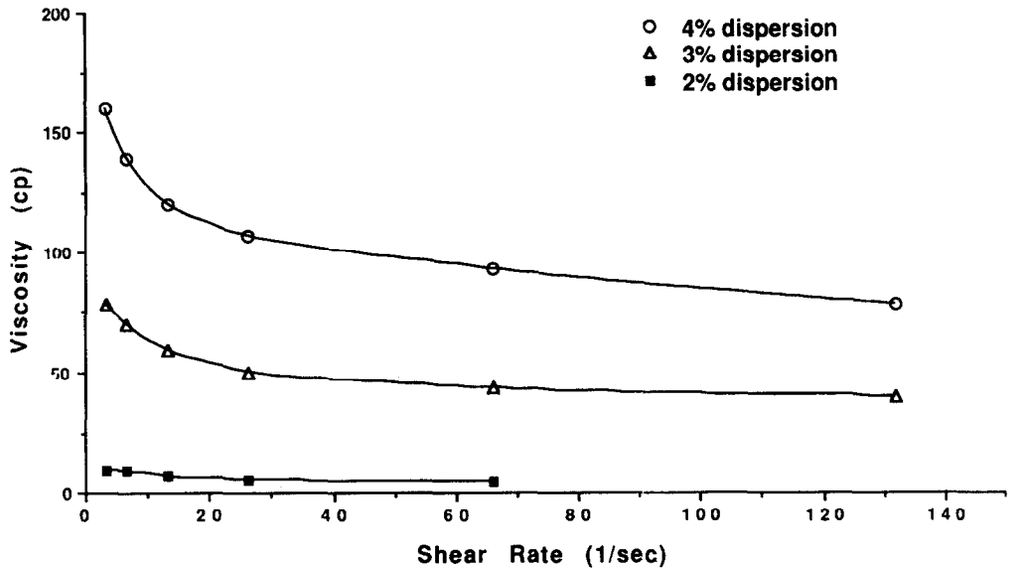

Fig. 4. Effect of shear rate and gum concentration on the apparent viscosity of taro gum in solution at 25°C. Standard errors of viscosity were less than 4 cp.

only indicate that the major gum fraction was greater than 100,000 Daltons. Our study further defined the molecular size of the major taro gum to be in the vicinity of one million Daltons.

Solubility and sorption isotherms

Taro gum is soluble in water. In a 3% dispersion of purified gum in water, an average of 88·7% or 2·66 g were soluble in 100 ml of water. The solubility data El-Mahdy and El-Sebaiy (1984) reported were based on a 10% dispersion. The solubility of their taro gums was 6·54 g in 100 ml of water. The higher number they reported reflected the higher concentration of their dispersion and possibly the lower purity of their gums. The increase in solubility of gums due to the presence of impurities has been known for other gums (BeMiller, 1973; Frost *et al.*, 1984). In comparison with other natural gums, according to literature data, the solubility of taro gum is similar to that of xanthan gum and guar gum but less than that of gum arabic.

Plots interrelating water contents of a food item with its water activities (a_w) at a constant temperature are known as moisture sorption isotherms. The sorption isotherm curve of the purified taro gum was a sigmoidal shape, which is common among food items rich in polymeric materials (Fig. 3). This corresponded well with the molecular size distribution data. In comparison with a commercial corn starch sample which was tested simultaneously, the sorption isotherm curve of taro corm was significantly different from that of the corn starch where a_w was equal to or greater than 0·7. This result indicates a greater water-binding capacity of taro gum.

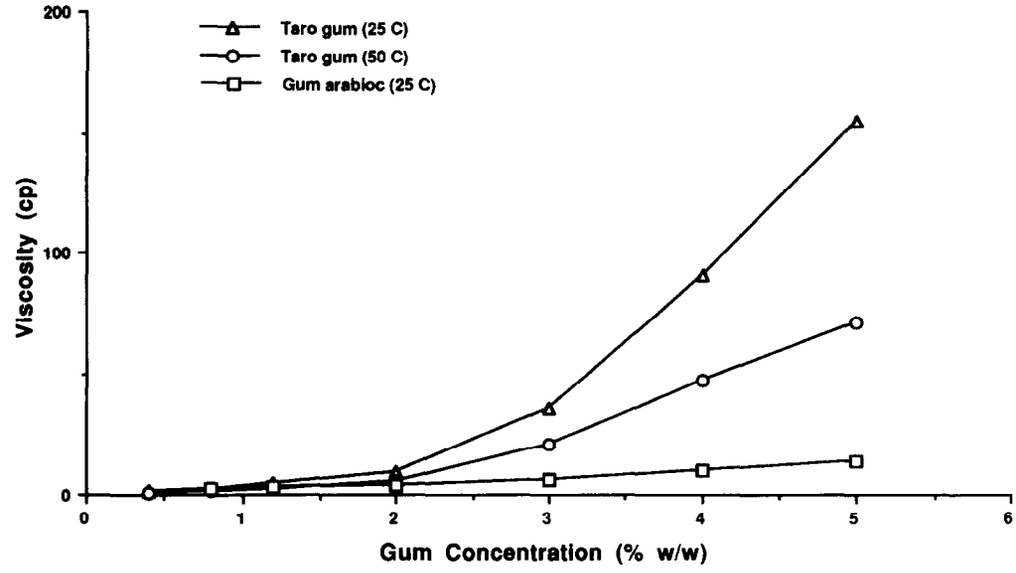

Fig. 5. Effect of concentration and temperature on the apparent viscosity of taro gum in solution measured at 80 s^{-1} shear rate. Viscosities of gum arabic solutions at 25°C were measured for comparison. Standard errors of viscosity were less than 3 cp.

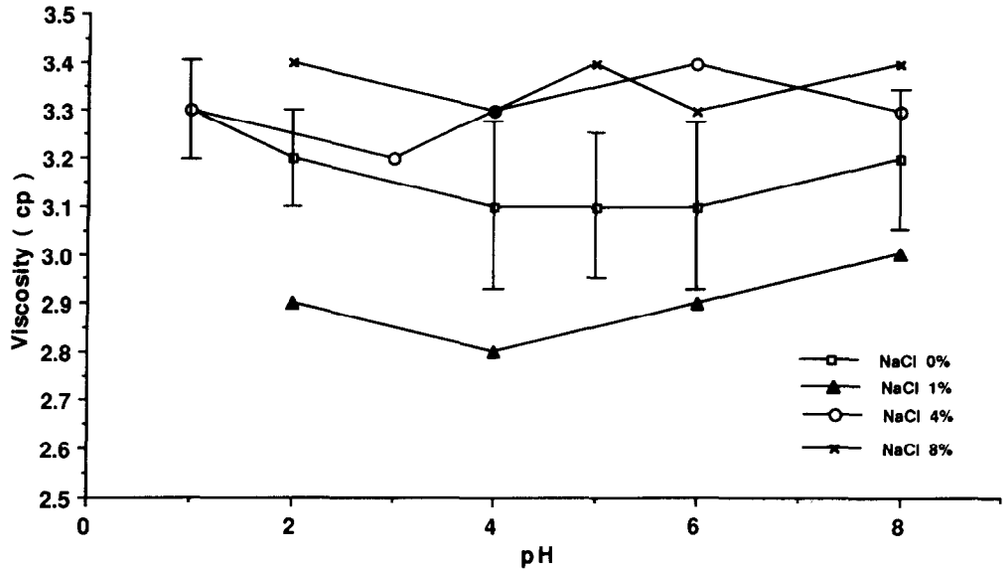

Fig. 6. The variation of viscosity with pH and ionic strength in 1% taro gum dispersions measured at 25°C. The shear rate was 80 s^{-1}. Standard errors of viscosity were less 0·3 cp; only standard error bars of the 0% NaCl group were depicted for purposes of clarity.

Viscosity behavior

Similarly to many other natural gums, the dispersions of taro gum at low concentration exhibited the typical behavior of Newtonian fluids. As shown in Fig. 4, the viscosity of a 2% gum dispersion was constant over the range of shear rates tested. However, the viscosity of a 4% gum dispersion was no longer a constant but rather decreased with increasing shear rates. This pseudoplastic behavior indicated an inner structural change among taro gum molecules due to shearing forces (Glicksman, 1982). At low concentrations, the response to shear orientation was not as obvious, and therefore deviated less from Newtonian behavior.

At concentrations lower than 2%, purified taro gums exhibited relatively low viscosity in comparison with other natural gums. El-Mahdy and El-Sebaiy (1984) compared taro gum with other natural gums at 1% concentration and found that the taro gum solution had the lowest viscosity, which was only one-sixth the viscosity of okra mucilage. When we compared taro gum solution with other gum solutions at 2% concentration, only gum arabic and taro gum had viscosity readings under 10 cp. However, taro gum viscosity increased exponentially above 2% concentration (Fig. 5). At 4% concentration, taro gum viscosity was almost ten times that of gum arabic. This interdependent relationship between viscosity and concentration indicates a highly branched structure of taro gums in which multiple association points exist among gum molecules. As anticipated, the visocisities of taro gum decreased as the temperature increased (Fig. 5).

Effect of pH and ionic strength on viscosity

The viscosity of taro gum dispersion was not sensitive to changes in either pH or ionic strength. As shown in Fig. 6, viscosity of a 1% dispersion was fairly constant over a pH range of 1 to 8 at a specified ionic strength. Similarly, the viscosity did not vary significantly over the ionic strength range from 0 to 8% of sodium chloride. The neutral property of taro gum was responsible for the lack of sensitivity to the changes of pH and ionic strength.

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