Physical and Chemical Studies of Taro Starches and Flours[1,2]

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ABSTRACT

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Taro (*Colocasia esculenta* (L.) Schott) flours were prepared from taro corms of Bun-long, Dasheen, Hawaii Red (Lehua), Hawaii White, and Niu'e varieties. Starch contents of the flours varied from 73 to 76% as determined by enzymatic analysis. Starch yields of the flours varied from 51 to 58%. Nitrogen contents varied from 0.33 to 1.35% and from 0.014 to 0.025% in the flours and starches, respectively. Taro starches had irregular, polygonal shapes and small granular sizes. Among the five varieties, Bun-long starch had the smallest average diameter (2.6 μm), whereas Dasheen starch had the largest (3.76 μm). Amylose contents in these five starch varieties varied from 18 to 22% as determined by iodine affinity and from 19 to 24% as determined by gel permeation chromatography. Molecular sizes of the taro amyloses at the peak of gel permeation chromatography ranged from degree of polymerization (DP) 150 to 550. Branch chain lengths of the taro amylopectin varied from DP 16.8 to 18.4 and from DP 37.2 to 40.5 for short and long branches, respectively. All five starch varieties gave an A-type X-ray diffraction pattern. The taro starches contained 0.23–0.52% lipid and 0.017–0.025% phosphorus. ^{31}P-nuclear magnetic resonance spectra revealed that the phosphorus in the starches was in the form of phosphate monoester derivatives. The onset gelatinization temperatures of the taro flours varied from 72 to 79°C, whereas those of the taro starches ranged from 69 to 74°C. Retrogradations of the starches and the flours, as measured by their enthalpy changes, appeared to be more severe than that of corn starch. Taro starch pastes had significantly higher viscosities than their flour counterparts. Among the varieties, Hawaii Red and Hawaii White starches had the highest peak viscosities, whereas Bun-long starch had the lowest. Both starch and flour pastes set to weak gels.

Taro (*Colocasia esculenta* (L.) Schott) is a tropical tuber crop and is cultivated widely in many countries, including the United States. Taro is a major crop of the islands of Hawaii and Samoa. In Hawaii, taro is cultivated in both wetland and dryland conditions. Native Hawaiians grow taro in wetland for the preparation of poi (taro paste). In addition, taro also has been used in baby food, taro chips, taro bread (Moy and Nip 1983), and taro sorbet (Hong and Nip 1990).

Taro has been reported to have 70–80% starch (dry starch basis, dsb) (Payne et al 1938, Tu et al 1979) with small granules (diameters between 1.4 and 5 μm) (Amin 1955, Sugimoto et al 1986). Taro also is rich in gums (mucilages). Up to 10.7% crude taro mucilages can be extracted from taro corms and tubers with boiling water (Gaind et al 1968). Purified gums (100 g) also are isolated from fresh taro corms (1 kg) (Taki et al 1972). Drum-drying properties and storage stability of tropical fruit-taro mixtures were reported by Nip (1979a,b). The use of crude taro gums as binding and emulsifying agents has been studied by Gaind et al (1968, 1969). Because of its small granular size, taro starch has been considered a good filling agent for biodegradable polyethylene film (Griffin and Wang 1983, Lim et al 1992) and as a fat substitute.

Some chemical and physical properties of several varieties of taro starch, such as Dasheen, Bun-long, Engler, Ishikawa-wase, and Takenokoimo, have been reported (Goering and DeHaas 1972, Higashihara et al 1975, Sugimoto et al 1986). Higher pasting and gelatinization temperatures of taro starches compared with those of other small granular starches, such as cow cockle, catchfly, and pigweed starch, were reported by Goering and DeHaas (1972). Amylose contents of Ishikawa-wase and Takenokoimo taro starch were reported as 13.5 and 10.8%, respectively (Sugimoto et al 1986). Developmental changes in starch properties of taro starches were reported by Sugimoto et al (1987). Taro starch was found more susceptible to pancreatin hydrolysis than other tuber and root starches (Sugimoto et al 1979).

In this study, five varieties of taro flours, Bun-long, Dasheen, Hawaii Red (Lehua), Hawaii White, and Niu'e, were investigated. Chemical structures and physical properties of the flours and starches, including the starch contents and starch yields of the flours, amylose contents and molecular sizes, amylopectin branch chain lengths, lipid and phosphorus contents, morphology, X-ray diffraction patterns of the starches, protein contents (as nitrogen), thermal properties, retrogradation rates, and pasting and gelling properties of both flours and starches, are reported.

MATERIALS AND METHODS

Porcine pancreatic α-amylase was twice crystallized, and *Aspergillus niger* glucoamylase was lyophilized. Both enzymes and crude α-amylase from *Bacillus* species were purchased from Sigma Chemical Co. (St. Louis, MO). *Pseudomonas* isoamylase was purchased from Hayashibara Shoji, Inc. (Okayama, Japan). Bio-Gel P-6 and Sepharose CL-2B gels were products of Bio-Rad Laboratories (Richmond, CA) and Pharmacia Inc. (Piscataway, NJ), respectively. Pullulan molecular size standards (Shodex P-82 standard) were purchased from Waters (Milford, MA). Other chemicals, all reagent grade, were used without further purification.

Preparation of Taro Flour

Corms from the five varieties of taro—Bun-long (from Hawaii), Dasheen (Hawaii), Hawaii Red (Lehua, Hawaii), Hawaii White (Hawaii), and Niu'e (American Samoa)—were used to prepare taro flours at the Department of Food Science and Human Nutrition, University of Hawaii, Honolulu.

Corms were washed to remove surface soil. The corms from all varieties except Dasheen were hand-peeled and trimmed to remove the skin and defective parts. The Dasheen variety was peeled with an abrasive peeler and hand-trimmed because of small corm size. After peeling and trimming, the corms were cut into smaller pieces before slicing with a Cuisinart food processor equipped with a 0.1-cm ultrathin blade. The slices were dried on perforated trays by using a mechanical convection oven (60°C for 20 hr). The dried slices were ground into flour using a Cross-Beater mill (Glen Mill Corp., Maywood, NJ) equipped with a 0.5-mm screen. The flour was then packed and heat-sealed in laminated bags of about 1 kg each.

The bags were transferred to the Department of Food Science and Human Nutrition, Iowa State University, Ames, for starch isolation and for physical and chemical analyses.

Analysis of Starch Content in the Taro Flour

Taro flour (about 50 mg, dsb) was suspended in 90% dimethyl sulfoxide (3 ml) and boiled in a water bath at 96°C for 1 hr. After cooling, methanol (10×) was added to precipitate the solid. The mixture was centrifuged, and the supernatant was discarded. A phosphate buffer solution (pH 6.9, 0.1*M*, 3 ml) and porcine

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pancreatic α-amylase (1,330 units) were added to the solid residues. The mixture was incubated in a shaker water bath (Versa-Bath, model 236, Fisher Scientific, Pittsburgh, PA) at 35°C for 4 hr. At the end of the incubation, glucoamylase (25 units) in an acetate buffer solution (pH 4.3, 0.1*M*, 0.55 ml) was added into the digestion mixture, and the pH of the mixture was 4.5. The digestion mixture was then incubated in the same shaker water bath at 55°C for 4 hr.

Glucose produced in the digest was quantitatively analyzed by measuring the absorbance at 520 nm using a mixture of hexokinase and glucose-6-phosphate dehydrogenase (Carroll et al 1970) coupled with chemical reduction of iodonitrotetrazolium (glucose diagnostic kits no. 115, Sigma).

Isolation of Taro Starch

Taro flour (400 g) was steeped in NaOH solution (0.05%, 2 L) for 2 hr and milled with a commercial blender (model 585-1, Hamilton Beach, Washington, NC) for 2 min. Starch was separated from the residue, and the milling procedure was repeated three times. The crude starch was collected and centrifuged (800 × *g*, 30 min); brownish gummy material on the top was removed by gentle washing. The starch was resuspended in water and centrifuged (5,000 × *g*, 15 min), and then the impurity was removed from the top layer. The process was repeated four to five times. The starch was then dried in a convection oven at 40°C for 48 hr.

Proteins and lipids also were removed before the starch was used for iodine potentiometric titration (IPT). Protein residue on the surface of the starch was removed by suspending the starch (20 g) in a NaCl solution (0.2*M*, 100 ml) containing toluene (10 ml). The suspension was vigorously stirred at 25°C for 8 hr, and the starch was separated by centrifugation (4,000 × *g*, 15 min). This process was repeated twice. The starch was washed with distilled water, rinsed with methanol, and dried in a convection oven (40°C, 48 hr). Defatting of the starch was performed by using a Soxhlet extractor and 85% MeOH (Schoch 1964a).

Determination of Nitrogen Content

Nitrogen contents of taro flours and taro starches were analyzed by a macro-Kjeldahl method with a Kjeltec digester and distilling system (Tecator, Inc., Hoganas, Sweden) (Steinke and Johnson 1991). Two grams of the flour and 4 g of the starch were used for the analysis. Protein contents of the samples were calculated by multiplying the nitrogen content by 6.25.

Microscopy

Scanning electron micrographs were taken with a JEOL JSM-35 scanning electron microscope (Tokyo, Japan). Starch samples were sprinkled on adhesive tapes, attached to specimen studs, and coated with gold-palladium (60:40).

Image Analysis of Starch Granule Size

Images of the starch granules were acquired at the Iowa State University Image Analysis Facility by using a Zeiss SEM-IPS image analysis system (Zeiss-Kontron, Thornwood, NY, IBAS version 1.31) equipped with a Sony 3 CCD color video camera (Sony Co., Cypress, CA). Samples of each starch were placed on a slide and viewed with a Zeiss Axiophot microscope at 125× magnification (100× by 1.25× optivar). The internal scaling feature of the image analysis software was calibrated to measure in micrometers. The starch images were interactively discriminated and edited to separate any touching particles. These particles were then measured to obtain area, maximum and minimum diameters, and diameter of an equivalent circle.

Amylose Content in the Taro Starch

Amylose contents were determined by both IPT (Schoch 1964b) and gel permeation chromatography (GPC) (Colonna and Mercier 1984). A Sepharose CL-2B column (2.6 cm i.d. × 75 cm) was used for GPC analysis. Fractions (5 ml) were collected and analyzed with a dual-channel Technicon AutoAnalyzer II (Bran & Lubbe, Elmsford, NY) for total carbohydrate (anthrone-sulfuric acid method [Wright and Gann 1966]) and for blue value (Juliano 1971). Amylose molecular size distributions were analyzed by GPC using pullulan standards.

Branch Chain Length of the Amylopectin

Starch (20 mg) was dissolved in distilled water (3.2 ml) by stirring the solution within a water bath at 96°C for 1 hr. An acetate buffer solution (0.1*M*, 0.4 ml) was added, and the pH was adjusted to 3.5. *Pseudomonas* isoamylase (900 units) (Lee et al 1968, Yokobayashi et al 1970) was added, and the mixture was incubated at 40°C for 48 hr. When the debranching reaction was completed, the digest was heated in a water bath at 96°C for 10 min to stop the enzyme activity. Branch chain length distribution was analyzed by a Bio-Gel P-6 gel permeation column. The chain length of each peak was determined by measuring reducing value using the modified Park-Johnson method (Hizukuri et al 1981, Jane and Chen 1992); total carbohydrate content was determined by using phenol-sulfuric analysis (Dubois et al 1956) at the peak fractions.

X-Ray Diffraction Pattern

X-ray diffraction patterns were obtained with copper, nickel foil-filtered, K_α radiation by using a Siemens D-500 diffractometer (Siemens, Madison, WI) at the Engineering Research Institute, Iowa State University, Ames. Operation was at 25 μA and 50 kV with a medium resolution and a step-scan mode at 0.05° per step with a counting time of 2 sec.

Lipid Content in Taro Starch

Lipid content in the taro starch was determined by using Goldfish solvent extractors (Laboratory Construction Co., Kansas City, MO). The solvent used was 85% methanol (Schoch 1964a).

Phosphorus Content in Taro Starch

The starch was thoroughly defatted by using a Soxhlet extractor and 85% MeOH to eliminate any phospholipid interference to the analysis. The defatted starch was charred and dry-ashed in a muffle furnace oven (550°C, 6 hr). The ash was then dissolved in a nitric acid solution (29%, 10 ml) and analyzed by the molybdenum blue spectrophotometric method (Smith and Caruso 1964).

^{31}P-Nuclear Magnetic Resonance Study of Taro Starch

Taro starch suspensions (25%) were hydrolyzed by heating with *Bacillus* α-amylase (pH 6.5) in a water bath at 96°C for 10 min with occasional shaking. The solution was allowed to cool down and was incubated with additional and excess α-amylase (70°C,

TABLE I
Starch Contents and Yields of Taro Flours

Sample	Starch Content[a] (%)	Starch Yield[b] (%)
Bun-long	75.1 ± 1.5	57.9 ± 3.2
Dasheen	73.0 ± 0.5	57.1 ± 3.1
Hawaii Red	76.1 ± 1.6	51.4 ± 3.3
Hawaii White	73.6 ± 0.3	52.8 ± 3.0
Niu'e	75.3 ± 0.9	56.5 ± 2.1

[a]Average of two replicates.
[b]Average of three replicates.

TABLE II
Nitrogen Contents of Taro Flour and Taro Starch[a]

Sample	Nitrogen Content, %	
	Flour	Starch
Bun-long	0.386 ± 0.001	0.014 ± 0.000
Dasheen	1.354 ± 0.003	0.018 ± 0.001
Hawaii Red	0.370 ± 0.004	0.018 ± 0.001
Hawaii White	0.328 ± 0.001	0.025 ± 0.000
Niu'e	0.849 ± 0.004	0.021 ± 0.000

[a]Average of two replicates.

2 hr). The enzyme activity was stopped by heating the digest in a water bath at 96° C for 30 min. The digest was then centrifuged (5,000 × *g*, 10 min) to remove residues. Deuterium oxide (D_2O, 20%) was added for field-frequency lock, and ethylenediaminetetraacetic acid was added (20 m*M*) for sharpening the signals. The solution was adjusted to pH 8.0 ± 0.1.

A Bruker WM-200 nuclear magnetic resonance spectrometer (USA Bruker Instruments, Mountain View, CA) was used for the study and operated at 81 MHz for ^{31}P spectra. A 65° flip angle (15 μsec), 16,000 data points, and 20,000 Hz sweep width were used for data acquisition. About 30,000 scans were collected at 25° C. All ^{31}P chemical shifts were referenced to external H_3PO_4 (85%) at 0.0 ppm.

Differential Scanning Calorimetry

Gelatinization and retrogradation properties of taro flours and starches were analyzed by using a Perkin-Elmer differential scanning calorimeter (DSC-7, Norwalk, CT) equipped with an

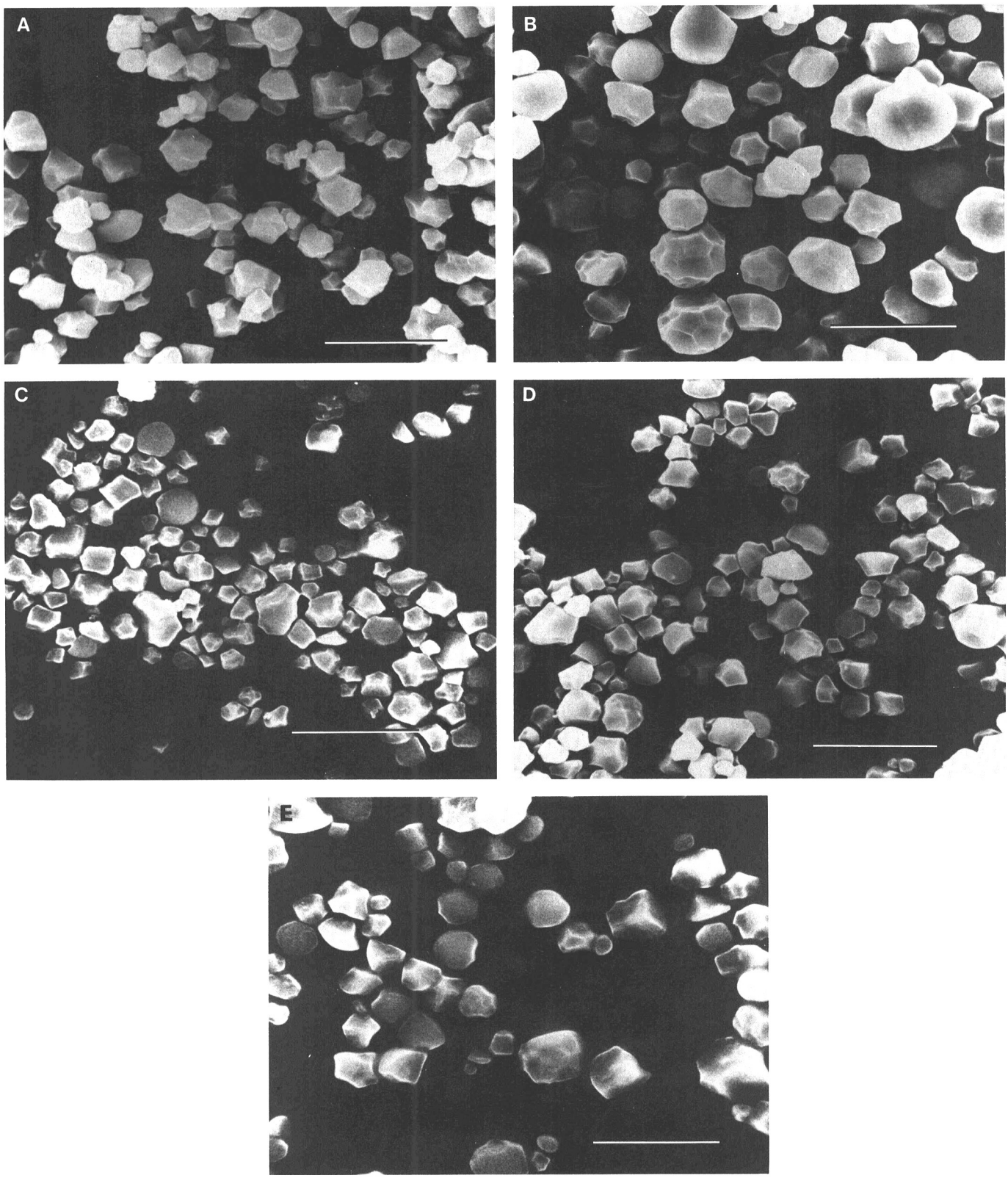

Fig. 1. Scanning electron micrographs of taro starches. **A,** Bun-long; **B,** Dasheen; **C,** Hawaii Red; **D,** Hawaii White; **E,** Niu'e. Bar = 10 μm.

intracooling I system. Aluminum pans (Perkin-Elmer) were used for the analyses. Flour or starch samples (about 2 mg each, dsb) were weighed in the sample pans, mixed with distilled water (about 6 mg), and sealed. The heating rate was 10°C per min. Enthalpy changes, integrated by using DSC-7 standard software, were calibrated on the basis of the melting enthalpy of indium metal. Flour and starch retrogradations were determined by storing the gelatinized samples at 4°C for 28 days. The retrograded samples were analyzed by differential scanning calorimeter and use of the same parameters.

Pasting and Gelling Properties

Pasting curves of taro flours and starches (8% each, dsb) were determined by using a Brabender Visco/Amylograph (model VA-5, 700 cm-g, Hackensack, NJ) operated with a total weight of suspension of 400 g (Smith 1964, Jane et al 1992). The flour and starch suspensions were equilibrated at 30°C and then heated at a rate of 1.5°C/min with constant stirring at 75 rpm. Stirring was continued for 30 min while the paste was held at 97.5°C, and the paste then was cooled to 52.5°C (1.5°C/min). The starch paste was transferred to aluminum pans (5 cm i.d. × 2.5 cm) wrapped with aluminum foil around the wall for additional depth (Takahashi et al 1989). For gel strength analysis, the samples were sealed in plastic bags and stored (25°C for 4 hr and 4°C for 72 hr).

Gel strength of the flour and starch pastes were measured with a Voland texture analyzer (model TA, Scarsdale, NY). Immediately before each measurement, the foil wrap was removed and the surface gel was sliced off with a cheese cutter. This exposed a fresh and smooth surface for texture analysis. A 2-mm-diameter probe and a 3-mm distance of penetration at the speed of 0.2 mm/sec were used through the analysis.

RESULTS AND DISCUSSION

Starch contents of Bun-long, Dasheen, Hawaii Red (Lehua), Hawaii White, and Niu'e taro flours are shown in Table I. The range of the starch contents varied from 73 to 76% (dsb). They are in agreement with the results (70–80%) reported by Payne et al (1938), Higashihara et al (1975), and Tu et al (1979). The starch contents also are similar to that of corn (about 75%). Starch yields from the taro flours (dsb) (Table I) varied from 51 to 58%.

Nitrogen contents of taro flours varied from 0.33% (Hawaii White) to 0.86% (Niu'e) to 1.35% (Dasheen) (Table II). The values are much greater than those found in the starches (0.014–0.025%, Table II). These results indicated that the protein contents of the flours varied from 2.1 to 8.4%, using 6.25 as a conversion factor and providing that all of the nitrogen was from protein. Protein was reported as one of the major components in taro mucilage (Yamashita and Yoshikawa 1973). Therefore, the nitrogen in the flour can be attributed to its mucilage. The nitrogen content in the flour also appeared to correlate with wetland and dryland cultivation. The results indicated that dryland cultivated varieties (i.e., Dasheen and Niu'e) had significantly higher nitrogen contents than the wetland cultivated varieties (Table II). The isolated starches (without the removal of protein by toluene and NaCl solution) contained only 0.09–0.16% protein, which suggested that the starches were fairly pure.

Scanning electron micrographs showed that taro starch granules had polygonal and irregular shapes with diameters of 1–5 μm (Fig. 1). The results agreed with those reported by Sugimoto et al (1986, 1987). The shapes of the granules suggested that they were compound starches. Diameters of taro starches analyzed by the image analyzer are shown in Table III. The results are in agreement with those reported by Amin (1955) and Sugimoto et al (1986). In addition, our results also indicated that, among the five varieties, Bun-long starch had the smallest granular size; equivalent circle diameters varied from 0.3 to 4.3 μm, with an average diameter of 2.6 ± 0.73 μm. Dasheen starch had the largest granular size; equivalent circle diameters varied from 0.4 to 6.9 μm, with an average diameter of 3.76 ± 1.18 μm. All of the taro starches were significantly smaller than corn starch (5–20 μm) and potato starch (30–100 μm) and were similar to small-granule wheat starch (Lineback 1984).

Small granular starch has been demonstrated to be a good filler for biodegradable plastic film (Lim et al 1992) and also has been suggested to provide a better mouth feeling as a lipid substitute (Daniel and Whistler 1990). Taro starch granules tended to coagulate (data not shown), which resulted in rough surface textures when used in starch-filled biodegradable plastic film (unpublished data from our laboratory). These coagulation tendencies may be attributable to the gum residues that remain on the surface of the starch granules, even though, on the basis of detected nitrogen content (Table II), the amount of gum was low (0.09–0.16%).

Starch amylose contents determined by IPT (Schoch 1964b) and by GPC (Colonna and Mercier 1984) were in reasonably good agreement. They varied from 18 to 22% and from 19 to 24% by IPT and GPC methods, respectively (Table IV). Among the varieties, Dasheen and Bun-long taro starches had greater amylose contents than the others, whereas Hawaii White and Hawaii Red had the smallest. Results obtained from the GPC method were, in general, greater than those obtained from the IPT method. The difference can be attributed to the presence of the intermediate components, molecules with branched structures and molecular sizes smaller than amylopectin, which were eluted at the same time as amylose. The amylose content of taro starch is similar to that of potato starch (about 20%) but lower than that of corn starch (28–30%) (Lineback 1984).

Gel permeation chromatograms showed that the molecular sizes of amyloses differed (Fig. 2). The peak molecular sizes of the taro amyloses varied between degree of polymerization (DP) 150 and 550, which are smaller than that of potato (DP 1,500) and of corn (DP 667) as calculated by K_{av} and using pullulan standards (Jane and Chen 1992). The low blue value that appeared in the Bun-long amylopectin peak (Fig. 2A) indicated that Bun-long amylopectin had short branch chains compared with those of the other varieties.

Branch chain lengths of taro amylopectins and their distributions are shown in Table V. The peak chain lengths of short branch chains (A and short B chains), which were similar to those of corn amylopectin, varied between DP 16.8 and 18.4. The chain lengths of long branch chains (long B chains) varied between DP 37 and 40. Bun-long taro had the shortest branch chains (DP 16.8 and 37.2 for short and long branches, respectively) among all the taro starches. These results were consistent with

TABLE III
Granular Size of Taro Starch Determined by the Image Analyzer[a]

Source	Area (μm^2)	Diameter, μm		
		Maximum	Minimum	Equivalent Circle
Bun-long	5.74 ± 2.92	3.08 ± 0.83	2.55 ± 0.78	2.60 ± 0.73
Dasheen	12.16 ± 6.99	4.26 ± 1.33	3.69 ± 1.21	3.76 ± 1.18
Hawaii Red	7.43 ± 3.33	3.40 ± 0.76	2.94 ± 0.71	3.00 ± 0.68
Hawaii White	7.01 ± 3.91	3.27 ± 1.00	2.85 ± 0.90	2.86 ± 0.86
Niu'e	9.20 ± 5.90	3.72 ± 1.11	3.18 ± 1.09	3.26 ± 1.05

[a]Average of 205 granule samples.

TABLE IV
Amylose Content in Taro Starch[a]

Sample	IPT[b] (%)	GPC[c] (%)
Bun-long	22.1 ± 0.1	23.5 ± 0.9
Dasheen	22.2 ± 0.3	24.3 ± 0.8
Hawaii Red	18.1 ± 0.1	19.8 ± 0.9
Hawaii White	18.5 ± 0.2	19.2 ± 0.9
Niu'e	19.6 ± 0.2	20.1 ± 0.8

[a]Average of two replicates.
[b]Iodine potentiometric titration.
[c]Gel permeation column chromatography using Sepharose CL-2B gel.

the low blue value observed in the Bun-long amylopectin peak (Fig. 2A). All five taro starches gave the A-type X-ray diffraction pattern (Fig. 3). This diffraction pattern agreed with that of the starch with short branch chain amylopectin (Hizukuri et al 1983, Hizukuri 1985).

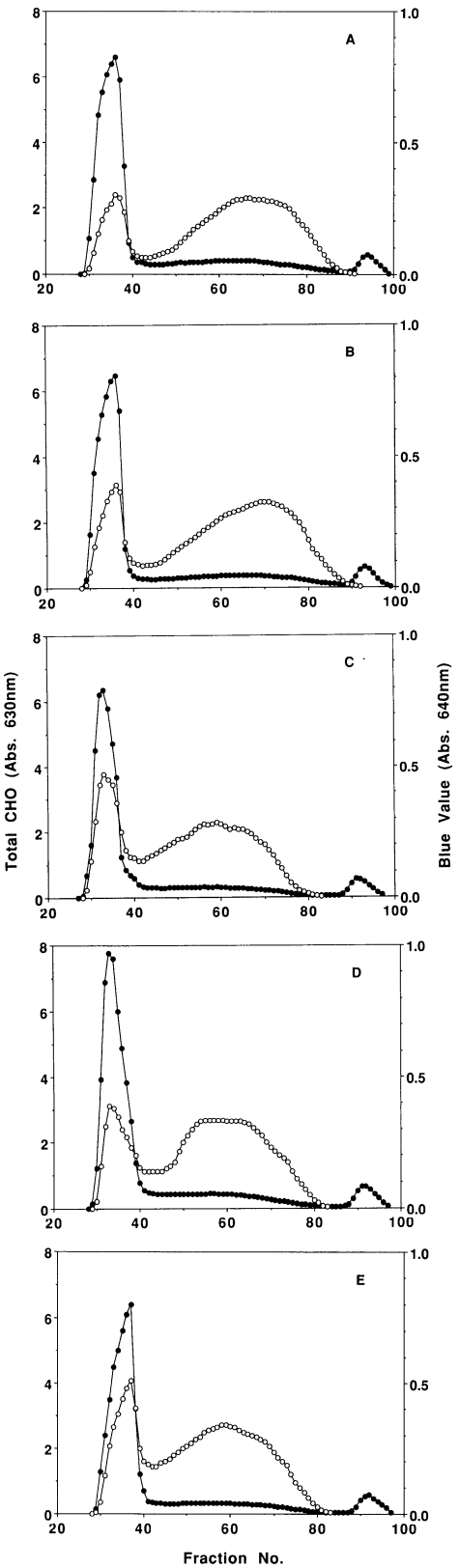

Fig. 2. Gel permeation chromatograms of taro starches as determined using a Sepharose CL-2B column (2.6 cm i.d. × 75 cm) and a NaCl (0.02%) solution as the eluent, 5 ml per fraction. Total carbohydrate (●) was analyzed by anthrone-sulfuric acid method, and blue value (○) was analyzed by iodine staining. Glucose was used as a marker. **A,** Bun-long; **B,** Dasheen; **C,** Hawaii Red; **D,** Hawaii White; **E,** Niu'e.

Lipid contents of taro starches varied from 0.24 to 0.52% (Table VI), which were less than that of corn starch (0.81%) analyzed by the same procedure. Phosphorus contents of the defatted taro starches varied from 0.017 to 0.025%, which was similar to that of defatted corn starch (0.017%) and significantly lower than that of potato starch (0.07%). However, ^{31}P-nuclear magnetic resonance spectra of all the taro starches showed signals at 3.99, 4.20, and 4.47 ppm (Fig. 4), corresponding to the phosphate monoester derivatives on C-6 (3.99 and 4.20 ppm) and C-3 (4.47 ppm) of glucose units (Lim 1990, Lim and Seib 1990). The spectra were similar to those of potato starch and indicated that the phosphorus in the taro starches was in the form of phosphate monoester derivatives. The small signal at 2.92 ppm (Fig. 4) was that of free phosphate. In contrast, the spectrum of normal corn starch exhibited a major signal at 0.061 ppm, which coincided with the signal of phospholipids (unpublished data from our laboratory). Spectra of other taro starches were identical and, thus, not shown.

Differential scanning calorimetric studies of taro flours and starches showed that the gelatinization temperatures of the flours (72.3–79.0°C) (Table VII) were higher than those of the starches (69.1–74.0°C) (Table VIII). The difference could be attributed to the presence of mucilage in the flours. In addition to protein, the mucilage also contains complex polysaccharides such as arabinogalactan (Taki et al 1972). The polysaccharide could compete with starch for moisture and result in a higher onset starch gelatinization temperature in the flour.

TABLE V
Branch Chain Length[a] and Distributions of Taro Amylopectin[b]

	Long Branch Chain		Short Branch Chain	
Source	**Chain Length[c]**	**Percent**	**Chain Length[c]**	**Percent**
Bun-long	37.2 ± 0.2	22.7 ± 0.2	16.8 ± 0.2	77.3 ± 0.2
Dasheen	39.6 ± 1.2	21.5 ± 1.5	18.4 ± 0.5	78.6 ± 1.6
Hawaii Red	38.4 ± 0.6	21.2 ± 1.5	18.0 ± 0.3	78.8 ± 1.5
Hawaii White	38.2 ± 0.6	22.0 ± 0.8	18.1 ± 0.3	78.0 ± 0.8
Niu'e	40.5 ± 0.0	19.0 ± 0.2	17.4 ± 0.2	81.1 ± 0.1

[a]Measured in degrees of polymerization.
[b]Average of two replicates.
[c]The chain length was determined by using peak fractions.

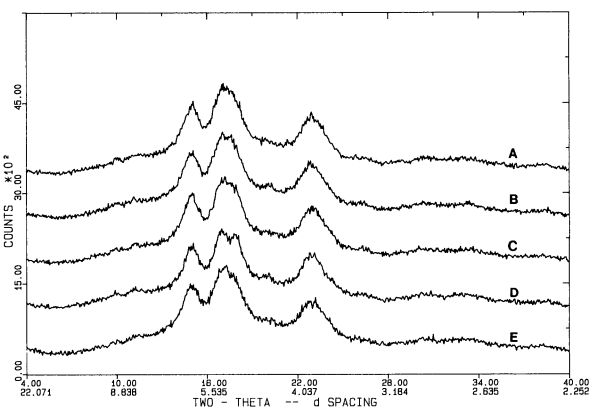

Fig. 3. X-ray diffraction patterns of the starches of taro varieties Bun-long, Dasheen, Hawaii Red, Hawaii White, and Niu'e (A–E, respectively).

TABLE VI
Lipid and Phosphorus Contents of Taro Starch[a]

Sample	Lipid (%)	Phosphorus (%)
Bun-long	0.25 ± 0.02	0.021 ± 0.001
Dasheen	0.38 ± 0.01	0.025 ± 0.011
Hawaii Red	0.36 ± 0.01	0.017 ± 0.004
Hawaii White	0.24 ± 0.02	0.025 ± 0.002
Niu'e	0.52 ± 0.03	0.020 ± 0.006

[a]Average of two replicates.

Among the taro flours and starches, Bun-long taro had the lowest onset gelatinization temperatures: 72.3 and 69.1°C for flour and starch, respectively. Retrogradations of taro starches after being stored at 4°C for 28 days were more severe than that of corn starch as measured by enthalpy changes (Table VIII). The small amylose molecules of taro starches (Fig. 2) may be responsible for the severe retrogradation (Jane and Chen 1992). Retrograded Bun-long flour and starch also showed the lowest onset temperatures (39.0 and 39.6°C, respectively). These consistent low onset temperatures can be attributed to the short branch chain lengths of Bun-long amylopectin (Table V). It is plausible that the shorter branch chain lengths (particularly the long B chains) of Bun-long amylopectin (Table V) were responsible for the significantly lower gelatinization temperatures of the starch (69.1 and 39.6°C for native and retrograded starches, respectively) (Table VIII) and the flour (72.3 and 39.0°C for native and retrograded flours, respectively) (Table VII) compared with those of other taro starches and flours.

The pasting properties of taro flours and starches are shown in Figures 5 and 6, respectively. At the same solid concentration level, the starch pastes displayed much greater viscosity than their flour counterparts. Pasting temperatures of the flour pastes (76–80°C) also were significantly higher than those of the starch pastes (70–75°C). The differences also can be attributed to the presence of mucilage. Among the flours, Dasheen flour had the highest peak viscosity and pasting temperature. This is consistent with its high mucilage content, reflected by both the high baseline of the amylogram and the high nitrogen (protein) content (Table II). Among the starch pastes, Hawaii White and Hawaii Red displayed the highest peak viscosity (about 1,400 BU), whereas

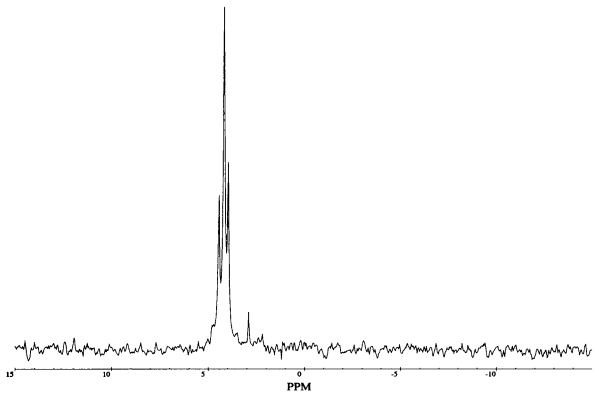

Fig. 4. ^{31}P-nuclear magnetic resonance spectrum of Hawaii White taro starch hydrolyzed by *Bacillus* α-amylase. The solution was adjusted to pH 8, and the chemical shifts were referenced to external H_3PO_4 (85%) at 0.0 ppm.

TABLE VII
Thermal Property of Taro Flour[a]

Source	Gelatinization Temperature,[b] °C T_o	T_p	T_c	ΔH^c (J/g)
Native flour				
Bun-long	72.3 ± 0.2	77.3 ± 0.1	85.6 ± 0.6	11.9 ± 0.2
Dasheen	78.6 ± 0.2	83.5 ± 0.1	92.4 ± 0.2	11.6 ± 0.1
Hawaii Red	77.4 ± 0.2	81.5 ± 0.2	90.1 ± 0.1	11.8 ± 0.4
Hawaii White	77.4 ± 0.2	81.3 ± 0.1	89.1 ± 0.2	12.0 ± 0.1
Niu'e	79.0 ± 0.0	83.0 ± 0.1	90.8 ± 0.1	12.2 ± 0.4
Retrograded flour[d]				
Bun-long	39.0 ± 0.7	49.5 ± 0.1	61.4 ± 1.4	5.2 ± 0.6
Dasheen	46.3 ± 0.2	57.5 ± 0.1	65.7 ± 0.1	3.3 ± 0.1
Hawaii Red	46.2 ± 0.1	56.2 ± 0.6	65.4 ± 0.5	5.0 ± 0.1
Hawaii White	45.7 ± 0.5	57.3 ± 0.5	66.1 ± 0.6	5.6 ± 0.1
Niu'e	45.0 ± 0.1	57.3 ± 0.3	66.1 ± 0.5	4.7 ± 0.2

[a] Average of three replicates.
[b] T_o, onset temperature; T_p, peak temperature; T_c, complete temperature.
[c] Enthalpy change.
[d] After 28 days at 4°C.

TABLE VIII
Thermal Property of Taro Starch[a]

Source	Gelatinization Temperature,[b] °C T_o	T_p	T_c	ΔH^c (J/g)
Native starch				
Bun-long	69.1 ± 0.0	73.6 ± 0.3	83.0 ± 0.1	15.5 ± 0.1
Dasheen	74.0 ± 0.6	79.0 ± 0.3	93.1 ± 0.3	14.0 ± 0.3
Hawaii Red	72.0 ± 0.6	76.6 ± 0.6	89.2 ± 0.2	15.2 ± 0.3
Hawaii White	72.2 ± 0.8	78.6 ± 0.9	90.5 ± 1.2	13.6 ± 0.6
Niu'e	74.0 ± 0.5	77.9 ± 0.3	88.7 ± 0.2	14.2 ± 0.8
Corn	66.5 ± 0.5	72.4 ± 0.4	82.0 ± 0.4	12.1 ± 0.5
Retrograded starch[d]				
Bun-long	39.6 ± 0.7	48.5 ± 0.1	57.7 ± 0.2	6.3 ± 0.6
Dasheen	45.0 ± 0.5	54.2 ± 0.2	65.9 ± 0.7	7.2 ± 0.4
Hawaii Red	43.2 ± 0.6	52.6 ± 0.6	63.2 ± 1.2	5.9 ± 1.0
Hawaii White	44.0 ± 1.0	54.0 ± 0.5	64.8 ± 0.7	7.3 ± 0.2
Niu'e	43.8 ± 0.2	53.4 ± 0.5	65.0 ± 0.5	7.3 ± 0.2
Corn	44.0 ± 0.8	51.6 ± 0.6	61.0 ± 0.4	3.7 ± 0.3

[a] Average of three replicates.
[b] T_o, onset temperature; T_p, peak temperature; T_c, complete temperature.
[c] Enthalpy change.
[d] After 28 days at 4°C.

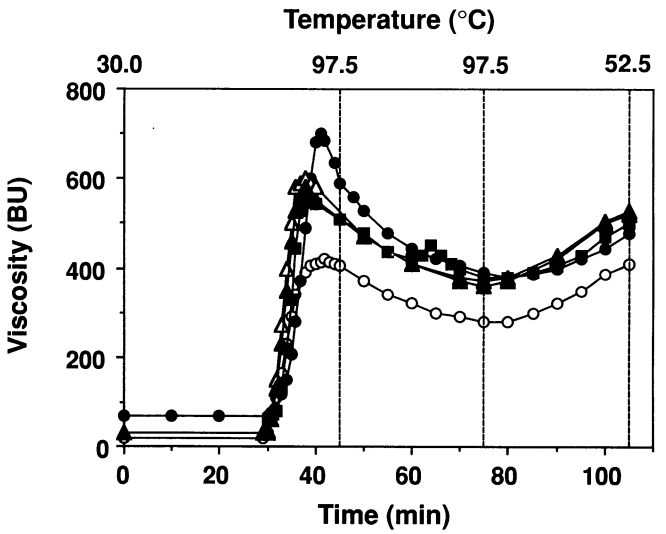

Fig. 5. Pasting properties of taro flours as measured by the Brabender Visco/Amylograph. The flours were prepared from taro corms of varieties Bun-long (○), Dasheen (●), Hawaii Red (△), Hawaii White (▲), and Niu'e (■).

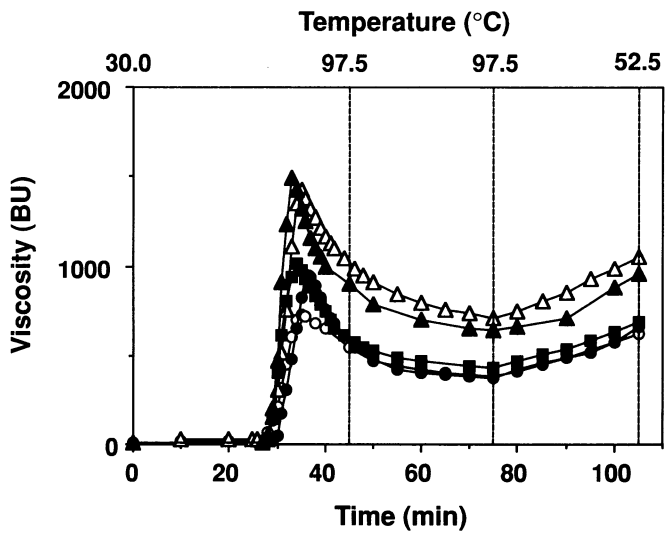

Fig. 6. Pasting properties of taro starches as measured by the Brabender Visco/Amylograph. The starches were isolated from flours of taro varieties Bun-long (○), Dasheen (●), Hawaii Red (△), Hawaii White (▲), and Niu'e (■).

TABLE IX
Gel Strength[a] of Taro Flour and Starch Pastes[b]

Source	Flour		Starch	
	4 hr at 25°C	72 hr at 4°C	4 hr at 25°C	72 hr at 4°C
Bun-long	1.5 ± 0.1	2.0 ± 0.1	1.9 ± 0.1	2.7 ± 0.2
Dasheen	1.3 ± 0.1	1.8 ± 0.1	1.5 ± 0.1	2.4 ± 0.1
Hawaii Red	1.2 ± 0.1	1.6 ± 0.1	1.5 ± 0.1	1.9 ± 0.1
Hawaii White	1.2 ± 0.1	1.6 ± 0.1	1.5 ± 0.1	2.1 ± 0.2
Niu'e	1.2 ± 0.1	1.4 ± 0.1	1.5 ± 0.1	1.8 ± 0.1

[a]Measured in grams.
[b]Average of two replicates on an 8% dry starch basis.

Bun-long taro had the lowest (about 700 BU). The low amylose contents of Hawaii Red and Hawaii White starches (Table IV) may contribute to the high viscosities and the low pasting temperatures of the pastes, whereas the high amylose contents of Bun-long and Dasheen starches resulted in the low viscosities and the high pasting temperatures of the pastes as well as the greater gel strength (Table IX). It is also plausible that the combination of the short branch chain lengths of Bun-long amylopectin (Table V) and high amylose content (Table IV) was responsible for the lowest viscosity exhibited by Bun-long starch paste. This is consistent with the effects of branch chain lengths of amylopectin on the viscosities of starch pastes reported by Jane and Chen (1992).

Taro starch pastes set to weak gels. After being stored at 4°C for 72 hr, strengths of the gels varied from 1.8 to 2.7 g, which were substantially lower values than that of corn starch (about 10 g). The phosphate monoester derivatives of the taro starches are believed responsible for the soft gels observed for the starches. The taro flour pastes prepared and stored under the same conditions displayed even weaker gel strength (1.4 to 2.0 g). Among the varieties, Bun-long and Dasheen taro flours and starches set to the strongest gels; this was directly correlated with their higher amylose contents compared with those of other varieties (Tables IV and IX). The weak (soft) gels might be desirable for uses in frozen foods and desserts.

Significant differences were found between the varieties of the taro flours as well as between the starches. It is known that Bun-long, Hawaii Red, and Hawaii White varieties were wetland cultivated and that Dasheen and Niu'e were dryland cultivated. Both Dasheen and Niu'e flours had very high protein contents. Niu'e starch also had very high lipid content (Table VI). Whether the soil moisture conditions affected these properties of taro is not clear. A comparison study using the same variety cultivated under different conditions will help to clarify the effects of soil moisture.

In conclusion, the five varieties of taro starches were different in their granular sizes. The starches had different amounts of amylose and different branch chain lengths of amylopectin, which resulted in their differences in pasting properties and gelatinization temperature. The starches had fairly low lipid contents (except Niu'e) and low phosphorus contents from phosphate monoester derivatives. All five starch varieties gave the A-type X-ray diffraction pattern. All of the flours displayed higher gelatinization temperatures and lower paste viscosities than those of their starch counterparts. High mucilage (protein) content in Dasheen flour resulted in a greater viscosity and a higher pasting temperature than those of other flours in the study.

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