A Better Understanding of Factors That Affect the Hardness and Stickiness of Long-Grain Rice

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ABSTRACT

Eight U.S. long-grain rice cultivars were studied for chemical compositions, physicochemical properties, and leaching characteristics in relation to hardness and stickiness of rice flour paste and cooked rice. There were differences in the chemical composition of rice kernels among the eight rice cultivars, including crude protein (6.6–9.3%), crude fat (0.18–0.51%), and apparent amylose content by iodine colorimetry (19.6–27.0%). Differences were also observed in gelatinization temperatures and enthalpies, pasting temperatures and viscosities, leached/insoluble amylose, soluble solids, and hardness and stickiness of rice flour pastes and cooked rice kernels. The quantity and molecular size distribution of the leached starch molecules varied greatly among the samples. Protein and crude lipid contents negatively correlated with hardness of rice flour paste and cooked rice, but positively correlated with stickiness. Apparent amylose content correlated with gel properties but not cooked rice texture, whereas the ratio of A and short B chains to long B chains of amylopectin correlated significantly with cooked rice texture.

U.S. rice is classified as long-, medium-, and short-grain based on kernel length and shape (Adair 1980). Long-grain rice represents the majority of rice produced in the United States. Cultivar selection is conventionally based on grain and milling yields, lodging, maturity, disease susceptibility, and plant heights (Slaton et al 1999). Diversification of rice cultivars is necessary because of the variation in adaptation to various locations. Although commercial long-grain cultivars are high yielding and possess typical long-grain characteristics, processing characteristics and eating quality of rice become less predictable because of diversification of cultivars.

Unlike other cereals, rice is principally consumed as a whole grain. Therefore, the texture of the whole rice kernel is of great importance to consumers. Amylose content has been traditionally used by breeders and the food industry as the most important texture determinant. Nevertheless, the relationship between amylose content and the final properties of the cooked rice cannot be well predicted. Hot-water insoluble (unextractable) amylose was the primary determinant of rice quality, whereas hot-water soluble (extractable) amylose had little effect on rice texture (Bhattacharya et al 1972, 1978, 1982; Bhattacharya and Sowbhagya 1979, 1980; Sowbhagya et al 1987). More recent studies suggested that the long B chains of amylopectin, which were strongly positively correlated with the insoluble amylose content, were the key determinant of rice texture. Long B chains in amylopectin strengthened the starch granules through intermolecular interaction, leading to a firm texture of cooked rice (Chinnaswamy and Bhattacharya 1986; Takeda et al 1987, 1989; Hizukuri et al 1989; Radhika-Reddy et al 1993; Ong and Blanshard 1995a; Ramesh et al 1999). Radhika-Reddy et al (1993) proposed that the insoluble amylose equivalent of rice actually reflected the fine structure of its amylopectin that determined rice quality. Rice cultivars with more insoluble amylose equivalent consisted of more long B chains, fewer short chains, and more long, unbranched external chains, which bound substantial amounts of iodine. Because insoluble amylose equivalent was indicative of amylopectin structure and was easy to determine, insoluble amylose equivalent was proposed as a simple and sensitive indicator of rice quality.

Amylopectin also leaches from starch granules with amylose during heating, and the hot-water soluble amylose and amylopectin primarily constitute the solids in the cooking water during rice processing. The amount of soluble component in cooking water is an important criterion for rice processing quality, and varies among rice cultivars. Mizukami et al (1999) showed that the yield of hot-water soluble amylose and amylopectin ranges were 0.3–2.4% and 3.1–4.1% by starch weight, respectively. Small amylopectin molecules leached more easily than large amylose molecules and different rice cultivars showed different composition and structure of leached materials. Mizukami et al (1999) proposed that amylopectin with extended long chains was resistant to solubilization, possibly by complexing with lipids or anchoring deep inside the crystalline lamellae to withstand breakdown.

There are many long-grain rice cultivars produced commercially in the United States, however little information is available regarding the predominant factors affecting rice texture. The objective of this study was to examine the chemical composition, physicochemical properties, and structures of leached/extractable starch components (amylose and amylopectin) of eight U.S. long-grain rice cultivars in relation to their texture attributes in rice flour paste and cooked rice.

MATERIALS AND METHODS

Materials

Rough-rice samples of cultivars Ahrent, Cocodrie, Francis, Cypress, Drew, Wells, XL7, and XL8 were obtained from the 2002 crop from various locations. Ahrent, Cocodrie, and Francis were obtained from the University of Arkansas Research and Extension Center, Stuttgart, AR. Cypress, Drew, and Wells were obtained from the University of Arkansas Northeast Research and Extension Center, Keiser, AR. Cultivars XL7 and XL8 were obtained from RiceTec, Inc., Alvin, TX. Ahrent, Cocodrie, Francis, Cypress, Drew, and Wells are inbred cultivars, and XL7 and XL8 are hybrid cultivars. All samples were air-dried at room temperature to minimize drying effects. Samples were stored in self-sealing plastic bags under ambient conditions before analyses.

Milling Quality and Physical Attributes

Samples of 150 g of rough rice were dehulled in a dehusker (THU-35, Satake Corporation, Hiroshima, Japan). The brown rice recovered was weighed and polished for 30 sec in a friction mill (McGill Miller #2, Rapsco, Brookshire, TX). The resulting milled rice was weighed and separated into head rice and broken kernels on a double-tray shaker table (GrainMan Machinery, Miami, FL) with 4.67-mm indentation on both trays. Brown rice, milled rice, and head rice yields were calculated as percentage by weight of rough rice. Only head rice kernels were used in the study. Grain translucency, whiteness, and degree of milling were measured

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with a milling meter (model MM-1B, Satake Engineering Co., Ltd., Tokyo, Japan).

Chemical Composition of Rice Flour

Head rice was ground into flour with a cyclone sample mill (Udy Corp. Ft. Collins, CO) fitted with a 100-mesh (150 μm) sieve. Duplicate 2-g samples were placed in aluminum moisture dishes and dried at 130°C in a convection oven for 60 min according to Approved Method 44-15A (AACC 2000). Apparent amylose content was determined by iodine colorimetry (Juliano et al 1981). Crude protein was measured by micro-Kjeldahl according to Approved Method 46-13. Crude lipid was measured according to Approved Method 30-20 with the following modifications: rice flour (4–5 g) was extracted with 70 mL of petroleum ether by boiling at 135°C for 20 min and rinsing for 30 min in a Soxtec system (Avanti 2055, Foss North America, Eden Prairie, MN). The difference between the weight of the cup containing the extracted lipid and the original weight of the cup was calculated to obtain the weight of the extracted crude lipid. The percentage of crude lipid was defined as the weight of extracted lipid divided by the weight of the original sample.

Physicochemical Properties

Gelatinization properties were assessed by a differential scanning calorimetry (DSC) (Pyris-1, Perkin-Elmer Co., Norwalk, CT). Starch (≈4.0 mg, db) was weighed accurately into an aluminum DSC pan and then moistened with 8 μL of deionized water using a microsyringe. The pan was hermetically sealed and allowed to stand for at least 1 hr before thermal analysis. Samples were heated from 25 to 120°C at a rate of 10°C/min. Enthalpy, onset, and peak temperatures were computed automatically. Triplicate measurements were performed for each sample.

The pasting characteristics were determined with a 10% (w/w) rice flour slurry using a Micro ViscoAmyloGraph (C. W. Brabender Instruments, South Hackensack, NJ) equipped with a 300-mg cartridge and operated at a speed of 250 rpm. The starch slurry was heated from 50 to 95°C at a rate of 3°C/min, held at 95°C for 10 min, and cooled down to 50°C at a rate of 3°C/min. The starch paste prepared with the Micro ViscoAmyloGraph was used for the gel property measurement. The starch paste was stored at 5°C for 24 hr and then measured with a texture analyzer (TA-XT2i, Texture Technologies Corp., Scardale, NY) using texture profile analysis (TPA). The paste was poured into three aluminum dishes (75 mm dia. × 20 mm height). The rims of the dishes were extended with aluminum foil to increase the height of the gel 1 cm above the rim (Takahashi et al 1989). The gel was compressed at a speed of pretest 2.0 mm/sec, test 0.2 mm/sec, and posttest 0.2 mm/sec, to a distance of 5.0 mm with a cylindrical probe (2.54 mm dia. × 2.54 mm height) under the TPA test mode. The peak force of the first penetration was termed hardness and the negative peak height during retraction of the probe was termed stickiness. Triplicate measurements were performed on each sample.

Rice was cooked and evaluated following the method of Sesmat and Meullenet (2001). Five kernels of cooked rice were used for the compression test to determine the hardness and stickiness with the texture analyzer.

Leached Carbohydrate Composition in Cooking Water

The sample preparation followed the method of Ong and Blanshard (1995b) with modifications. Milled rice (10 g) was cooked with 20 g of deionized water in a boiling water bath for 15 min and the soluble components in the cooking water were characterized by high-performance size-exclusion chromatography (HPSEC) (Waters, Milford, MA). The HPSEC system consisted of a 515 HPLC pump with an injector of a 100-μL sample loop, an in-line degasser, a 2410 refractive index detector maintained at 40°C, and a series of Shodex OHpak columns (KB-802 and KB-804) maintained at 55°C. The mobile phase was 0.1*M* $NaNO_3$ and 0.2% NaN_3 at a rate of 0.7 mL/min. Dextran standards, including 5,200, 11,600, 23,800, 48,600, 148,000, 273,000, 410,000 and 872,300 of weight average molecular-weight (*Mw*) (PSS Polymer Standards Service-USA, Inc.), and sugars with degree of polymerization (DP) of 1–7 (Sigma Chemical Co.) were used to construct the regression line for molecular weight (MW) determination.

The soluble component was autoclaved at 121°C for 10 min (model 8816A, Amsco International, Pittsburgh, PA) and then sonicated for 40 sec (model 8891, 42 kHz, Cole-Parmer, Vernon Hills, IL) for molecular size analysis of native samples. The soluble component was diluted with threefold deionized water and then treated with isoamylase (800 units, crystalline *Pseudomonas* isoamylase, Hayashibara Biochemical Laboratories Inc., Okayama, Japan) following the method of Kasemsuwan et al (1995) with modifications (Wang and Wang 2000); the chain length distribution of isoamylase-debranched starch was then determined. The amount of amylose that leached into the water from the rice during the cooking process was determined by comparing the area of the amylose peak in the HPSEC chromatogram of debranched sample with that of a known concentration of debranched rice starch.

After the liquid that contained the soluble component was poured off and characterized, the cooked rice was placed in a weighing dish and dried at 40°C for 48 hr. The soluble solids (%, db) were determined as the percentage of weight loss from the original 10 g of rice.

Starch Isolation and Characterization

Starch samples were prepared based on the alkali-steeping method of Yang et al (1984) with slight modifications. A 10-g milled rice sample was soaked in 40 mL of 0.1% NaOH for 24 hr. The soaked sample was then wet-milled in an Osterizer blender for 4 min at speed 6, filtered though a U.S. standard sieve #230, and centrifuged at 1,500 × *g* for 15 min. The supernatant was transferred into a 250-mL volumetric flask while the top yellow, curd-like layer of the residue was discarded by carefully scraping it off with a spatula. The remaining starch residue was again extracted with 0.1% NaOH and centrifuged using the same speed. The pH of the residue was then adjusted to pH 6.5 with 0.2*M* HCl, and washed with 40 mL of deionized water three times. The starch residue was dried in a convection oven at 40°C for 24 hr and ground into powder using mortar and pestle to pass through a standard 100-mesh sieve. Starch sample was defatted with water-saturated 1-butanol by the procedure described by Patindol and Wang (2002).

TABLE I
Milling Quality and Physical Attributes of Rice Cultivars Ahrent, Cocodrie, Cypress, Drew, Francis, Wells, XL7, and XL8

	Ahrent	Cocodrie	Cypress	Drew	Francis	Wells	XL7	XL8
Brown rice yield (%)	80.0	80.2	79.3	79.3	77.2	81.3	75.0	77.4
Total milled rice yield (%)	70.0	71.1	69.8	70.7	69.1	72.7	63.5	65.2
Head rice yield (%)	60.0	64.3	66.1	61.3	55.7	62.0	44.3	45.4
Whiteness (%)	37.7	36.6	41.7	37.6	42.7	42.6	49.6	50.9
Transparency (%)	2.74	3.57	4.49	4.23	4.47	4.38	3.71	3.69
Milling degree	85	86	115	95	119	118	145	151

The relative amounts of amylose, amylopectin, and intermediate material in defatted isoamylase-debranched starch samples were analyzed by HPSEC following the method of Kasemsuwan et al (1995) as modified by Wang and Wang (2000). Amylopectin, intermediate material, and amylose content were calculated automatically from the area of their corresponding peaks.

Statistical Analysis

Experimental data were analyzed by using the general linear models procedure (SAS Institute, Cary, NC), and least significance differences were computed at $P < 0.05$.

RESULTS AND DISCUSSION

Milling Quality and Physical Attributes of Rice Kernels

The milling quality, dimensions, and transparency of the kernels from the eight cultivars are presented in Table I. Significant differences in the milling quality of the cultivars were observed. The hybrid cultivars XL7 and XL8 showed the lowest brown rice yield, total milled rice yield, and head rice yield. It is not clear whether the heterozygous hybrids had a less homogenous composition compared with the normal rice cultivars, resulting in breakage occurrence during milling. Although Francis had a brown rice and total milled rice yield similar the to others, it had a significantly lower head rice yield. Head rice yield, which is the ultimate milling quality indicator, was higher for Cypress (66.1%) and Cocodrie (64.3%). The hybrids XL7 and XL8 appeared whiter with medium transparency, and they were milled to a greater extent than the other cultivars.

Chemical Composition, Physicochemical Properties, and Textural Attributes

The chemical composition, physicochemical properties, and textural attributes of the eight long-grain rice cultivars are summarized in Table II. Differences were observed in the approximate composition of rice kernels including crude protein (6.6–9.3%), crude fat (0.18–0.51%), and apparent amylose content by iodine colorimetry (19.6–27.0%). Two hybrids, XL7 and XL8, had a slightly higher amylose content but significantly lower crude protein and crude fat contents under the same milling conditions. The lower crude protein and crude fat contents of XL7 and XL8 were ascribed to a higher degree of milling.

The gelatinization temperatures of most rice cultivars were ≈76–77°C for onset and 80–81°C for peak temperature. Drew had a much lower onset temperature of 73.7°C and peak temperature of 78.8°C. A wider range was observed in gelatinization enthalpy among rice cultivars evaluated, ranging from 7.4 to 11.5 J/g with Ahrent and Drew having a much lower gelatinization enthalpy. Cultivars XL7 and XL8 had gelatinization properties similar to the other inbred cultivars. The differences in gelatinization characteristics of different long-grain rice cultivars implied potential variation during processing such as time and energy requirement for processing.

When the pasting properties of the rice flours were measured by a Micro ViscoAmyloGraph, the pasting profiles varied greatly among the eight rice cultivars. Pasting properties ranges were 73.3–76.2°C for pasting temperatures, 680–982 Brabender units (BU) for peak viscosity, 316–604 BU for breakdown, and 395–523 BU for setback viscosity. Cocodrie had the highest pasting temperature and setback viscosity but the lowest peak and breakdown viscosities. Francis had the highest peak and breakdown viscosities. Drew had the lowest pasting temperature, which reflected its low gelatinization temperature. Although all samples are long-grain cultivars with a high amylose content, their distinct pasting properties were supported by previous reports (Perez and Juliano 1979; Radhika-Reddy et al 1993; Ong and Blanshard 1995b) that amylose content alone was not appropriate to predict rice functionality.

The gelling properties of flour pastes after storage at 5°C for 24 hr showed distinct differences among the eight cultivars. Hybrids XL7 and XL8 existed almost as a separate group from the inbred cultivars, although differences also existed among the inbred cultivars. XL7 and XL8 had the greatest gel hardness and stickiness values, which were twofold higher than those of Ahrent. The low crude fat content in XL7 and XL8 might partly explain their high gel hardness because lipids would interfere with starch molecule reassociation, particularly amylose, thus retarding the retrogradation process. The gels of Cypress and Drew were harder, while Cocodrie had the highest stickiness among the inbred cultivars.

The textural attributes of cooked rice kernels also varied among rice cultivars with Francis being harder, while XL7, XL8, and Wells were stickier. The discrepancy in hardness between flour gels and cooked kernels of different rice cultivars was attributed to differences in shear force during measurement. When a flour

TABLE II
Chemical Composition and Physicochemical Properties of Milled Rice Flour and Cooked Rice Texture from Rice Cultivars Ahrent, Cocodrie, Cypress, Drew, Francis, Wells, XL7, and XL8[a]

	Ahrent	Cocodrie	Cypress	Drew	Francis	Wells	XL7	XL8
Chemical composition								
Moisture (%)	9.0e	11.0a	10.5bc	10.5bc	10.7b	10.3c	10.3c	9.8d
Crude protein (%, db)	9.3a	8.3b	7.2c	6.6d	7.2c	6.8d	7.0cd	6.8d
Crude fat (%, db)	0.48b	0.50ab	0.38d	0.51a	0.33e	0.46c	0.18g	0.24f
Apparent amylose (%, db)	19.6d	27.0a	24.3b	23.7b	21.5c	21.0c	26.6a	26.2a
Gelatinization								
Onset temperature (°C)	76.6c	76.5c	75.6d	73.7e	77.1b	77.4a	76.5c	77.0a
Peak temperature (°C)	81.3ab	80.6cd	80.3d	78.8e	81.0bc	81.9a	80.3d	81.2b
Enthalpy (J/g)	7.4d	11.5a	9.0c	7.9d	8.6c	10.2a–c	10.3b	10.4b
Pasting properties								
Pasting temperature (°C)	75.5b	76.2a	74.3d	73.3e	74.9c	75.3b	74.9c	76.1a
Peak viscosity (BU)	817c	680d	909b	784c	982a	933ab	818c	765c
Breakdown (BU)	429d	316f	534c	427d	604a	570b	438d	402e
Setback (BU)	397d	523a	429b–d	446bc	410cd	395d	466b	448b
Gelling properties								
Hardness (g-force)	9.53e	13.70c	15.43b	16.00b	12.77c	11.00d	20.63a	19.37a
Stickiness (g-force)	3.03c	5.30a	3.47bc	4.03b	3.63bc	2.97c	6.23a	5.80a
Cooked rice properties								
Hardness (g-force)	5,480f	6,395c–e	5,985ef	6,121d–f	7,486a	6,741b–d	7,449ab	6,996a–c
Stickiness (g-force)	320c	228c	314c	452b	438b	604a	603a	598a
Soluble solids (%, db)	2.04b	1.43b	1.90b	1.79b	1.88b	1.94b	2.99a	3.39a

[a] Mean values of duplicates in rows followed by the same letter are not significantly different ($P < 0.05$).

paste was prepared using a Micro ViscoAmyloGraph, a constant shear was applied and the shear caused fragmentation of starch granules as evidenced from the presence of breakdown in viscosity. Fragmentation enabled more starch molecules to become solubilized in water, which then interacted with each other to form a gel network structure. Thereafter, the extent of starch fragmentation and the structures of starch molecules might determine the gel hardness and stickiness. In contrast, there was no shear involved in cooking rice kernels, and most starch granules were assumed to be intact after the cooking procedure with some solubilized molecules. The cooked rice hardness therefore would likely be dominated by the extent of starch swelling, the leached starch molecules, or the unextractable amylose content. The role of protein in rice texture also cannot be neglected. The cooking water of both hybrids contained a much higher amount of soluble solids, which was attributed to their higher degree of milling and suggested a potential lower yield with XL7 and XL8 in processing for instant rice or other similar applications.

Leached Carbohydrate Composition in Cooking Water

Each rice cultivar showed a characteristic molecular size distribution profile of leaching molecules during cooking compared with a native Cypress rice starch (Fig. 1). The number of degrees of polymerization (DP) above each peak represents molecular size calculated from the dextran standards. It was apparent that large starch molecules with DP > 1,000 leached out and became solubilized in the cooking water along with small molecular-sized saccharides, presumably naturally present in rice kernels, and both amylose and amylopectin molecules leached out from starch granules.

The presence of a peak with DP 24 was intriguing but its origin was not clear, possibly due to breakdown of amylopectin branch chains. Both XL7 and XL8 had significantly smaller amounts of small molecular-size saccharides with DP < 24 and a larger amount of large molecules, whereas the other cultivars contained a much higher concentration of small saccharides. The larger amount of solubilized starch molecules in XL7 and XL8 probably was a result of their high degree of milling. With most of the bran

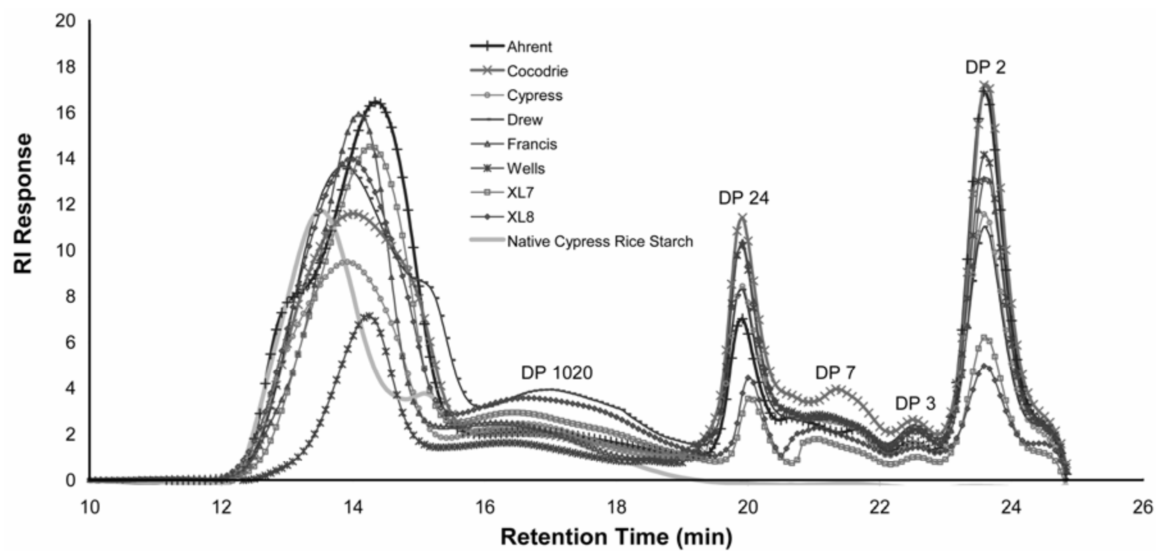

Fig. 1. Molecular size distribution of cooking water-soluble components analyzed by high-performance size-exclusion chromatography.

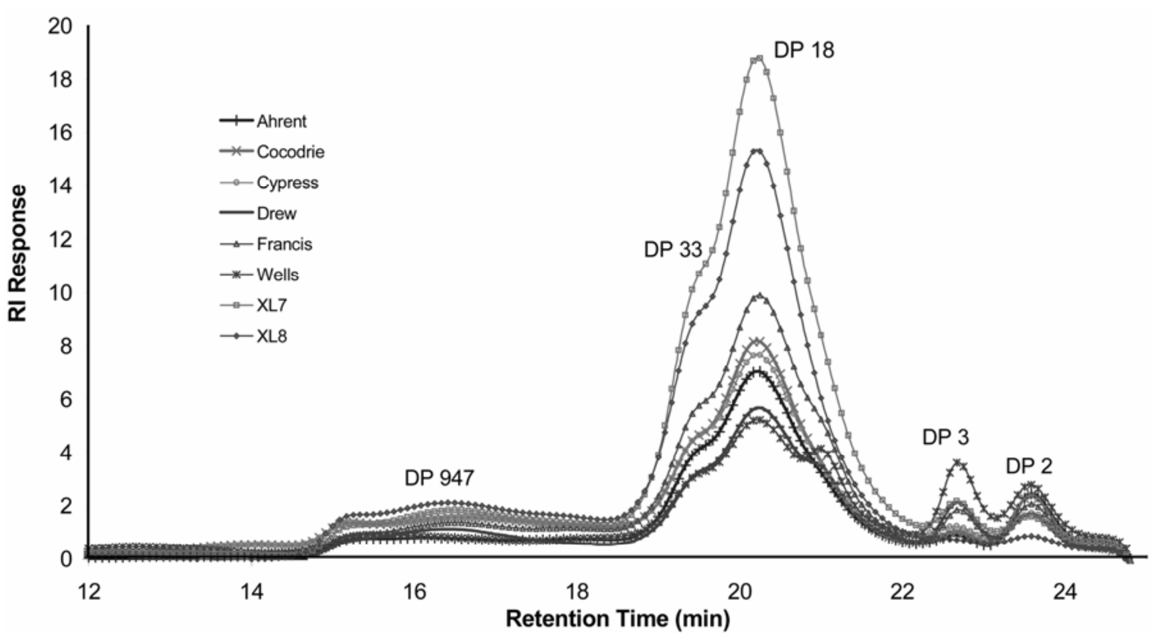

Fig. 2. Molecular size distribution of cooking water-soluble components debranched by isoamylase and analyzed by high-performance size-exclusion chromatography.

layer being removed, starch on the rice kernel surface leached out easier. Cocodrie had the largest amount of saccharides with DP < 24, whereas Wells had the smallest amount of large molecular size molecules.

The starch molecules in the supernatants of cooking water were debranched with isoamylase to show the real amylose and amylopectin distribution because of overlapping of amylose and small amylopectin molecules (Fig. 1). Their molecular size distributions are presented in Fig. 2, and results are summarized in Table III. The first small fraction was amylose and the second major fraction was amylopectin. Within the amylopectin fraction, the first peak with a peak maximal at DP 33 was the long-branch chains and the second peak with a peak maximal at DP 18 was the short-branch chains. XL8 had the largest amylose fraction, followed by XL7; Wells and Ahrent had lower leached amylose contents. Both XL7 and XL8 also had a much larger amount of leached amylopectin, which distinctly separated them from the other cultivars. The soluble solids (Table II) also indicated that XL7 and XL8 had different amounts of soluble solids.

The amount of leached amylose was minimal during cooking of rice kernels. Nevertheless, the leached amylose varied greatly among rice cultivars (0.19–0.78%) with two hybrids XL7 and XL8 showing the largest amounts of leached amylose. The insoluble amylose content, defined as the difference between amylose and leached amylose contents, was 11.71–17.78%. This was the portion of amylose that remained within starch granules during cooking and was indicative of the fine structure of amylopectin that determined rice quality (Radhika-Reddy et al 1993).

Characterization of Starch Structure

The structures of the eight rice starches were characterized to help explain differences in physicochemical properties. The HPSEC profiles of isoamylose-debranched starches are presented in Fig. 3. Fraction I (Fr. I) was composed of mostly amylose, fraction II (Fr. II) included long B chains of amylopectin with a peak DP 35, and fraction III (Fr. III) contained A and short B chains of amylopectin with a peak DP 17. The proportion of Fr. I was reported as the amylose content (Table III) and was much lower (12.1–18.0%) than those by iodine colorimetry (19.6–27.0%) (Table II). Takeda et al (1987, 1989) studied amylopectin of low-, intermediate-, and high-amylose rice cultivars and concluded that the actual amylose contents of apparent high-amylose (30–32%) rice starches were much lower (15.5–18.5%). It was the long-B chains in amylopectin that contributed to the high affinity for iodine for high-amylose rice cultivars. Our results agreed with those of Takeda et al (1987, 1989) and suggested that amylose content determined by HPSEC of isoamylose-debranched rice starch would probably be more representative of the true amylose content in rice starch.

The ratio of Fr. III to Fr. II may be used as an index of the extent of amylopectin branching; the higher the ratio, the higher the degree of branching (Biliaderis et al 1981). The ratios of the eight rice starches ranged from 3.2 for XL7 to 3.8 for Ahrent, Cocodrie, and Drew, which were close to the values of Japanese indica rices reported by Takeda et al (1987). Ahrent and Cocodrie showed a third peak at DP 9, which was not observed in the other starches.

Statistical Analysis

To identify any significant correlation among various physicochemical properties and chemical composition, a statistical analysis was conducted and the results are summarized in Tables IV and V. Both protein and fat had a negative impact on the hardness but positive influence on the stickiness of both the flour gel and

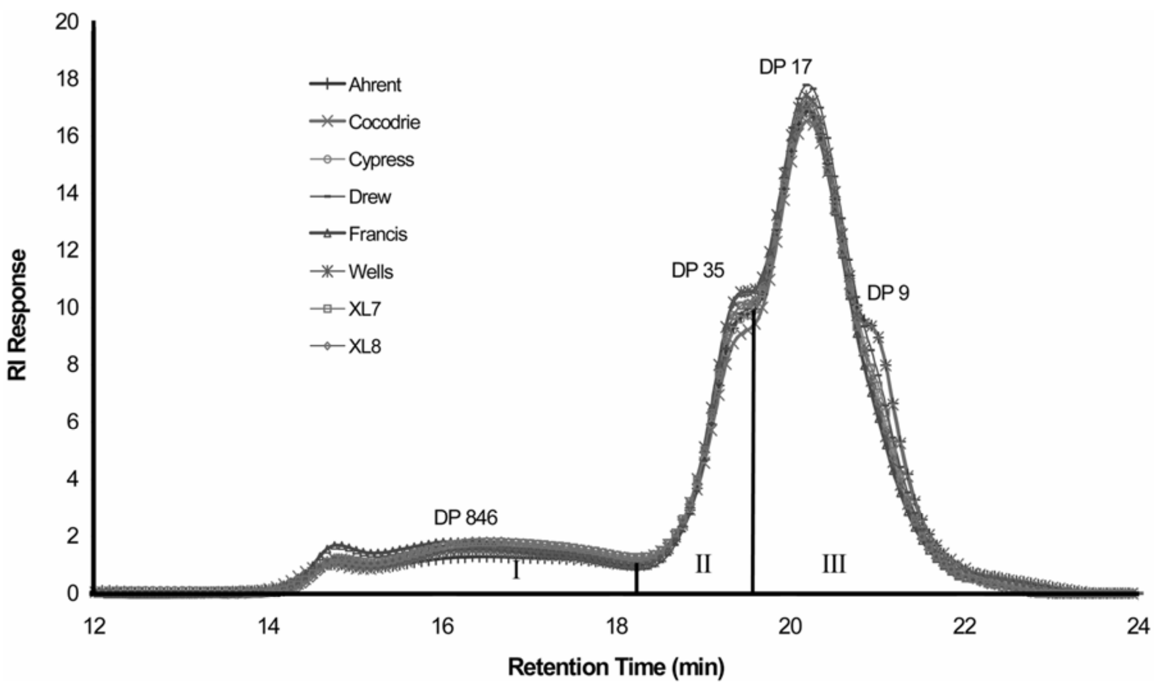

Fig. 3. Molecular size distributions of isoamylase-debranched starches analyzed by high-performance size exclusion chromatography.

TABLE III
Amylose, Leached Amylose, and Insoluble Amylose Contents of Isoamylase-Debranched Rice Starches Analyzed by High-Performance Size-Exclusion Chromatography

	Ahrent	Cocodrie	Cypress	Drew	Francis	Wells	XL7	XL8
Amylose content (%)	12.1	15.0	15.2	14.9	18.0	13.6	15.7	16.5
Leached amylose content (%)	0.39	0.25	0.40	0.24	0.22	0.19	0.40	0.78
Insoluble amylose content (%)	11.71	14.75	14.80	14.66	17.78	13.41	15.30	15.72

cooked rice. However, Juliano et al (1965) reported that for rice samples of similar amylose levels, higher protein correlated with reduced tenderness and cohesiveness. The presence of fat could interfere with the retrogradation of starch molecules, particularly amylose; therefore rice with a higher fat content showed a lower gel hardness (r = –0.73) and softer cooked rice texture (r = –0.69). Higher fat contents, which came from lower degrees of milling, were associated with lower amylose contents, reduced leached amylose, reduced soluble solids. This negative correlation supported the observed greater gel hardness of XL7 and XL8 because of their lower lipid contents.

Although apparent amylose by iodine colorimetry is commonly used as an indicator to predict the textural properties of rice cultivars, this study did not show a strong relationship between the apparent amylose content and the cooked rice hardness and stickiness of these rice cultivars. Nonetheless, the apparent amylose content significantly affected the pasting properties of rice flours, including setback viscosity (r = 0.87), gel hardness (r = 0.81), and gel stickiness (r = –0.82). The relative amylose content by HPSEC of debranched starch correlated strongly with cooked rice hardness (r = 0.73) and gel hardness (r = 0.52) but not gel stickiness. When amylopectin structure was correlated with textural attributes, it was noted that cooked rice hardness decreased with an increasing proportion of A and short B chains (Fr. III), but the cooked rice stickiness increased with an increasing proportion of Fr. III, which agreed with previous reports (Chinnaswamy and Bhattacharya 1986; Takeda et al 1987, 1989; Hizukuri et al 1989; Radhika-Reddy et al 1993; Ong and Blanshard 1995a; Ramesh et al 1999).

The leached amylose by HPSEC had no effect on cooked rice texture, whereas the insoluble amylose correlated strongly with cooked rice hardness (r = 0.73). Higher soluble solids corresponded to reduced gel and cooked rice stickiness and increased gel hardness. The gel stickiness positively correlated with the peak viscosity (r = 0.61) but negatively correlated with setback viscosity (r = –0.72). Both gelatinization and pasting properties did not show good correlation with cooked rice texture but some did correlate with gel properties.

CONCLUSIONS

The insoluble amylose showed a stronger correlation with the cooked rice texture than did the apparent amylose or leached amylose. The higher the amount of leached amylose, the harder the final cooked rice texture. The structure of amylopectin (ratio of A and short B chains to long B chains) played an important role in determining cooked rice texture but not rice flour gel. Protein and fat strongly affected cooked rice texture as well as gel properties. The apparent amylose content was not suitable to predict the cooked rice texture but it could serve as a good indicator for gel hardness of rice flour paste. Although all of the cultivars used in this study were long grain, they had significant differences in physicochemical properties and texture, which consequently would have an impact on their processing and food applications.

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TABLE IV
Correlation Matrix for Data on Chemical Composition and Physicochemical Properties[a]

	Protein	Crude Fat	Apparent Amylose	Amylose (HPSEC)	Fr.III/Fr.II of Amylopectin	Leached Amylose (HPSEC)	Insoluble Amylose (HPSEC)
Lipid	0.40						
Apparent amylose	–0.30	–0.43					
Amylose (HPSEC)	–0.55*	–0.60*	0.42				
Fr.III/Fr.II of amylopectin	0.53*	0.65*	–0.01	–0.45			
Leached amylose (HPSEC)	–0.08	–0.60*	0.39	0.17	0.14		
Insoluble amylose (HPSEC)	–0.55*	–0.54*	0.39	0.99**	–0.47	0.06	
Soluble solids	–0.34	–0.85**	0.35	0.26	–0.36	0.83**	0.18
Onset temperature	0.22	–0.36	–0.13	–0.08	–0.41	0.18	0.07
Pasting temperature	0.44	–0.18	0.18	–0.05	0.05	0.37	–0.09
Peak viscosity	–0.30	–0.14	–0.62*	0.21	–0.59*	–0.31	0.24
Breakdown viscosity	–0.37	–0.12	–0.60	0.24	–0.59*	–0.32	0.27
Setback viscosity	0.04	–0.06	0.87**	0.24	0.22	0.07	0.24
Gel hardness	–0.57*	–0.73**	0.81**	0.52*	–0.30	0.53*	0.47*
Gel stickiness	0.22	0.60*	–0.82**	–0.38	0.16	–0.50*	–0.33
Cooked rice hardness	–0.54*	–0.69**	0.32	0.73**	–0.79**	0.07	0.73**
Cooked rice stickiness	0.69**	0.58*	–0.06	–0.23	0.68**	–0.29	–0.20

[a] Correlation coefficients followed by * and ** are significant at $P < 0.01$ and 0.001, respectively.

TABLE V
Correlation Matrix for Additional Data on Chemical Composition and Physicochemical Properties[a]

	Soluble Solids	Onset Temp.	Pasting Temp.	Peak Viscosity	Breakdown Viscosity	Setback Viscosity	Gel Hardness	Gel Stickiness	Cooked Rice Hardness
Soluble solids									
Onset temperature	0.27								
Pasting temperature	0.25	0.81**							
Peak viscosity	–0.10	0.23	–0.34						
Breakdown viscosity	–0.12	0.20	–0.36	0.99**					
Setback viscosity	–0.03	–0.16	0.25	–0.79**	–0.77**				
Gel hardness	0.69**	–0.21	–0.11	–0.32	–0.30	0.50*			
Gel stickiness	–0.61*	–0.09	–0.35	0.61*	0.61*	–0.72**	–0.80**		
Cooked rice hardness	0.44	0.41	0.15	0.25	0.27	0.12	0.48	–0.47	
Cooked rice stickiness	–0.70**	–0.21	0.04	–0.26	–0.29	0.28	–0.46	0.3	–0.58*

[a] Correlation coefficients followed by * and ** are significant at $P < 0.01$ and 0.001, respectively.

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