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Physicochemical properties and leaching behavior of eight U.S. long-grain rice cultivars as related to rice texture

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ABSTRACT

There are many long-grain rice cultivars produced commercially in the U.S.; however, little work has been done on correlating the structure and physicochemical properties of starch with their texture. The physicochemical properties, leaching behavior, and texture attributes of eight long-grain rice cultivars were studied. Differences were observed in the approximate composition of kernels, including crude protein (6.6-9.3%), crude lipid (0.18-0.51%), and apparent amylose content (25.5-30.9%). These cultivars also differed slightly in thermal properties, such as onset temperature (73.7° to 77.4°C) and peak temperature (78.8° to 81.9°C). Although they showed a similar pasting temperature, their peak viscosities ranged from 680 to 982 Brabender units. The amount and the molecular size distribution of the leached starch molecules varied greatly among the samples. The leached amylose, instead of the apparent amylose, was suggested to play an important role in cooked rice texture.

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MEET THE STUDENT-AUTHOR

Devon K. Cameron

I am a native of Springdale, Ark., and a May 2003 graduate of the Dale Bumpers College of Agricultural, Food and Life Sciences where I majored in food science. I received a scholarship to attend the University of Arkansas and have also received scholarships from Ozark Food Processor's Association and Gerber Foods. I was involved in the Food Science Club, Student Sierra Coalition, Odyssey of the Mind, Gamma Beta Phi honor society, and Alpha Zeta Fraternity.

I worked as a lab technician for Dr. Ya-Jane Wang, my faculty sponsor. She encouraged me to do this project for the research and writing experience. I submitted the paper to the Institute of Food Technologists Student Association's undergraduate research competition. I was accepted as one of six finalists to present the paper in Chicago. I now attend Graduate School at the University of Arkansas. I have learned many things and I am grateful for this valuable and rewarding experience.

INTRODUCTION

Unlike other cereals, rice is principally consumed as a whole grain. Therefore, the texture of the whole grain is of great importance to consumers. Rice is classified in the U.S. as long-, medium-, and short-grain based on kernel length and shape (Adair, 1980). Long-grain rice represents the majority of rice produced in Arkansas as well as in the U.S. Cultivar selection is generally 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 their variation in adaptation to various locations.

Although commercial long-grain cultivars are high yielding and possess typical long-grain characteristics, the properties of cooked rice become less predictable because of diversification of cultivars. Studies have shown that the classical relationships between amylose content and the final properties of the cooked rice are not always consistent and the fine structure of amylose and amylopectin may be more responsible for the cooked rice texture (Ong and Blanshard, 1995; Perez and Juliano, 1979: Reddy et al., 1993). Water-unextractable amylose, instead of the total amylose content of rice, has been found to correlate with the pasting behavior and texture attributes of rice (Battacharya et al., 1978) and can be used as an index of the amylopectin structure (Reddy et al., 1993).

There are many long-grain rice cultivars produced commercially in the U.S. The objective of this study was to examine the physicochemical properties of milled rice and the structures of leached/extractable starch components (i.e. amylose and amylopectin) of eight long-grain cultivars in relation to their texture attributes. Results from this study would help explain any observed differences in processing, cooking, and eating characteristics among these cultivars.

MATERIALS AND METHODS

Materials. Rough-rice samples of cultivars Ahrent, Cocodrie, Francis, Cypress, Drew, Wells, XL7, and XL8 were obtained from the 2002 crop of various locations. 'Ahrent', 'Cocodrie', and 'Francis' were obtained from the University of Arkansas Research and Extension Center, Stuttgart, Ark. 'Cypress', 'Drew', and 'Wells' were obtained from the University of Arkansas Northeast Research and Extension Center, Keiser, Ark. Cultivars XL7 and XL8 were obtained from RiceTec Inc., Alvin, Tex. 'Ahrent', 'Cocodrie', 'Francis', 'Cypress', 'Drew', and 'Wells' are inbred lines and XL7 and XL8 are hybrid lines. All samples were dried under gentle drying conditions to eliminate drying effects. Samples were stored in self-sealing plastic bags under ambient conditions before analysis. 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 s in a friction mill (McGill Miller #2, Rapsco, Brookshire, Tex.). The resulting milled rice was weighed and separated into head rice and broken kernels on a double-tray shaker table (GrainMan Machinery, Miami, Fla.) with 4.67-mm indentation on both trays. Only head rice kernels were used in the study.

Chemical Composition of Rice Flour. Head rice was ground into flour with a cyclone sample mill (Udy Corp. Ft. Collins, Colo.) fitted with a 100-mesh sieve. Duplicate samples of 2 g 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 (AACC, 2000). Crude lipid was measured according to Approved Method 30-20 (AACC, 2000) with the following modifications: rice flour (4-5 g) was extracted with 70 mL petroleum ether by boiling at 135˚C for 20 min and rinsing for 30 min using a Soxtec system (Avanti 2055, Foss North America, Eden Prairie, Minn.). The difference between the weight of the cup containing the extracted oil 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.

Gelatinization Characteristics. Gelatinization properties were assessed by a differential scanning calorimeter (DSC) (Pyris-1, Perkin-Elmer Co., Norwalk, Conn.). Starch (approximately 4.0 mg, dry basis) 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 h prior to thermal analysis. Samples were heated from 25º 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.

Pasting and Gelling Properties of Rice Flour. The pasting characteristics were determined with a 10% (w/w) rice flour slurry using a Micro ViscoAmyloGraph (C.W. Brabender Instruments, Inc., South Hackensack, N.J.) equipped with a 700-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 h and then measured with a TA-XT2i Texture Analyzer (Texture Technologies Corp., Scardale, N.Y.) using texture profile analysis (TPA). The paste was poured into three aluminum dishes (75 mm diameter x 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 pre-test 2.0 mm/s, test 0.2 mm/s, and post-test 0.2 mm/s, to a distance of 5.0 mm with a cylindrical probe (2.54 mm diameter x 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.

Leached Carbohydrate Composition in Cooking Water. The sample preparation followed the method by Ong and Blanshard (1995) with modifications. Milled rice (10 g) was cooked with 20 g deionized water in a boiling water bath for 15 min and the solubles in the supernatant were characterized by high-performance size-exclusion chromatography (HPSEC) (Waters Corporate, Milford, Mass.) without dilution following the method of Kasemsuwan et al. (1995) with modifications (Wang and Wang, 2000). The solubles were autoclaved at 121°C for 30 min and then sonicated for 20 s for molecular size analysis of native samples. The solubles were diluted with three-fold deionized water and then treated with isoamylase (crystalline Pseudomonas isoamylase, Hayashibara Biochemical Laboratories Inc., Okayama, Japan) for molecular size analysis of debranched samples.

Textural Attribute of Cooked Rice. 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 with a TA-XT2i Texture Analyzer.

Statistical Analysis. Experimental data were analyzed by using the general linear models procedure (1999 version; SAS Software Institute, Inc., Cary, N.C.), and least significance differences were computed at $P < 0.05$.

RESULTS AND DISCUSSION

Chemical Composition, Physicochemical Properties, and Textural Attributes. The chemical composition, physicochemical properties, and textural attributes of the eight rice cultivars are summarized in Table 1. Differences were observed in the approximate composition of rice kernels, including crude protein (6.6-9.3%), crude lipid (0.18-0.51%), and apparent amylose content (25.5-30.9%). The hybrids XL7 and XL8 had different chemical compositions from the other inbred cultivars with a slightly higher amylose content and significantly lower crude protein and crude lipid contents.

The gelatinization temperatures of most rice cultivars were around 76 to 77°C for onset and 80 to 81°C for peak temperature. 'Drew' had a much lower onset temperature of 73.7°C and peak temperature of 78.8°C. A larger variation was observed in gelatinization enthalpy ranging from 7.4 to 11.5 Joule/g. Again 'Drew' also showed a lower gelatinization enthalpy. Cultivars XL7 and XL8 had similar gelatinization properties as the other cultivars. Their differences in gelatinization characteristics suggested potential variation during processing. Rice with a lower onset temperature and a lower enthalpy is easier to cook and requires less energy for processing.

When the pasting properties of the rice flours were measured by Micro ViscoAmyloGraph, the cultivars showed distinct pasting profiles. The range of the pasting temperatures were from 73.3 to 76.2°C, peak viscosity from 680 to 982 Brabender units (BU), breakdown from 316 to 604 BU, and setback viscosity 395 to 523 BU. '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 lower gelatinization temperature. Although all samples are long-grain cultivars with a higher amylose content, their distinct pasting properties suggested their differences in the fine structures of amylose and amylopectin because the pasting properties were mainly controlled by the starch component in rice flour. These results supported the previous reports (Ong and Blanshard, 1995; Perez and Juliano, 1979; Reddy et al., 1993) that amylose content alone was not appropriate to predict the rice properties.

The gelling properties of flour pastes after storage at 5°C for 24 h showed distinct differences among the eight cultivars. Both hybrids XL7 and XL8 almost existed as a separated group from inbred cultivars, although differences also existed among the inbred cultivars. XL7 and XL8 had the highest gel hardness and stickiness values twice as high as those of 'Ahrent' and 'Wells'. The low crude lipid content in XL7 and XL8 might partly explain their high gel hardness because lipids would interfere with starch molecule reassociation, thus retarding the retrogradation process. The gels of 'Cypress' and 'Drew' were harder while 'Cocodrie' had the highest stickiness among the inbred cultivars.

When the textural attributes of cooked rice kernels were evaluated, 'Francis' had the highest hardness while XL7, XL8, and 'Wells' had the highest stickiness. The discrepancy in hardness between flour gels and cooked kernels of different cultivars might be attributed to their differences in shear force. When a flour paste was prepared using Micro ViscoAmyloGraph, a constant shear was applied and the shear caused starch granules fragmentation as evidenced from the presence of breakdown in viscosity. The fragmentation of starch granules enabled more starch molecules to become solubilized in water, which then interacted with each other to form 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 be possibly dominated by the extent of starch swelling, the leached starch molecules, and/or the unextractable amylose content.

The molecular size distribution of the leached molecules varied greatly among the eight cultivars and each cultivar showed a characteristic profile compared against a native rice starch (Fig. 1). The number of degrees of polymerization (DP) above each peak represents the molecular size calculated from the pullulan standards. It was apparent that large starch molecules with DP > 1,000 leached out and 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 a DP of 24 was intriguing but its origin was not clear although possibly from breakdown of amylopectin branch chains. Both XL7 and XL8 had significantly lower amounts of small molecular-sized 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 suggested that either the molecular structures of starch molecules (amylose and/or amylopectin) in hybrids were different from those of the inbreds and could leach out easier, or the starch molecules were not as tightly organized within the starch granules as others. 'Cocodrie' had the largest amount of saccharides with DP < 24 whereas 'Wells' had the smallest amount of large molecular size molecules.

Because of overlapping of amylose and small amylopectin molecules (Fig. 1), the starch molecules in the supernatants of cooking water were debranched with isoamylase and their molecular size distributions are presented in Fig. 2. The first small peak was the amylose component and the second large peak was the 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 peak followed by XL7, and '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. Based on the profiles and the refractive index response, XL7 and XL8 leached out the most starch molecules, and 'Wells' the least.

In order to identify any significant correlation among various physical and chemical properties, a statistical analysis was conducted and the results are listed in Table 2. Both protein and lipid were found to have a negative impact on the hardness of the flour gel, and the cooked rice with lipids showed higher correlation coefficients. This negative correlation supported the much greater gel hardness of XL7 and 'XL8 'because of their lower lipid contents. The presence of lipid could interfere with the retrogradation of starch molecules, particularly amylose, therefore rice with a higher lipid content showed a weaker gel and softer texture. Although apparent amylose content 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. Nevertheless, the apparent amylose content significantly affected the pasting properties of rice flours, including setback viscosity (r=0.587), gel hardness (r=0.696), and gel stickiness (r=-0.746). The onset gelatinization temperature was not influenced by the apparent amylose content but negatively correlated with the lipid content. The gel stickiness positively correlated with the peak viscosity (r=0.621) but was negatively correlated with setback viscosity (r=-0.701). The leached amylose showed a stronger correlation with the cooked rice texture than did the apparent amylose. The higher the amount of leached amylose, the harder the final cooked rice texture. Although the leached amylopectin also showed a positive correlation with the hardness of the cooked rice, it is believed the leached amylose dominated the cooked rice texture due to its linear structure and greater tendency to reassociate.

Although all of the cultivars used in this study were long-grain, they had significant differences in physicochemical properties and cooked rice texture, which consequently would have an impact on their processing and food applications. The apparent amylose content was not suitable to predict the cooked rice texture but could serve as a good indicator for gel hardness of rice flour paste.

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TABLE 1. Chemical composition and physicochemical properties of milled rice flour and cooked rice hardness from rice cultivars Ahrent, Cocodrie, Cypress, Drew, Francis, Wells, XL7, and XL8.[z]

	Ahrent	Cocodrie	Cypress	Drew	Francis	Wells	XL7	XL8
Chemical composition								
Moisture (%)	9.0d	11.0a	10.5b	10.5b	10.7a	10.3b	10.3b	9.8c
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)	25.5c	30.9a	28.4abc	29.7ab	27.8bc	26.8a	30.4a	30.1ab
Gelatinization								
Onset temperature (ºC)	76.6c	76.5c	75.6d	73.7e	77.1b	77.4a	76.5c	77.0a
Peak temperature (ºC)	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	10.2abc	10.3b	10.4b
Pasting properties								
Pasting temperature (ºC)	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	429bcd	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)	5480f	6395cde	5985ef	6121def	7486a	6741bcd	7449ab	6996abc
Stickiness (g-force)	320c	228c	314c	452b	438b	604a	603a	598a

[z] Mean values in rows followed by the same letter are not significantly different at $P < 0.05$.

TABLE 2. Correlation matrix for data on chemical composition, physicochemical properties, and cooked rice hardness.[z]

	Protein	Lipid	Apparent amylose	Onset temperature	Peak viscosity	Setback viscosity	Leached amylose	Gel stickiness	Gel hardness	Cooked rice hardness
Lipid	0.403*									
Apparent amylose	0.36	-0.367*								
Onset temperature	-0.225	-0.834**	0.293							
Peak viscosity	-0.327	-0.132	-0.494*	-0.105						
Setback viscosity	0.319	0.053	0.587**	0.129	-0.981**					
Leached amylose	-0.358	-0.810**	0.580**	0.796**	-0.353	0.376*				
Gel hardness	-0.573**	-0.742**	0.696**	0.560**	-0.294	0.353*	0.844**			
Gel stickiness	0.129	0.576**	-0.746**	-0.607**	0.621**	-0.701**	-0.750**	-0.757**		
Cooked rice hardness	-0.432*	-0.568**	0.293	0.495**	0.202	-0.124	0.383*	0.367*	-0.339	
Cooked rice stickiness	0.601**	0.505**	0.12	-0.593**	-0.225	0.262	-0.415*	-0.407*	0.168	-0.409*

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

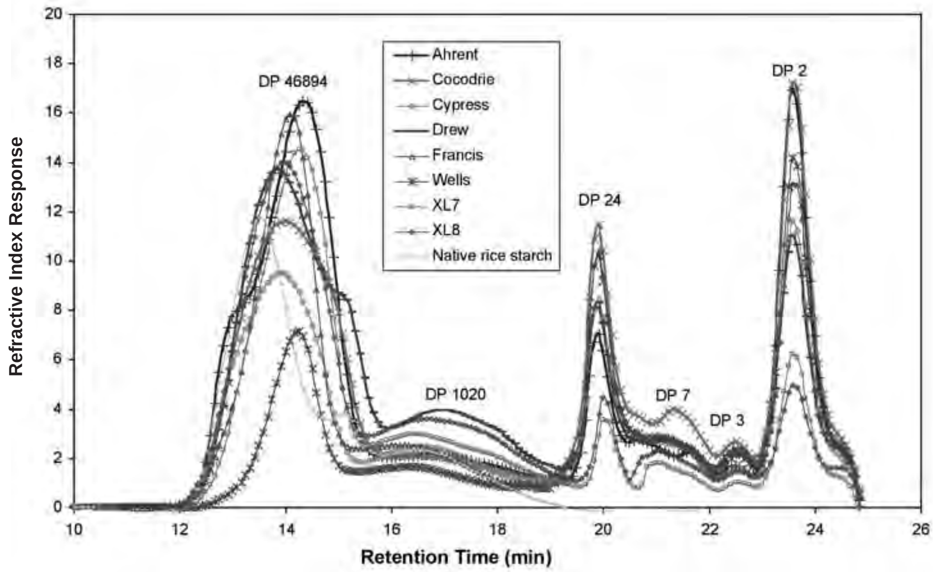

Fig. 1. Molecular size distribution of cooking water solubles analyzed by high-performance size exclusion chromatography. DP = degree of polymerization.

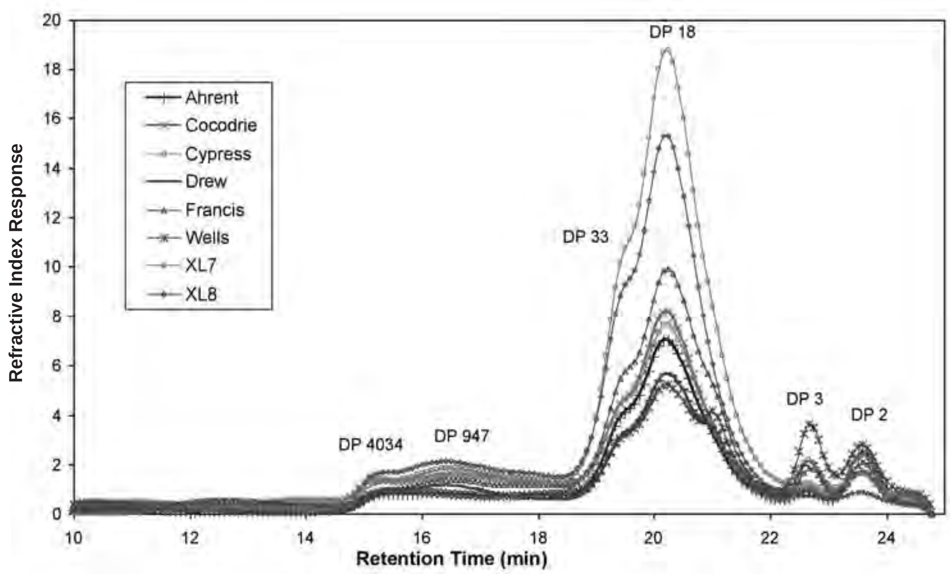

Fig. 2. Molecular size distribution of cooking water solubles debranched by isoamylase and analyzed by high-performance size exclusion chromatography. DP = degree of polymerization.