Comparison of Physical and Chemical Properties of Medium-Grain Rice Cultivars Grown in California and Arkansas

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ABSTRACT: The physical attributes, chemical composition, and physicochemical properties of 2 medium-grain rice cultivars from Arkansas (Bengal, Medark) and from California (M202, M204) were compared when grown in their respective locations and grown together in Arkansas to better understand the impacts of heredity and environment on medium-grain rice quality. Variations existed in grain dimensions, particularly length distribution, among cultivars and between crop years. When grown separately, the Arkansas cultivars tended to have higher protein and lipid contents but lower amylose contents than the California cultivars. M204 contained a significantly higher apparent amylose content (21.0%) compared with the other 3 cultivars (14.3% to 16.4%). The Arkansas rice cultivars exhibited higher pasting and gelatinization temperatures and produced harder gels and less sticky cooked rice. However, when the 4 cultivars were grown together in Arkansas, differences in protein and amylose contents, gelatinization and pasting properties, and cooked rice texture decreased. This study demonstrated that genetics, location, and crop year all contributed to variations in rice chemical and physical characteristics.

Keywords: Arkansas rice, California rice, medium-grain rice, physicochemical properties, rice quality

Introduction

Arkansas is the leading rice-producing state in the United States, followed by California, Louisiana, Mississippi, Texas, and Missouri. Long-grain rice accounts for more than 70% of U.S. production and is grown almost entirely in the South. Medium-grain accounts for more than one-fourth of total U.S. production and is grown in both California and the South (ERS-USDA 2007); however, the markets for California and southern medium-grain rice are different (Moldenhauer and others 2004). The majority of California medium-grain rice is for export markets such as Japan, Turkey, and Jordan, and the remaining is for the consumer markets such as cereals and beer. In contrast, southern medium-grain rice is mainly utilized in the U.S. and Puerto Rico consumer markets (ERS-USDA 2007).

In the United States, the classification of rice into short-, medium-, and long-grain classes is based on grain dimensions. Medium-grain cultivars are bred to combine the good agronomic and quality characteristics of long- and short-grain cultivars. Rice cultivars are also referred to as japonica or indica varieties, a classification of culture adaptation. Japonica cultivars are typically shorter grains and grow well in a temperate climate, whereas indica cultivars are typically long grains and grow well in tropical areas (Hartmann and others 1981). All medium-grain cultivars grown in the United States are classified as temperate japonicas, and all long-grain cultivars are classified as tropical japonicas (Mackill 1995). Hybridizations of long-grain tropical japonica and short-grain temperate japonica produced U.S. medium-grain rice. The southern and California medium-grain rice cultivars are from distinct pedigrees (Dilday 1990) because of differences in climate and applications. Bengal is a successful southern medium-grain released in 1993 and is still the leading medium-grain variety grown in Arkansas. Medark is a new high-yielding medium-grain cultivar released in 2005 as an alternative to Bengal and is derived from Bengal and Short Rico. Both M202 and M204 are Calrose quality type. M202 is the leading medium-grain rice variety grown in California with M204 usually running second or third.

Although genetics plays a major role in determining rice functionality, environment and cultural practices also have been shown to significantly affect composition and, consequently, cooking characteristics of rice (Bett-Garber and others 2001; Dang and Copeland 2004). The major environmental factor affecting starch composition and structure that has been extensively studied is the temperature during grain development. Rice amylose content varies with the cultivar and inherent level of amylose generally decreases with increasing grain filling temperature (Asaoka and others 1984; Sano and others 1985). Hirano and Sano (1998) reported that granule-bound starch synthase (GBSS) activity, responsible for synthesis of amylose, is higher at 15 °C than at 25 °C in developing grains. The temperature impact is greater in low-amylose cultivars and lesser in intermediate- and high-amylose cultivars. It has also been reported that there is an increase in the average chain length of amylopectin in rice grains grown at high temperatures (Asaoka and others 1989; Jiang and others 2003). Cultural practices such as nitrogen fertilization can also alter protein or amylose content (Paule and others 1979; Perez and others 1996).

An integrated approach of studying the physical and chemical properties of the rice grain is crucial to understand the impacts of environment and genetic make-up on variability in the functionality of medium-grain rice cultivars grown in Arkansas and California. The objective of this study was to compare the physical attributes, chemical composition, and physicochemical properties of 2 medium-grain rice cultivars from California (M202, M204) and

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from Arkansas (Bengal, Medark) grown in their respective locations and grown together in Arkansas.

Materials and Methods

Materials

Rough rice samples of Bengal and Medark were obtained from the 2002 crop grown at the Univ. of Arkansas Rice Research and Extension Center, Stuttgart, Ark., U.S.A. Milled rice samples of M202 and M204 were provided by the Rice Experiment Station, California Cooperative Rice Research Foundation, Biggs, Calif., U.S.A. Because of disease concern, Arkansas rice varieties are not allowed to be grown in California, Bengal, Medark, M202, and M204 were all grown only at the Univ. of Arkansas Rice Research and Extension Center in 2003. All rough rice samples were milled by multiple passes through a lab-scale continuous, vertical friction mill (Model RicePal 31; Yamamoto, Tokyo, Japan). The friction mill was set to a medium milling level, and the settings were adjusted to achieve a similar milling degree for all samples according to the residual surface lipid content (0.75% to 0.89%) determined by near-infrared (NIR) spectroscopy with an Infratec 1241 Grain Analyzer (Foss Tecator AB, Hoganas, Sweden). The resulting milled rice was weighed and separated into head rice and broken kernels on a double-tray shaker table (GrainMan Machinery, Miami, Fla., U.S.A.). Samples were stored in self-sealing plastic bags under ambient conditions. Head rice was ground into flour with a cyclone sample mill (Udy Corp., Ft. Collins, Colo., U.S.A.) fitted with a 100-mesh sieve.

Physical attributes of milled rice kernels

The dimensions (length, width, and thickness) of 135 grains of head rice were measured with a Satake rice image analyzer equipped with a NaiS image checker 30R (Satake Corp., Hiroshima, Japan). Grain whiteness was measured with a Satake milling meter (Model MM-1B; Satake Engineering Co., Ltd., Tokyo, Japan).

Chemical composition of rice flour

Duplicate samples of 2 g rice flour were placed in aluminum moisture dishes and dried in a convection oven at 130 °C for 60 min according to Approved Method 44-15A (AACC 2000). Apparent amylose content of flour was determined by iodine colorimetry (Juliano and others 1981). Crude protein content was measured by micro-Kjeldahl according to Approved Method 46-13 (AACC 2000), and crude lipid content was measured according to Approved Method 30-20 (AACC 2000) with the following modifications. Rice flour (4 to 5 g) was extracted with 70 mL petroleum ether by boiling at 135 °C for 20 min and rinsing for 30 min in a Soxtec system (Model Avanti 2055; Foss North America, Eden Prairie, Minn., U.S.A.). The difference between 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 dry weight of the original sample.

Gelatinization, pasting, and gelling properties of rice flour

Gelatinization properties were assessed by a differential scanning calorimeter (DSC) (Pyris-1; Perkin-Elmer Co., Norwalk, Conn., U.S.A.). Flour (about 4 mg, db) was weighed into an aluminum DSC pan and then moistened with 8 μL deionized water using a microsyringe. The pan was hermetically sealed and equilibrated at room temperature for at least 1 h prior to scanning from 25 to 130 °C at 10 °C/min. Duplicate measurements were obtained for each sample.

The pasting characteristics of rice flour were determined at 10% (w/w) concentration with a Micro ViscoAmyloGraph (C.W. Brabender Instruments Inc., South Hackensack, N.J., U.S.A.) equipped with a 350-cmg cartridge and operated at 250 rpm. The slurry was heated from 50 to 95 °C at 3 °C/min, held at 95 °C for 5 min, and cooled to 50 °C at a rate of 3 °C/min. Duplicate measurements were performed on each sample.

The flour paste prepared with the Micro ViscoAmyloGraph was used for the measurement of gelling properties. The paste was poured into 3 glass dishes (27-mm dia × 39-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 and others 1989). The starch paste was stored at 5 °C for 24 h and then measured with a TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, N.Y., U.S.A.) by texture profile analysis (TPA). The gel was compressed at a speed of pretest 1.0 mm/s, test 0.5 mm/s, and posttest 1.0 mm/s to a distance of 5.0 mm with a cylindrical probe (5-mm dia × 33-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 done on each sample.

Cooked rice texture

Rice was cooked and evaluated following the method of Sesmat and Meullenet (2001) with modifications. Rice (10 g) was placed in a 100-mL beaker with 17 g deionized water, steamed in a rice cooker (National, model SR-W10FN) for 30 min, and set on warm for 5 min. Ten cooked rice kernels were compressed at a speed of pretest 2.0 mm/s, test 0.5 mm/s, and posttest 0.5 mm/s to a distance defined to compress the kernels to 90% of their original height. The test was performed with a large flat plate (100-mm dia) under the TPA test mode of the Texture Analyzer. Six replications were performed for each cooked sample, and 2 cooked samples were prepared for each rice sample.

Statistical analysis

Experimental data were analyzed by using the general linear models procedure, the ANOVA procedure, and Duncan's multiple range test (1999 version; SAS Software Inst. Inc., Cary, N.C., U.S.A.). Least significant differences were computed at $P < 0.05$. Data were also analyzed using the correlation procedure (Pearson's correlation coefficients) in SAS.

Results and Discussion

Physical attributes of milled head rice

The average value and distribution for length, width, and thickness of head rice from all 4 cultivars and from the 2 crop years are shown in Figure 1, 2, and 3, respectively. The distribution of the grain dimensions is important to processing and can be used as a quality indicator. It is more desirable to have a narrow and consistent distribution of kernel dimensions than a wide distribution for ease of processing and consistency in quality. Grain length seemed to be the physical attribute greatly affected by genetic background and environment (Figure 1). The grain length increased for all samples grown in 2003, with M202 and M204 showing the most increase. Bengal exhibited a wider grain length distribution, whereas M202 showed a narrower range for both years. There were slight differences in average value and distribution for grain width and thickness among rice samples for the 2 crop years (Figure 2 and 3). M202 and M204 became wider, whereas Bengal and Medark grew thicker for the 2003 crop year. The California cultivars were milled to a greater extent in 2002 because of their lower residual lipid contents, and other samples were milled to a similar range of degree of milling as measured by NIR (Table 1). It was also observed that the California cultivars were much whiter when grown separately in 2002 and decreased in whiteness when grown in Arkansas in 2003. Arkansas cultivars also showed a slight decrease in whiteness in 2003.

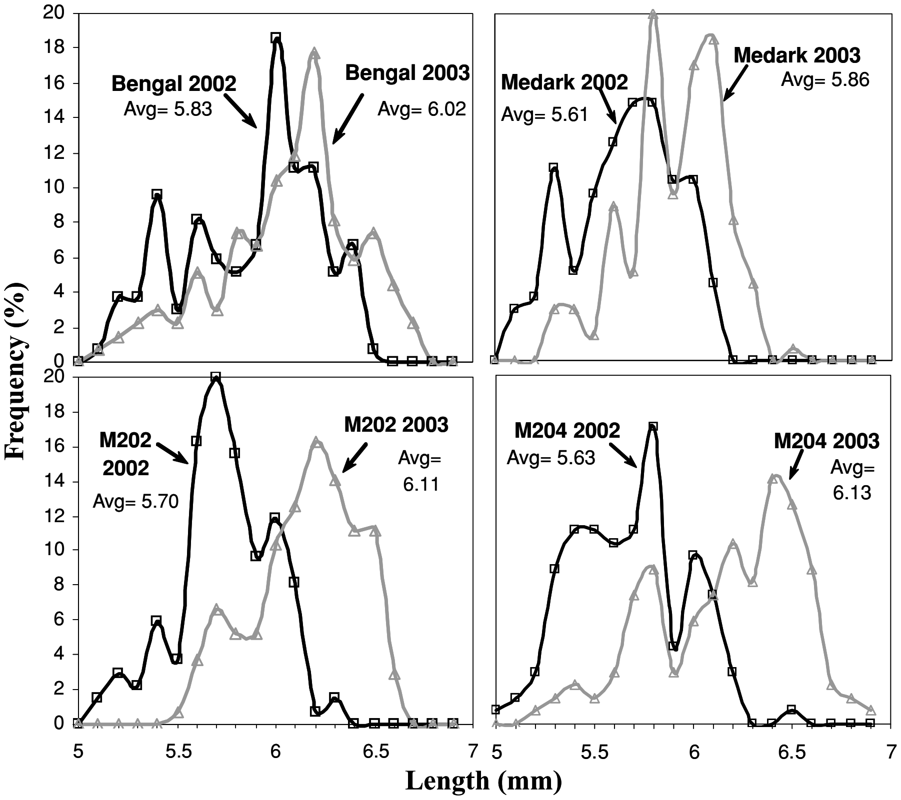

Figure 1—Grain length distributions and average values of cultivars Bengal, Medark, M202, and M204 for crop years 2002 and 2003.

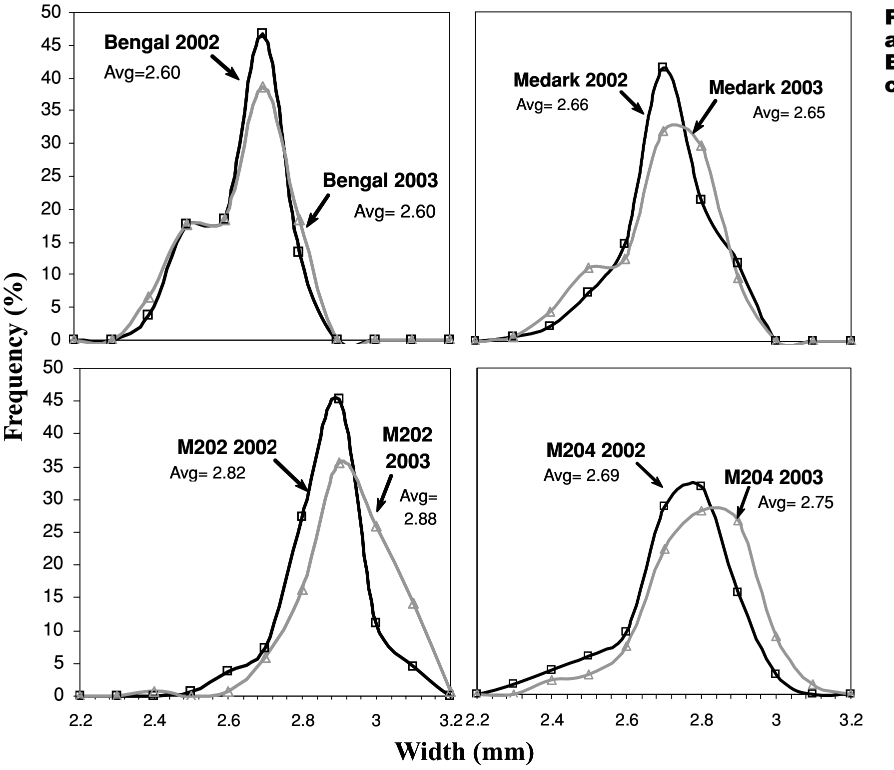

Figure 2—Grain width distributions and average values of cultivars Bengal, Medark, M202, and M204 for crop years 2002 and 2003.

Chemical composition

The Arkansas medium-grain rice cultivars were generally higher in protein content but lower in crude lipid and apparent amylose contents than the California rice cultivars when grown separately in 2002 (Table 1). The protein and lipid contents of Bengal and Medark increased but their apparent amylose contents remained unchanged in 2003 compared with those in 2002, confirming that the chemical composition of rice cultivars can vary by crop year. Significant changes in chemical composition were noted for the California cultivars when they were grown in Arkansas in 2003. They increased in protein content by approximately 3%, increased in crude lipid content by 0.4%, but decreased in apparent amylose content by 3% to 4%. Temperature data taken from Stuttgart, Ark., in 2002 and 2003 and from Durham, Calif., in 2002 are displayed in Figure 4. The weather station at Durham is approximately 6 km north of the research station at Biggs, Calif., where the rice was grown. The months of June to August were graphed to ensure that the grain filling stage was included. The maximum temperatures for Arkansas and California in 2002 and 2003 were similar, ranging from 30 to 35 °C. Their major differences were in the minimum temperatures, where California was consistently lower than Arkansas. The present result for apparent amylose content supports previous reports that a lower growing temperature resulted in a higher apparent amylose content, possibly from increased production of GBSS protein (Sano 1984; Sano and others 1985).

Rice protein content is strongly influenced by nitrogen fertilization (Perez and others 1996) or nitrogen availability in soil (Landers 1972). Higher solar radiation in California could also lead to a decrease in rice protein content (Juliano 1985). The effect of environment on lipid content was not clear; however, it is suspected that the increase in crude lipid content was a result of the increase in grain dimension for 2003. All rice samples increased in the average values of grain length and width in 2003 but were still milled using the same milling condition as in 2002. Therefore, there was probably more residual bran in 2003 samples, thus resulting in a higher crude lipid content. The results also suggest that NIR measurement is not as sensitive as crude lipid measurement to determine the degree of milling of milled rice.

The effects of variety, location, and crop year on rice physical and chemical characteristics were analyzed by ANOVA (Table 2).

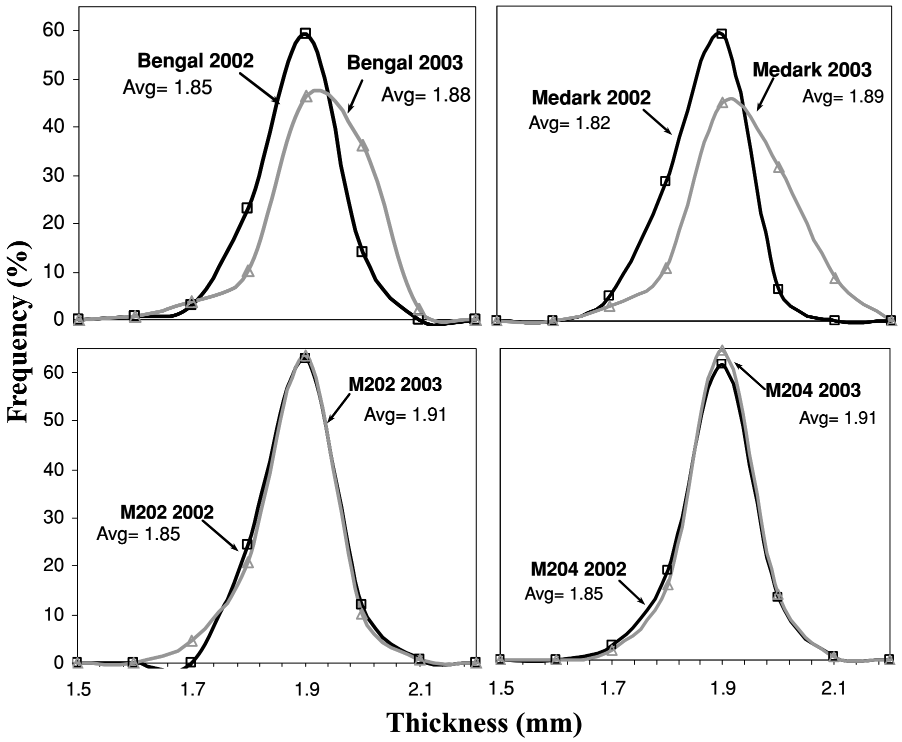

Figure 3—Grain thickness distributions and average values of cultivars Bengal, Medark, M202, and M204 for crop years 2002 and 2003.

Table 1—Chemical composition, degree of milling, and whiteness of milled rice flour from rice cultivars Bengal, Medark, M202, and M204.[a]

					%, db		
Crop year	Cultivar	Location	Degree of milling[b]	Whiteness	Crude protein	Apparent amylose	Crude lipid
2002	Bengal	AR	0.84a	40.5b	6.7c	14.3cd	0.44c
	Medark	AR	0.75b	37.7c	7.2b	16.0bc	0.33d
	M202	CA	0.68c	44.1a	5.4d	16.4b	0.34d
	M204	CA	0.46d	44.4a	5.7d	21.0a	0.23e
2003	Bengal	AR	0.78b	35.7d	7.6b	13.3d	0.55b
	Medark	AR	0.86a	32.9f	8.2a	15.7bc	0.54b
	M202	AR	0.85a	33.9e	8.2a	13.4d	0.74a
	M204	AR	0.89a	35.2d	8.5a	16.4b	0.74a

[a] Mean values of duplicate measurements in a column followed by the same letter are not significantly different at $P < 0.05$.
[b] Degree of milling = % oil by NIR.

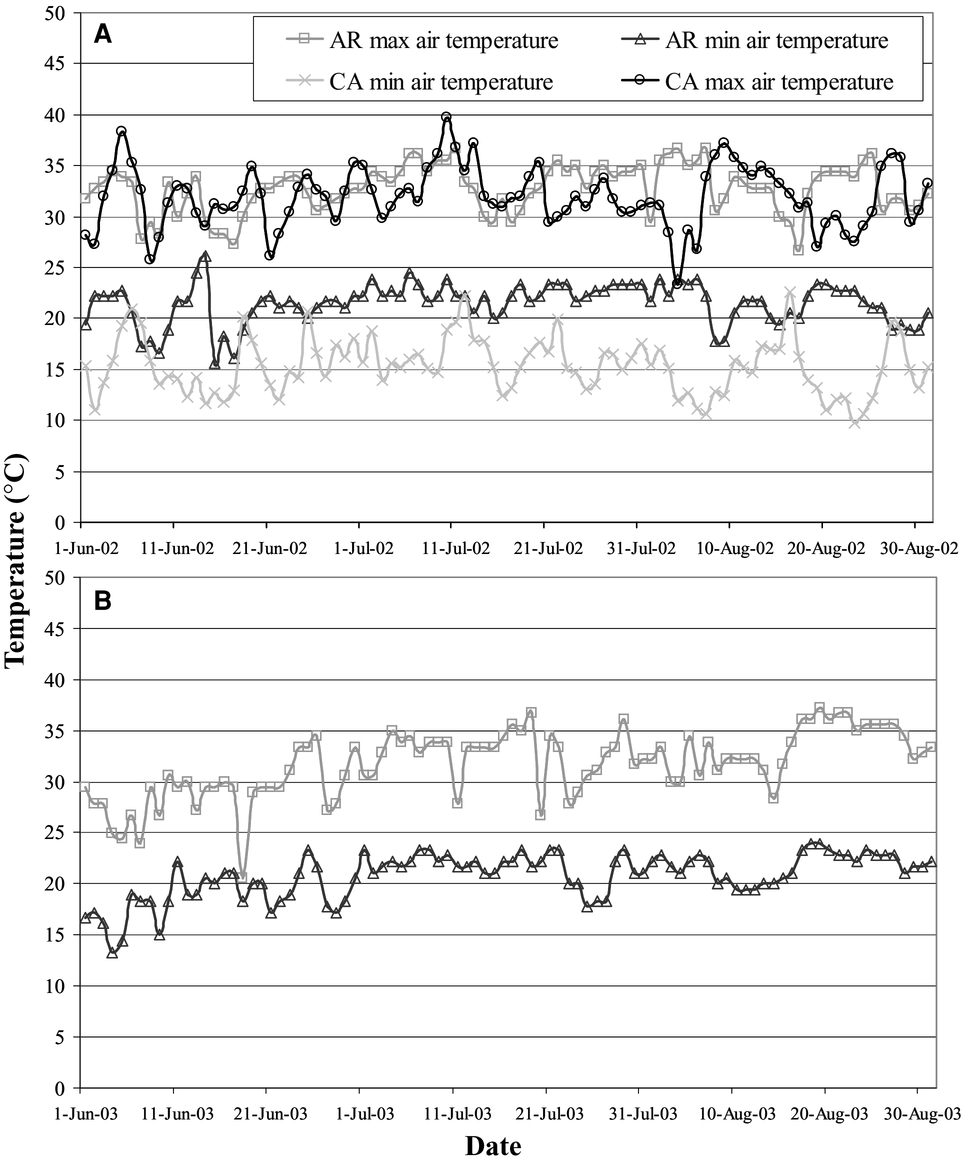

Figure 4—Weather data for Durham, Calif., and Stuttgart, Ark., for June to August 2002 (A) and 2003 (B).

Location was found to be the most influential factor affecting rice characteristics. The difference between crop years was also significant for grain length and crude protein and crude lipid contents. These results demonstrate that environmental factors such as location and crop year are as important as genetics in determining physical attributes and chemical composition of medium-grain rice (Bett-Garber and others 2001; Dang and Copeland 2004).

Table 2—*F*-values for the effects of variety, location, and crop year on physical and chemical characteristics of medium-grain rice cultivars Bengal, Medark, M202, and M204.[a]

	Variety	Location	Crop year
Grain length	3.2	45.4**	10.5*
Grain width	15.63**	2.61	0.02
Grain thickness	0.09	0.02	2.09
Apparent amylose content	11.2*	18.3**	0.5
Crude protein content	16.5**	474.4**	63.5**
Crude lipid content	13.9**	559.1**	80.4**

[a] Values with * are significant at $P < 0.05$ and values with ** at $P < 0.01$.

Gelatinization and pasting properties

The gelatinization properties of 4 medium-grain rice cultivars from the 2 crop years are listed in Table 3. When grown in their respective locations, the California cultivars displayed significantly lower onset and peak gelatinization temperatures than the Arkansas cultivars. However, the gelatinization temperatures of the California cultivars increased and became similar to those of the Arkansas cultivars when they were all grown in Arkansas. Because gelatinization properties are predominantly governed by amylopectin structure, variations likely existed in the synthesis and/or organization of amylopectin in the California cultivars from the 2 different locations. Variety, location, and crop year again showed great impacts on the rice gelatinization properties. Onset gelatinization temperature and enthalpy were highly correlated with variety ($r^2 = 0.728$ and 0.723, respectively, at $P < 0.05$), whereas peak gelatinization temperature and enthalpy were highly correlated with location ($r^2 = 0.788$ and 0.853, respectively, at $P < 0.05$).

The pasting properties of rice flours as measured by a Micro ViscoAmyloGraph are summarized in Table 4. Bengal and Medark showed significantly higher pasting temperatures and lower final viscosities, but similar peak and breakdown viscosities as compared to M202 and M204 when grown in their respective locations in 2002. Pasting and gelatinization properties are often used as quality indicators for processing or product characteristics. Pasting or gelatinization temperature gives an indication of the temperature at which the rice must be processed to fully cook the starch. Therefore, the Arkansas cultivars would require a higher processing temperature than the California cultivars. The higher final viscosity of M202 and M204 corresponded to their higher amylose contents. The influences of protein and lipid on pasting properties of the rice cultivars are not clear. The removal of protein has been reported to decrease peak and final viscosities of rice flour, suggesting a positive correlation of protein and pasting viscosities (Martin and Fitzgerald 2002; Fitzgerald and others 2003). However, this correlation was not observed in our study. Lipid–amylose complexes may also have an impact on the pasting properties of rice flours because they can increase starch gelatinization temperature and suppress starch swelling (Maningat and Juliano 1980; Ozcan and Jackson 2002). The higher pasting temperatures of Bengal and Medark may have resulted from their higher crude protein and crude lipid contents, although their apparent amylose contents were lower than M202 and M204.

The pasting properties of the 4 rice cultivars were similar when grown together in Arkansas in 2003. When compared to the same cultivars from the previous year, all 4 rice cultivars displayed a significant increase in pasting temperature and final viscosity but a decrease in total setback, which may be ascribed to their higher protein and lipid contents. Lipid has been shown to inhibit starch swelling (Tester and Morrison 1990), and protein surrounding starch granules may also exert a similar influence on starch granules. Protein was reported to protect against starch breakdown in rice (Hamaker and Griffin 1993) which, nevertheless, was not observed in this study.

Flour gel and cooked rice texture

Table 5 lists the properties of the flour gel and the cooked rice of rice samples for both crop years. In 2002, the Arkansas cultivars had slightly higher gel hardness than the California cultivars. In 2003, most cultivars increased in gel hardness and decreased in gel stickiness. The decrease in gel stickiness may be attributed to their higher lipid contents. For cooked rice texture, the California cultivars seemed to be slightly harder, yet stickier, when grown in their native location, but they increased in hardness and decreased

Table 3—Gelatinization properties of milled rice flour from cultivars Bengal, Medark, M202, and M204 as measured by differential scanning calorimetry.[a]

Crop year	Cultivar	Location	Onset temperature	Peak temperature (°C)	Enthalpy (J/g)
2002	Bengal	AR	70.3a	75.2a	7.7ab
	Medark	AR	70.2a	75.3a	8.3ab
	M202	CA	67.2bc	72.7b	7.1b
	M204	CA	64.5c	72.5b	7.1b
2003	Bengal	AR	68.1ab	74.6a	8.8a
	Medark	AR	68.6ab	74.4ab	7.2ab
	M202	AR	68.5ab	73.6ab	8.2ab
	M204	AR	68.5ab	74.2ab	7.9ab

[a] Mean values of duplicate measurements in a column followed by the same letter are not significantly different at $P < 0.05$.

Table 4—Pasting properties of rice flour from cultivars Bengal, Medark, M202, and M204 as measured by Micro ViscoAmyloGraphy.[a]

Crop year	Cultivar	Location	Pasting temperature (°C)	Peak viscosity (BU)	Break-down (BU)	Total setback (BU)	Final viscosity (BU)
2002	Bengal	AR	68.4c	1008a	657a	−357c	651d
	Medark	AR	68.9b	969ab	546bc	−277b	692c
	M202	CA	67.0d	997a	551b	−270b	737b
	M204	CA	66.5e	956ab	461e	−127a	830a
2003	Bengal	AR	69.0b	944ab	551b	−235b	709bc
	Medark	AR	69.6a	893b	499de	−154a	739b
	M202	AR	69.0b	966ab	555b	−159a	807a
	M204	AR	69.6a	937ab	508cd	−135a	803a

[a] Mean values of duplicate measurements in a column followed by the same letter are not significantly different at $P < 0.05$.

Table 5—Flour gel properties and cooked rice texture of medium-grain rice cultivars Bengal, Medark, M202, and M204.[a]

			Flour gel (g-force)		Cooked rice (g-force)	
Crop year	Cultivar	Location	Hardness	Stickiness	Hardness	Stickiness
2002	Bengal	AR	6.6bc	3.0a	59.5e	8.1bc
	Medark	AR	7.4ab	3.4a	65.2cd	8.5b
	M202	CA	6.1c	2.7ab	64.2d	8.4b
	M204	CA	6.2bc	3.1a	65.1cd	9.6a
2003	Bengal	AR	7.8a	1.9c	59.7e	8.4b
	Medark	AR	8.2a	1.6c	66.8bc	7.6cd
	M202	AR	6.5bc	1.9c	71.2a	7.3d
	M204	AR	7.9a	2.2bc	68.6b	8.0bc

[a] Mean values of duplicate measurements in a column followed by the same letter are not significantly different at $P < 0.05$.

in stickiness when grown in Arkansas. Bengal showed similar hardness and stickiness for both crop years, but Medark increased in hardness and decreased in stickiness in 2003.

Conclusions

Genetics, environment, and crop year were all found to be very important in affecting the physical and chemical properties of medium-grain rice cultivars. When the 4 cultivars were grown in their native locations, the Arkansas rice cultivars were significantly wider in grain length distribution, higher in gelatinization temperature and enthalpy, pasting temperature, and peak viscosity, but lower in apparent amylose content, total setback, and final viscosity. Consequently, the Arkansas rice would require different processing conditions such as a higher process temperature or longer process time, and may produce rice products with different textural attributes when compared with the California cultivars. However, when all 4 cultivars were grown together in Arkansas, the differences in composition and gelatinization and thermal properties were significantly reduced. Nonetheless, differences in composition and properties still existed between the 2 crop years for the same rice cultivars and among the 4 rice cultivars grown together in Arkansas.

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