Genotype and Environmental Influences on Pasting Properties of Rice Flour

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ABSTRACT

Cereal Chem. 81(4):486–489

The pasting behavior of flour from several Australian rice (*Oryza sativa* L.) cultivars, differing in amylose content and grown in three different locations and three seasons, were determined using the Rapid Visco Analyser. Genotype, growth season, and growth location all affected the pasting behavior of rice flour. The amylose content of the same cultivar was significantly higher in the coolest growing season, resulting in RVA traces with lower peak viscosity and higher setback than samples with lower amylose content. When the same cultivar of rice was grown in different locations in the same season, there were no significant differences in the total starch, protein, lipid, and amylose content of the flour, but there were significant differences in the pasting behavior. This indicates that environmental as well as genetic factors influence the pasting behavior of rice flour. Flour from parboiled and quick-cooking rice did not paste and had low viscosities compared with unprocessed rice. Results from this study showed that the pasting behavior of rice flour was related to genotype and was influenced by environmental factors that brought about subtle changes in the grains that were not picked up by chemical analyses.

Knowledge of pasting properties is often an important indicator of the processing quality of foods and their constituents. For example, such knowledge can assist a processor in optimizing ingredient concentrations and temperature-pressure-shear limits to achieve a desired product. Pasting properties are often assessed from pasting curves obtained using a Rapid Visco Analyser (RVA), a heating and cooling viscometer that monitors the resistance of a sample to controlled shear. The pasting behavior of starch-water pastes is influenced by the chemical and physical properties of the sample, including the amount and type of starch, and the presence of lipids, proteins, and low molecular weight solutes.

The chemical and physical properties of starch samples are influenced by genotype and environmental conditions during plant growth. Geddes et al (1965) found that the apparent amylose content of potato tuber starch measured by iodine affinity varied from ≈13 to 20%, depending on temperature during the period of tuber growth. A higher temperature (30°C compared with 25°C) led to a decrease in apparent amylose content, which affected the pasting properties of the starch. The viscosity of the whole starch increased during development, and this change was associated with the amylose fraction (Geddes et al 1965). Two Australian rice cultivars, Amaroo and Illabong, grown at two different temperature regimes (38/21°C and 26/15°C for day/night) had different pasting profiles on the RVA (Lisle et al 2000; Fitzgerald et al 2003). For both cultivars, flour from grains grown at the higher temperatures had significantly larger peak and final viscosities than grains at for the cooler conditions.

In this study, we have examined the pasting behavior of rice flour from the cultivars Doongara, Langi, and Kyeema grown in three different locations and in three seasons. Parboiled and quick-cooking forms of Doongara were also assessed. Doongara is a high-amylose, long grain cultivar, with a firm cooked texture; Langi is a low-amylose, long grain cultivar with a soft texture; and Kyeema is a low-amylose, long grain fragrant rice. The pasting behavior of the flours was affected by genotype, growth season, and growth location.

MATERIALS AND METHODS

Samples

All rice samples were from SunRice Australia (Leeton NSW, Australia). Samples were obtained for rice grown in the 1998/1999, 1999/2000, and 2000/2001 seasons (Table I), and from several locations in southern New South Wales Murrumbidgee Irrigation Area (MIA), Coleambally Irrigation Area (CIA), and Murray Valley (MV) for the 1998/1999 season. All of these locations are in southwestern NSW, in the same climatic region, within 80 km of each other. Rice samples were ground using a hammer mill (Newport Scientific CM6000, Warriewood NSW, Australia). The resulting rice flour was brushed through a 250-μm sieve to ensure uniformity of particle size. The moisture content of each sample was determined in duplicate using the air-oven method (Approved Method 44-15A, AACC 2000). The total starch content and percent amylose of the rice flour samples were estimated using the concanavalin A binding method of Matheson and Welsh (1988). The protein and lipid contents were determined by Approved Methods 46-12 and 30-25 (AACC 2000), respectively.

The size of starch granules in situ in rice grains from different growth locations was measured from environmental scanning electron microscopic (ESEM) images of fractured rice grains (Dang and Copeland, *unpublished data*). Whole milled rice grains were manually snapped in two in the transverse direction. The fractured grain was mounted on an aluminum stub using double-sided adhesive tape, with the broken surface oriented upwards. Images were obtained without further specimen preparation using an environmental electron microscope (XL30, Philips, Denmark) with a GSE detector at a pressure of 1 torr and an accelerating voltage of 15 kV. The working distance was 10 mm.

RVA Analysis of Rice Samples

The pasting behavior of rice flour was tested on duplicate samples with a Newport Scientific RVA-4, using Approved Method 61-02 (AACC 2000). Sample weights were adjusted to correct for moisture content. Each flour sample (3.50 ± 0.01 g, based on 12% moisture) was added to 25.0 ± 0.1 g of water (adjusted to correct for sample moisture content) in a new test canister. The paddle was stirred vigorously to disperse the sample. The canister and paddle were inserted into the instrument, and the RVA trace was recorded over 12.5 min. Differences between samples in RVA parameters (peak viscosity, pasting temperature, trough viscosity,

TABLE I
Temperature and Yield Characteristics of Rice Growing Seasons[a]

Season	Avg Max Temp (°C)	Avg Min Temp (°C)	Avg Yield (tonnes/ha)
1998/1999	28.6	14.2	9.2
1999/2000	28.1	13.9	8.2
2000/2001	29.4	14.6	9.5

[a] Temperature data collected over the rice growing season from October to April; yield data provided by the Cooperative Research Centre for Sustainable Rice Production, NSW, Australia.

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Publication no. C-2004-0519-03R.

final viscosity, breakdown [peak viscosity minus trough viscosity], and setback from trough [final viscosity minus trough viscosity]) were assessed by analysis of variance.

RESULTS

Effect of Growth Season

Rice samples were obtained from three seasons, 1998/1999, 1999/2000, and 2000/2001, which differed in temperature and yield characteristics (Table I). Rainfall data were not included as rice is grown under irrigation. Significant differences were observed in the amylose content of Langi and Doongara between all three seasons, whereas for Kyeema, the amylose content in the 2000/2001 season was significantly lower than in the other two seasons. The amylose content for all three cultivars was highest in the 1999/2000 season (Table II), which was the coolest of the three seasons (Table I). The RVA traces of Langi, Doongara, and Kyeema flours from the different seasons showed the 1999/2000 season samples had the lowest peak viscosities and highest final viscosities and setback values (Table II).

Effect of Growth Location

Samples of rice were obtained for each of the three cultivars grown in the 1998/1999 season in different locations, all of which were in the same climatic region. There were no significant differences between total starch, amylose, protein, and lipid contents for the same cultivar from different growth locations (Table III). However, pasting curves and RVA parameters were significantly different for the same cultivar from different regions.

Effect of Genotype

To assess the effect of genotype more thoroughly, subsamples of grains from each cultivar from the three seasons were mixed before grinding, and the combined samples were used for RVA analyses. The combined sample of Doongara rice flour had an amylose content of 28.7% and gave RVA traces with lower peak viscosity and higher setback value compared with the combined flour samples of Langi and Kyeema, which had amylose contents of 18.7 and 19.3%, respectively. For the combined samples, all RVA parameters for Doongara rice were significantly different from those of Langi and Kyeema, which differed only in peak viscosity and breakdown values (Table IV).

Effect of Processing

The parboiled rice used in this study was a commercial product that had been prepared by steeping and draining brown Doongara rice. The drained grains were steamed to gelatinize the starch and the cooked grains are partially dried, milled, and then dried

TABLE II
Effect of Growth Season on Amylose Content and RVA Parameters of Rice Flour Samples[a]

Sample	Season	AM (%)	Viscosity (cP) Peak	Trough	Breakdown	Final	Setback	PT (°C)
Doongara	1998/1999	28.1 ± 0.3a	2,681d	1,418g	1,264j	3,055m	1,638p	79.9s
	1999/2000	29.2 ± 0.4b	2,740e	1,514h	1,226j	3,562n	2,049q	79.9s
	2000/2001	27.3 ± 0.4c	2,870f	1,349i	1,521k	3,167m	1,818r	77.9t
Langi	1998/1999	18.5 ± 0.4a	3,241d	1,720g	1,521i	3,366m	1,646q	83.1s
	1999/2000	19.1 ± 0.7b	3,068e	1,616h	1,453j	3,445n	1,829r	83.0s
	2000/2001	17.2 ± 0.6c	3,429f	1,724g	1,705k	3,264p	1,539q	83.1s
Kyeema	1998/1999	19.2 ± 0.4a	3,493c	1,834e	1,659f	3,486h	1,652k	82.9p
	1999/2000	19.4 ± 0.5a	3,406c	1,779e	1,627f	3,517i	1,738m	82.6p
	2000/2001	18.1 ± 0.2b	3,675d	1,752e	1,923g	3,335j	1,583n	82.2p

[a] All values are the average of duplicate measurments. AM, amylose content (%) of total starch; PT, pasting temperature (°C). RVA viscosity parameters were compared only within each cultivar for the three different seasons. For each cultivar and within each column, values followed by different letters indicate significant difference between the seasons (ANOVA).

TABLE III
Effect of Growth Location on RVA Parameters of Rice Flour Samples[a]

Sample	Location	AM (%)	Starch (%)	Granule Size (μm)	Protein (%)	Lipid (%)	PT (°C)
Doongara	MIA	28.2 ± 0.4	82.6 ± 1.1	4–10	6.2 ± 0.3	1.5 ± 0.1	77.4
	CIA	28.5 ± 0.5	83.9 ± 2.3	5–11	6.1 ± 0.2	1.6 ± 0.5	76.8
Langi	MIA	18.5 ± 0.1	84.1 ± 1.7	3–10	6.4 ± 0.4	1.4 ± 0.1	77.5
	CIA	18.3 ± 0.4	84.8 ± 0.5	4–10	6.3 ± 0.1	1.5 ± 0.4	77.5
	MV	18.0 ± 0.2	85.2 ± 2.9	4–9	6.4 ± 0.4	1.3 ± 0.1	78.2j
Kyeema	MIA	19.3 ± 0.4	85.2 ± 1.3	4–11	6.6 ± 0.4	1.6 ± 0.4	78.3j
	CIA	19.5 ± 0.3	86.5 ± 2.4	4–10	6.7 ± 0.3	1.5 ± 0.1	78.9j

[a] All values are the average of duplicate measurements. AM, amylose content (%) of total starch; PT, pasting temperature (°C). Granule size diameter (μm) from ESEM images (*n* = 50). Starch, protein, and lipid contents (%, dry weight). For each cultivar, values followed by different letters indicate significant difference between the growing locations (ANOVA). Values in the same column without letters were not significantly different.

TABLE III (continued)
Effect of Growth Location on RVA Parameters of Rice Flour Samples

Sample	Location	Viscosity (cP) Peak	Trough	Breakdown	Final	Setback
Doongara	MIA	2,271a	1,636	635	2,812c	1,176e
	CIA	2,384b	1,687	697	3,025d	1,338f
Langi	MIA	2,587	2,023b	564e	2,927	904
	CIA	2,549	1,743c	806f	2,674h	931
	MV	2,765a	1,833d	932g	2,868	1,035i
Kyeema	MIA	2,730a	2,019c	711e	2,979	960g
	CIA	2,806b	2,281d	525f	3,048	767h

further to a lower moisture content. The final product had a moisture content of 11%. This process results in an amber, glassy rice grain that resists water penetration, hence, the product requires a longer cooking time (>30 min) compared with white rice (20 min). Quick-cooking rice is produced in a process similar to that for parboiled rice, except that after milling, the partially dried rice is heated and puffed at high temperature to achieve a porous structure that gives rise to quick-cooking properties. The final product had a moisture content of 10% and required a much shorter time to cook (5 min) compared with white rice. Parboiled and quick-cooking rice flours did not paste in the RVA. Viscosities were low, and the characteristic starch peak and setback were not observed (Fig. 1).

DISCUSSION

As an aqueous dispersion of starch is heated and subjected to shear forces, the starch granules absorb water and swell, resulting in an increase in viscosity. Glucan polymers with lower molecular weight, particularly amylose molecules, begin to leach from the granules as they are disrupted under shear. The viscosity of the paste increases to a peak that corresponds to the point when the number of swollen, but still intact, starch granules is maximum. Peak viscosity is indicative of water-binding capacity and ease with which starch granules are disintegrated, and it is often correlated with final product quality (Thomas and Atwell 1999; Tran et al 2001).

The peak is followed by a breakdown in viscosity to a minimum (trough viscosity), as a result of granule rupture and leaching of granular components during exposure to high temperature and shear. The rate and degree of swelling and breakdown are characteristic of the starch source and are affected by other components in the paste, by modifications and processing of the starch, and by the temperature and shear force. For example, a cross-linked starch would tend to resist breakdown and have a higher trough viscosity compared with its non-cross-linked counterpart. For rice, a higher breakdown is considered to be an indicator of better palatability. In a study comparing the physicochemical properties of rice cultivars, the one with the highest breakdown value was rated the most palatable (Tran et al 2001).

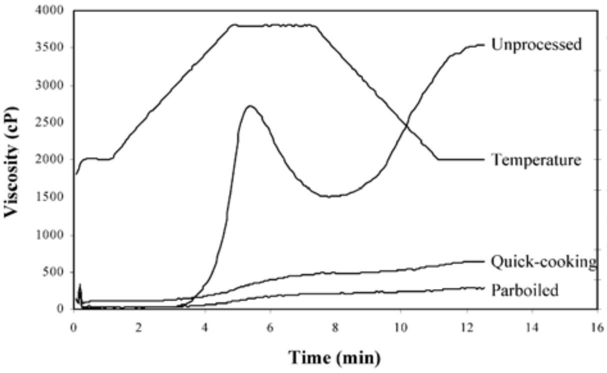

Fig. 1. Effect of processing on RVA pasting curves of Doongara rice.

As the gelatinized starch cools, retrogradation of amylose and amylopectin results in an increase in viscosity until a gel is formed at the end of the test. The increase in viscosity from the minimum to the final value is referred to as the setback and has been correlated with the texture of various end products. High setback is also an indication of the amount of swelling power of the sample and is usually related to the amylose content of the sample. The amylose component of the starch retrogrades more readily than amylopectin due to its essentially linear structure. The straight chain structure of amylose allows it to readily form hydrogen bonds between molecules, resulting in rigid gels (Martin and Smith 1995). Amylopectin molecules reassociate more slowly compared with amylose molecules.

Of the flours used in this study, Doongara had the highest amylose content, and its RVA trace showed a lower peak viscosity and a lower pasting temperature compared with Langi and Kyeema (Table II). Starch from Doongara, which had a higher amylose content, as expected had a higher setback value than the lower amylose starches of Langi and Kyeema. The pasting temperature and setback were not significantly different for Langi and Kyeema, which have similar amylose content (Table II). Shinde et al (2003), in studying the pasting properties of flour from two wheat cultivars, also found that final viscosity was higher for the flour with higher apparent amylose content. Flour pastes from parboiled and quick-cooking rice had little viscoelasticity (Fig. 1) due to the disruption of crystalline structure of native starch granules during processing.

The concanavalin A method of Matheson and Welsh (1988) was used to determine amylose content of all samples used in this study. This method, which separates amylose from amylopectin, was shown with a range of rice samples to give slightly higher values for amylose content than potentiometric titration with iodine (Matheson and Welsh 1988).

Doongara and Langi rice grown in the cooler 1999/2000 season had slightly higher but significantly different amylose content than rice grown in the warmer seasons. The lower peak viscosities and higher setback values observed in the RVA traces of the respective samples from the 1999/2000 season indicates the high sensitivity of the viscoelastic properties to subtle changes in the composition of the flour (Table II).

The pasting curves and RVA parameters were significantly different for the same cultivar grown in different but nearby locations in the same season (Table III). The peak viscosity and setback values were significantly different for flour of Doongara and Kyeema rice grown in the MIA compared with CIA. For Langi, flour obtained from rice grown in the MV differed from rice from the MIA and CIA with respect to these properties. The amylose content was not affected by the growth location, indicating that the differences in peak viscosity and setback values were related to other factors. Properties such as total starch, protein, and lipid content, and size of starch granules are unlikely to have caused the differences in RVA traces because these did not vary between growth locations (Table III). Nor were differences in moisture content of samples from the various locations responsible for differences in viscosity values because the sample and water weights were carefully adjusted to take account of sample moisture content.

TABLE IV
Effect of Genotype on Amylose Content and RVA Parameters of Rice Flour Samples[a]

		Viscosity (cP)					
Sample	**AM (%)**	**Peak**	**Trough**	**Breakdown**	**Final**	**Setback**	**PT (°C)**
Doongara	28.7 ± 0.3a	2,720c	1,448f	1,397h	3,280k	1,858n	78.3q
Langi	18.7 ± 0.2b	3,259d	1,701g	1,595i	3,390m	1,688p	82.9r
Kyeema	19.3 ± 0.2b	3,543e	1,798g	1,768j	3,460m	1,655p	82.4r

[a] Subsamples from all three seasons were mixed to obtain a combined sample. All values are the average of duplicate measurements. AM amylose content (%) of total starch; PT, pasting temperature (°C). Each RVA parameter was compared between the cultivars by ANOVA. Within each column, values followed by different letters indicate significant difference. Doongara differed from Langi and Kyeema in all of the parameters; whereas Langi and Kyeema differed from each other only in peak viscosity and breakdown ($P < 0.01$).

We propose that the difference in viscosities may be a result of differences in fine structure of amylose or amylopectin in the samples. Klucinec and Thompson (2002) found that the development of a starch gel is affected by both the nature of amylopectin and the amylose-to-amylopectin ratio of the gel. Localized abiotic and biotic factors at the three growth locations may have induced subtle but significant differences in the fine structure of amylose and amylopectin, which affected their water-absorbing capacity, and in turn, the viscoelastic properties of starch pastes. Such factors could influence the activity of some of the multitude of enzymes that act in concert in the biosynthesis of starch molecules. The activities of enzymes of starch synthesis in rice grains are sensitive to temperature during the early stages of grain filling, which can influence the structure of the starch, and in turn, the cooking quality of the rice (Martin and Smith 1995; Inouchi et al 2000; Lisle et al 2000). Amylopectin from rice plants grown at 25°C had increased amounts of short chains and decreased amounts of long chains compared with amylopectin from plants grown at 30°C, and it was concluded that the temperature between five and 10 days after pollination strongly influenced the structural characteristics of endosperm starch of rice plants (Inouchi et al 2000). The availability of nitrogen during plant growth also influences pasting behavior of rice starch. Fitzgerald et al (2003) found that the setback, peak, and final viscosities decreased as the amount of nitrogen applied during plant growth was increased. Nitrogen nutrition did not affect the amylose content or the amylopectin structure of the rice, but it did affect the viscosity of the flour.

The results suggest that the environment affected the fine structure of amylose and amylopectin, which was not picked up by chemical analysis of major constituents. Analyzing starch, protein, and lipid may be a good means of predicting behavior. However, subtle differences may not be observed by chemical and microscopic analyses and may require actual pasting analyses to confirm the behavior of the rice and starch in food systems.

In conclusion, this study has shown that the pasting behavior of rice flour was related to genotype and was influenced by environmental factors that brought about subtle changes in the grains that were not evident from analyses of total starch, protein and lipid content, and the amylose-to-amylopectin ratio.

ACKNOWLEDGMENTS

Jennifer Dang was the recipient of a scholarship from the Cooperative Research Centre for Sustainable Rice Production. We wish to thank Newport Scientific for the use of the mill and for helpful advice in interpreting RVA curves.

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[Received May 19, 2003. Accepted September 18, 2003.]