# Amylopectin-Staling of Cooked Nonwaxy Milled Rices and Starch Gels

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## ABSTRACT

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Varietal differences in Instron hardness testing of cooked rice after amylopectin-staling was demonstrated among nonwaxy rices with similar amylose content and gelatinization temperature (GT). In addition, intermediate- to high-GT rices showed greater amylopectin-staling of cooked rice than did low-GT rices of similar amylose contents. Storage modulus of 25% starch gels measured by small-strain oscillatory shear also showed greater increase during staling for 17.5 hr at 8°C in intermediate- to high-GT starches than in low-GT starches. The data are consistent with the lower glycemic index and higher resistant starch in cooked intermediate- to high-GT rice than in low-GT rice.

Hardness measurements on freshly cooked, milled rices are not very sensitive indexes for differentiating rices of similar starch properties (del Mundo et al 1989). Instron hardness, using the Ottawa texture-measuring system extrusion cell, gave significant correlation with the sensory evaluation of hardness of freshly cooked rice, but, again, it could not differentiate among rices of similar starch properties (IRRI 1991). Similar results were obtained with the rheolograph micro on pairs of freshly cooked rices (IRRI 1991). These pairs, however, were differentiated with the Tensipresser multibiting test using an aqueous slurry of cooked rice (Tsuji and Nakatani 1990).

Earlier studies showed that amylopectin contributed more to differences in gel viscosity in $0.2N$ KOH than amylose did, particularly in high-amylose rices (Juliano and Perdon 1975). Studies using cooked waxy rices showed that storage at 2–4°C for four days resulted in greater varietal differences in hardness of cooked rice than in freshly cooked rice cake (Antonio et al 1975).

Biliaderis and Zawistowski (1990) studied the time-dependent changes in network properties of aqueous starch gels by using small-strain oscillatory shear measurements (0.2 Hz and $<2\%$ strain) and differential scanning calorimetry. The storage modulus ($G'$) time profiles revealed a two-phase gelation process: 1) an initial rapid rise due to amylose, and then 2) a phase of slower $G'$ development from amylopectin recrystallization (Biliaderis and Tonogai 1991). The $G'$ of freshly prepared rice starch gels showed a linear relationship with amylose content of the starch (IRRI 1991).

Accelerated amylopectin-staling of starch gels (including those of cooked rice) by cooling >4 hr at 2–4°C and then heating 4 hr at 42°C allowed rapid study of gel-staling (Slade et al 1987). This article reports our studies to demonstrate varietal differences among rices of similar apparent amylose contents or gelatinization temperature (GT) in: 1) amylopectin-staling of cooked, nonwaxy rice as indexed by Instron hardness, and 2) 25% nonwaxy rice starch gels as indexed by $G'$. Preliminary results on nonwaxy and waxy cooked rices were presented earlier (Juliano et al 1991).

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## MATERIALS AND METHODS

Rice samples were obtained from the farm at the International Rice Research Institute, Los Baños, Laguna, Philippines, with the following exceptions: Akibare and Milyang 23 from the Yeongnam Crops Experiment Station, Milyang, Korea; Century Patna 231 and Toro 2 from the USDA Rice Research Southern Region, Beaumont, TX; and seven rices from the California Cooperative Rice Research Foundation, Biggs, CA. The rice samples were aged three to four months before dehulling with a Satake THU35 dehuller and milling with a Satake TM-05 pearler.

IR62, IR72, and IR36-based amylose extender (*ae*) mutant samples were parboiled (Biswas and Juliano 1988) by soaking rough rice for 8 hr in 60°C water and parboiling with steam in a Hirayama model HA-24 autoclave for 30 min at 100°C or for 10 min at 120°C (1.0 kg/cm$^2$). The parboiled samples were cooled and dried in trays at 20–25°C to 12–13% moisture and then dehulled and milled in a Satake TM-05 pearler with a 5330 abrasive disk at 1,730 rpm to ~8% bran-polish removal.

Alkali spreading value, an index of starch gelatinization temperature, was measured in duplicate on six grains of milled rice soaked in 1.7% KOH for 23 hr at 30°C (Little et al 1958). Milled rice was ground with a Udy cyclone mill with a 60-mesh sieve. The flour was analyzed for apparent amylose content (Juliano et al 1981).

Milled rice (20 g) was placed in 150-ml beakers, and a predetermined amount of water was added based on amylose content: 34 ml for low amylose, 38 ml for intermediate amylose, and 42 ml for high amylose. The rice was cooked, four beakers at a time, for 20 min in Toshiba RC4B automatic electric cookers with excess (200 ml) water in the outer pot (Perez and Juliano 1979). The cooker was left undisturbed for at least 10 min after cooking. The cooked rice was then drained and cooled in plastic bags. Duplicate samples (17 g) of cooked rice were placed in the Ottawa texture-measuring system extrusion cell (10-cm$^2$) and pressed with a 145-g weight for 1 min before extrusion. Hardness was the maximum force (kilograms per 7 cm$^2$) needed to extrude the rice through the cell's perforated base at the crosshead speed of 10 cm/min. Hardness was also measured at the same chart speed using the 0–50-kg load cell. Milled rice (20 g) was similarly cooked in 150-ml beakers with 40 ml of water, and the cooked rice hardness was determined as described above.

Accelerated staling was undertaken by storing cooked rice in plastic bags overnight at 2–4°C and reheating for 4 hr in a 42°C forced-draft oven with a water reservoir inside to maintain 65–75% rh. A water bath at 42°C was not effective for the heating phase of the staling. Reheating of staled cooked rice was done at 100°C for 3 min, followed by 10 min of standing. Hardness was measured for duplicate samples of staled and staled-reheated cooked rices. Data were subjected to analysis of variance and Duncan's multiple range test.

Rapid Visco Analyzer (RVA) (Newport Scientific Instruments, Narrabeen, N. S. W., Australia) curves were obtained in duplicate on 3 g of rice flour (12% moisture) in 25 ml of water that was held for 1.5 min at 50°C, heated to 95°C at 12°C/min, held for 2 min at 95°C, and then cooled to 30°C at 12°C/min (Blakeney et al 1991). Viscosity values of interest, given in stirring number units (1 SNU = 10 cPs), are peak viscosity, final viscosity at 95°C, and viscosity cooled to 50 and 30°C. Breakdown is the decrease in viscosity during heating at 95°C relative to peak viscosity. Setback is viscosity cooled to 50 or 30°C minus peak viscosity. Consistency is viscosity cooled to 50 or 30°C minus final viscosity at 95°C. Standard deviation of mean viscosity was calculated.

Starch was prepared from selected milled or brown rice by removing protein from wet-milled flour in a Waring Blendor and using sodium dodecyl benzene sulfonate extraction or alkaline protease treatment (Maniñgat and Juliano 1980). The starches were prepared as gels by heating starch slurries of the appropriate starch concentration (25%) in a hermetically sealed, stainless steel container (80-mm i.d. × 1-mm thick) (Biliaderis and Tonogai 1991). The disk was immersed in a boiling water bath (98–100°C, 15 min) and subsequently quench-cooled in a water bath at 25°C (15 min). Starches producing gels prone to mechanical damage by removal from the container, including low-amylose and half of the intermediate-amylose starches, were formed in a hermetically sealed, stainless steel cylinder (12.5-mm i.d. × 33-mm length) following the same heating and quench-cool regimes. Gel disks (30-mm diameter) were immediately cut to fit the parallel-plate geometry of a rheometer.

The mechanical properties of the starch gels were monitored by small-amplitude oscillatory testing using a Bohlin VOR rheometer (Bohlin Rheologi, Edison, NJ) operated with parallel-plate geometry of 30-mm diameter and a torque element of 93.2 g·cm. Measurements were conducted at 25°C in a frequency range of 0.1–20.0 Hz. The kinetic aspects of gel structure development (storage at 8°C) of 25% (w/w) starch gels were probed at 0.2 Hz and <1.4% strain. Data were collected at 30-min intervals for 17.5 hr. In these experiments, the sample was covered with a thin layer of paraffin oil to prevent water loss due to evaporation. The $G'$ was the dynamic rheological parameter used to evaluate the gels.

Apparent amylose content (Juliano et al 1981) and photometric final GT (Juliano and Perdon 1975) of rice starch were determined in duplicate. Nonstarch and starch lipids were determined in duplicate for the starch samples according to Maniñgat and Juliano (1980).

## RESULTS AND DISCUSSION

### Amylopectin-Staling of Cooked Rice

*Adjusted water-rice ratio.* Analysis of variance showed that cooked-rice Instron hardness was significantly affected by replication, treatment, variety, and treatment × variety. The South Korean low-amylose, low-GT pair (Akibare and Milyang 23) had hardness values similar to that of freshly cooked rice (Table I). However, upon amylopectin-staling, Milyang 23 (indica-japonica) was harder than Akibare (japonica). The difference was removed by reheating the staled cooked rice. The staled-reheated cooked rices were harder than freshly cooked rice, suggesting that the amylopectin-staling was not completely reversible.

The long-grain, low-amylose pair differing in GT (Century Patna 231 and Toro 2) also had hardness values similar to those of freshly cooked rice (Table I). Amylopectin-staling increased hardness more in the intermediate- to high-GT Century Patna 231 than in the low-GT Toro 2. However, reheating the staled cooked rice restored hardness values that were similar to that of the freshly cooked rice, probably because they have lower amylose than that of the South Korean rices.

Among intermediate-amylose rices, the low-GT IR48 was differentiated from the intermediate-GT C4-63G and IR64 by the hardness of its freshly cooked rice (Table I). Amylopectin-staling again increased cooked rice hardness more in the intermediate-GT rices than in the low-GT rice. Reheating softened the staled cooked rice of the intermediate-GT rices, but they were still harder than freshly cooked rice.

Among the three high-amylose rices, the ranking of freshly cooked rice hardness (Table I) conformed with gel-consistency values: soft for IR62, medium for IR36, and hard for IR74. Amylopectin-staling increased hardness, particularly for IR62. Reheating of staled cooked rice softened IR62, but not IR36 and IR74. The staled-reheated rices were harder than freshly cooked rice.

The IR36-based *ae* mutant 2064 had a hardness value similar to those of IR62 and IR36 in freshly cooked rice, but it required more water to cook. Amylopectin-staling made the mutant grain harder than IR74 and other high-amylose samples (Table I). The staled-reheated mutant rice was softer than the corresponding high-amylose samples, including IR62 and IR36.

Parboiling increased the hardness of freshly cooked IR62 (intermediate GT), IR74 (low GT), and IR36-based *ae* mutant rices, but it eliminated amylopectin-staling (Table I), except for the *ae* mutant. Reheating had no significant effect on the hardness

TABLE I
Effect of Accelerated Staling of Amylopectin on Instron Hardness of Selected Cooked Nonwaxy and Parboiled Nonwaxy Rices

| Sample | Amylose (% db) | Alkali Spreading Value | Water-Rice Ratio | Instron Cooked Rice Hardness[a] (kg/7 cm$^2$) Freshly Cooked | Staled | Staled-Reheated |
|---|---|---|---|---|---|---|
| Raw Rices | | | | | | |
| Akibare | 18.7 | 7.0 | 1.7 | 4.8 ± 0.3 a | 5.8 ± 0.2 b | 5.5 ± 0.3 b |
| Milyang 23 | 18.8 | 7.0 | 1.7 | 4.6 ± 0.1 a | 6.4 ± 0.3 c | 5.6 ± 0.1 b |
| CP 231 | 15.4 | 3.6 | 1.7 | 5.0 ± 0.6 a | 9.5 ± 1.1 b | 4.8 ± 0.5 a |
| Toro 2 | 16.6 | 7.0 | 1.7 | 5.2 ± 0.6 a | 7.2 ± 0.4 b | 5.4 ± 0.5 a |
| C4-63G | 20.4 | 4.6 | 1.9 | 4.9 ± 0.1 a | 9.8 ± 0.4 c | 6.0 ± 0.1 b |
| IR64 | 24.4 | 4.8 | 1.9 | 5.6 ± 0.9 a | 10.5 ± 0.4 c | 6.7 ± 0.4 b |
| IR48 | 20.9 | 7.0 | 1.9 | 7.0 ± 0.5 a | 8.7 ± 0.7 b | 9.0 ± 0.1 b |
| IR62 | 26.6 | 5.2 | 2.1 | 5.4 ± 0.3 a | 9.5 ± 0.1 c | 8.6 ± 0.5 b |
| IR36 | 26.1 | 5.9 | 2.1 | 6.6 ± 0.1 a | 8.6 ± 0.8 b | 8.8 ± 0.5 b |
| IR74 | 28.4 | 7.0 | 2.1 | 6.9 ± 0.1 a | 9.6 ± 0.1 b | 9.6 ± 0.1 b |
| IR36 *ae* | 36.2 | 6.8 | 2.65 | 6.1 ± 0.1 a | 13.7 ± 0.7 c | 8.4 ± 0.0 b |
| Parboiled rices[b] | | | | | | |
| IR62 (100°C) | 26.5 | 5.5 | 2.1 | 9.3 ± 1.4 a | 12.0 ± 3.5 b | 8.8 ± 3.0 a |
| IR62 (120°C) | 26.8 | 6.0 | 2.1 | 10.8 ± 2.3 a | 12.6 ± 3.1 a | 13.1 ± 0.8 a |
| IR74 (100°C) | 28.2 | 7.0 | 2.1 | 11.9 ± 1.9 a | 13.0 ± 1.9 a | 13.5 ± 2.3 a |
| IR74 (120°C) | 28.8 | 7.0 | 2.1 | 11.0 ± 2.6 a | 11.3 ± 2.5 a | 10.1 ± 1.2 a |
| IR36 *ae* (100°C) | 35.5 | 5.2 | 2.0[c] | 11.4 ± 0.7 a | 21.6 ± 1.0 b | 12.4 ± 1.7 a |

[a] Mean ± standard deviation ($n = 2$). Staling by >4 hr at 2–4°C and 4 hr at 42°C at 65–75% rh. Reheating by 3 min at 100°C and 10 min standing. Values in the same line followed by the same letter are not statistically different at $P = 0.05$ by Duncan's multiple range test. LSD (0.05) = 0.57 kg/7 cm$^2$.

[b] Parboiled by steaming steeped rough rice at 100°C for 30 min or at 120°C for 10 min.

[c] Based on actual water absorbed during cooking from weight of excess water after cooking at water-rice ratio of 2.65.

of staled cooked rice (except for the *ae* mutant). The irreversible fraction of staled amylopectin probably involves amylose because this fraction increased with amylose content of cooked rice (except for the *ae* mutant).

*Fixed water-rice ratio.* Similar results were obtained for the nine nonwaxy rices cooked at a constant water-rice ratio of 2.0 (Table II); however, hardness values were lower, particularly for low- and intermediate-amylose samples. Analysis of variance showed cooked rice hardness was significantly affected by replication, treatment, variety, and treatment × variety. Toro 2 had harder freshly cooked rice than the other three low-amylose samples. Amylopectin-staling made Century Patna 231 the hardest, but it completely resoftened on reheating to the value of freshly cooked grain, as did Toro.

Among the intermediate-amylose samples, C4-63G was softest when freshly cooked, followed by IR64, and then IR48 (Table II). Amylopectin-staling hardened C4-63G and IR64 more than IR48, and only C4-63G and IR64 partially resoftened on reheating.

Among freshly cooked high-amylose rices, IR62 was softest and IR74 the hardest (Table II). The intermediate-GT rices showed more amylopectin-staling on storage than did the low-GT IR74. IR74 even increased in hardness on reheating. Unlike an earlier study using a similar ratio of 2.1 (Table I), IR74 had harder values due, in part, to the lower water level used in the current study (2.0 vs. 2.1). These studies verified the critical role of water-rice ratio in affecting cooked rice hardness (Juliano and Perez 1983).

## RVA Viscosity Values of Milled Rice

The RVA viscosity values of the low-amylose Korean samples showed higher pasting viscosity for Milyang 23 (indica-japonica) than for Akibare (japonica). This resulted in lower breakdown and higher setback at 50°C and in lower consistency at 30°C for Milyang 23 (Table III). Indica-japonica Korean rices were reported earlier as having higher amylograph viscosity than japonica Korean rices (IRRI 1984). The differences between Century Patna 231 and Toro 2 were few, except for the higher consistency of Toro 2 at 50 and 30°C.

Among intermediate-amylose rices, IR64 had the highest peak viscosity, and IR48 had the highest cooled-paste viscosity (Table III). C4-63G and IR64 had higher breakdown than IR48 did, resulting in higher setback at both 50 and 30°C. With a higher peak viscosity than that of IR62, IR74 had low breakdown and lower setback, both at 50 and 30°C. The RVA viscosity of IR36 was closer to that of IR74 than to that of IR62; IR36 also had higher consistency than did IR62 and IR74 at 50 and 30°C .

The *ae* mutant of IR36 had the lowest RVA viscosity among the samples, and it did not give a distinct peak nor breakdown (Table III). Thus, its setback and consistency at 50 and 30°C were also lower than those of high-amylose rices.

TABLE II
Effect of Accelerated Staling of Amylopectin on Instron Hardness of Selected Nonwaxy Milled Rice Cooked at a Constant Water-Rice Ratio of 2.0

| Sample | Instron Cooked Rice Hardness,[a] kg/7 cm$^2$ Freshly Cooked | Staled | Staled Reheated |
|---|---|---|---|
| Akibare | 3.0 ± 0.1 a | 4.0 ± 0.2 b | 3.7 ± 0.1 b |
| Milyang 23 | 3.1 ± 0.1 a | 4.5 ± 0.3 b | 3.4 ± 0.0 a |
| CP 231 | 3.2 ± 0.1 a | 6.6 ± 0.0 b | 3.6 ± 0.1 a |
| Toro 2 | 3.7 ± 0.1 a | 4.3 ± 0.1 b | 3.7 ± 0.0 a |
| C4-63G | 4.1 ± 0.0 a | 7.3 ± 0.1 c | 4.8 ± 0.0 b |
| IR64 | 4.8 ± 0.2 a | 8.8 ± 0.1 c | 5.6 ± 0.0 b |
| IR48 | 5.4 ± 0.2 a | 6.4 ± 0.2 b | 6.2 ± 0.1 b |
| IR62 | 5.6 ± 0.2 a | 8.4 ± 0.4 c | 7.6 ± 0.0 b |
| IR36 | 6.4 ± 0.4 a | 9.5 ± 0.4 c | 8.5 ± 0.4 b |
| IR74 | 7.9 ± 0.1 a | 9.8 ± 0.4 b | 10.6 ± 0.7 c |

[a] Mean ± standard deviation ($n = 2$). Staling by >4 hr at 2–4°C and 4 hr at 42°C at 65–75% rh. Reheating by 3 min at 100°C and 10 min standing. Means in the same line followed by the same letter are not statistically different at $P = 0.05$ by Duncan's multiple range test. LSD (0.05) = 0.51 kg/7 cm$^2$.

## Correlation Coefficients Among Properties

The correlation coefficients among the 10 nonwaxy rices, excluding the *ae* mutant, showed that hardness of freshly cooked rice with a constant water-rice ratio of 2.0 correlated better with the RVA viscosity than did hardness of freshly cooked rice with adjusted water-rice ratio (Table IV). Hardness of staled rice correlated less with RVA breakdown, setback, and consistency than did hardness of freshly cooked rice. RVA breakdown, setback, and consistency were significant only for rices at a fixed water-rice ratio of 2.0. Correlation coefficients between hardness of staled cooked rice and RVA values were all significant, except for RVA peak viscosity. The hardness of staled-reheated cooked rice had higher correlation coefficients with RVA viscosity than did the hardness of freshly cooked or staled cooked rice. Slightly better correlations were obtained with RVA setback and consistency at 30°C than at 50°C.

A related study confirmed varietal differences in amylopectin-staling among rices with similar low-amylose contents. Amylopectin-staling of seven California-grown, low-GT, low-amylose rices (16.0–19.6%) showed freshly cooked rice Instron hardness of 4.9–6.1 kg/7 cm$^2$. Koshihikari (17.8% amylose) was the softest, and M-202 (16.0% amylose) was the hardest. Amylopectin-staling increased the hardness of cooked rice, which was 6.8 ± 0.1 for Koshihikari and 7.7–8.7 kg/7 cm$^2$ for the six others. Koshihikari also had the highest RVA peak viscosity (300 vs. 252–295 SNU), highest breakdown (136 vs. 88–126 SNU), and lowest setback,

**TABLE III**
**Rapid Visco Analyzer Viscosities of Nonwaxy Rice Flours[a,b]**

| Sample | Peak Viscosity | Breakdown | Setback at 50°C | Consistency at 50°C | Setback at 30°C | Consistency at 30°C |
|---|---|---|---|---|---|---|
| Akibare | 246 ± 1 | 96 | −6 | 89 | 38 | 134 |
| Milyang 23 | 264 ± 9 | 78 | 10 | 88 | 38 | 116 |
| CP 231 | 282 ± 2 | 104 | −24 | 80 | 8 | 112 |
| Toro 2 | 290 ± 11 | 112 | −22 | 91 | 10 | 122 |
| C4-63G | 228 ± 10 | 90 | 18 | 106 | 58 | 148 |
| IR64 | 252 ± 1 | 102 | −20 | 81 | 38 | 140 |
| IR48 | 232 ± 4 | 46 | 35 | 82 | 104 | 150 |
| IR62 | 198 ± 2 | 58 | 92 | 150 | 181 | 238 |
| IR36 | 260 ± 4 | 52 | 124 | 176 | 198 | 251 |
| IR74 | 298 ± 42 | 28 | 123 | 150 | 211 | 238 |
| IR36 *ae* | 94 ± 1 | 2 | 52 | 54 | 88 | 90 |

[a] Rice flour (3 g) in 25 ml of water, heated at 50°C for 1.5 min. heated to 95°C at 12°C/min. 2 min at 95°C, and cooled to 30°C at 12°C/min. Peak viscosity is mean ± SD ($n = 2$).

[b] Viscosity values given in stirring number units (1 SNU = 10 cPs).

**TABLE IV**
**Linear Correlation Coefficient[a] Among Properties of 10 Nonwaxy Rices Differing in Starch Properties**

| | Cooked Rice Hardness (kg/7 cm$^2$) | | | | | Rapid Visco Analyzer[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Adjusted Water | | | Constant Water | | | | Setback | | Consistency | |
| Property | Staled | Staled-Reheated | Fresh | Staled | Staled-Reheated | Peak | Breakdown | 50°C | 30°C | 50°C | 30°C |
| Adjusted water | | | | | | | | | | | |
| Hardness, fresh | 0.51 | 0.88** | 0.85** | 0.68* | 0.77** | −0.02 | −0.75* | 0.60 | 0.65* | 0.41 | 0.57 |
| Hardness, staled | | 0.52 | 0.54 | 0.84** | 0.51 | −0.19 | −0.32 | 0.32 | 0.35 | 0.26 | 0.34 |
| Hardness, reheated | | | 0.93** | 0.77** | 0.91** | −0.29 | −0.95** | 0.85** | 0.89** | 0.68* | 0.81** |
| Constant water | | | | | | | | | | | |
| Hardness, fresh | | | | 0.84* | 0.99** | −0.18 | −0.88** | 0.89** | 0.92** | 0.79** | 0.89** |
| Hardness, staled | | | | | 0.85** | −0.23 | −0.64* | 0.72* | 0.75* | 0.69* | 0.76* |
| Hardness, reheated | | | | | | −0.23 | −0.89** | 0.93** | 0.96** | 0.85** | 0.95** |
| RVA peak[c] | | | | | | | 0.40 | −0.31 | −0.35 | −0.20 | −0.30 |
| RVA breakdown | | | | | | | | −0.90** | −0.92** | −0.72* | −0.84** |
| RVA setback 50°C | | | | | | | | | 0.99** | 0.95** | 0.98** |
| RVA setback 30°C | | | | | | | | | | 0.92** | 0.98** |
| RVA consistency 50°C | | | | | | | | | | | 0.96** |

[a] ** = $P < 0.01$, * = $0.05 > P > 0.01$.

[b] Viscosity values given in stirring number units (1 SNU = 10 cPs).

[c] Rapid Visco Analyzer.

**TABLE V**
**Lipids and Storage Modulus ($G'$) of 25% Aqueous Starch Gels at 8°C as a Function of Time and Variety[a]**

| | | | | Lipids, % | | $G'$ (kPa) at $G'_f/G'_0$[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety | Preparation Method | Amylose (% db) | Final Gelatinization Temperature (°C) | Starch | Total | 0 hr | 5 hr | 10 hr | 15 hr | 17.5 hr | $G'_0$ |
| IR37307-8-ch | Protease | 9.8 | 69 | 0.52 | 0.80 | 0.37 | 0.38 | 0.39 | 0.40 | 0.41 | 1.11 |
| IR24 | DoBS[c] | 19.5 | 66 | 0.43 | 0.58 | 0.41 | 0.44 | 0.46 | 0.49 | 0.50 | 1.20 |
| CP 231 | DoBS | 17.4 | 76 | 0.07 | 0.29 | 0.24 | 0.27 | 0.32 | 0.42 | 0.49 | 2.04 |
| Akibare | DoBS | 23.6 | 68 | 0.51 | 0.72 | 0.58 | 0.65 | 0.70 | 0.73 | 0.75 | 1.29 |
| Milyang 23 | DoBs | 23.4 | 66.5 | 0.57 | 0.81 | 0.69 | 0.93 | 1.04 | 1.17 | 1.23 | 1.78 |
| IR48 (a)[d] | DoBS | 27.3 | 64.5 | 0.56 | 0.84 | 1.30 | 1.74 | 1.89 | 2.02 | 2.08 | 1.60 |
| IR64 (b) | Protease | 27.4 | 74.5 | 0.96 | 1.16 | 2.08 | 5.60 | 13.2 | 21.9 | 25.3 | 12.2 |
| C4-63G (b) | Protease | 26.6 | 76.5 | 0.83 | 1.05 | 1.10 | 1.47 | 1.99 | 2.78 | 3.26 | 2.96 |
| Arlesienne | DoBS | 29.2 | 62 | 0.53 | 0.70 | 2.35 | 3.13 | 3.46 | 3.77 | 3.88 | 1.65 |
| IR8 (a) | DoBS | 31.6 | 63 | 0.38 | 0.56 | 6.46 | 9.46 | 12.0 | 13.4 | 14.4 | 2.23 |
| IR62 | Protease | 34.6 | 74 | 0.62 | 0.87 | 2.19 | 6.88 | 12.8 | 19.5 | 23.1 | 10.5 |
| IR32 | Protease | 32.0 | 74 | 0.75 | 1.05 | 1.94 | 5.43 | 9.50 | 13.7 | 15.6 | 8.04 |

[a] Data from Juliano et al (1991), except for Century Patna 231, IR48, IR62, and IR32 ($n = 2$).

[b] Ratio of $G'$ at 17.5 and 0 hr.

[c] Sodium dodecyl benzene sulfonate.

[d] Letters in parenthesis indicate different batches of sample.

both at 50°C (−74 vs. −60 to −25 SNU) and 30°C (−32 vs. −20 to 22 SNU).

### Storage Modulus of 25% Starch Gels

Apparent amylose contents of rice starch (Table V) were higher than those of milled rice (Table I) due to protein removal during starch preparation. Initial G′ of 25% starch gels was lowest for the low-amylose rices and highest for low-GT, high-amylose IR8 (Table V). During storage at 8°C, considerable differences in G′ increases were noted among the samples. Low-GT samples showed a $G'_f/G'_0$ ratio of 1.11–2.23 where f = 17.5 hr and 0 = 0 hr of storage. Intermediate- to high-GT samples had a $G'_f/G'_0$ ratio of 2.04–12.2. IR64 and IR62 had the highest G′ at 17.5 hr of storage; IR37307-8-ch and IR24 had the lowest.

Among the low-amylose starches, Milyang 23 showed higher G′ than Akibare at 0 time and after amylopectin-staling; the difference was enhanced by gel storage (Table V). This confirms the Instron hardness data on cooked milled rice (Tables I and II). IR37307-8-ch and IR24 had the least amylopectin-staling. By contrast, the starch of high-GT Century Patna 231 had the lowest initial G′, but it had the highest percentage of increase among starches of low-amylose rices.

Among the four intermediate-amylose samples, the japonica Arlesienne (with the highest amylose content) had the highest initial G′ (Table V). IR64 (intermediate GT) showed the fastest increase in G′ when the starch gels were stored; Arlesienne and IR48 (low GT) showed the slowest. C4-63G (intermediate GT) showed intermediate increase in G′, based on the $G'_f/G'_0$ ratio. This is consistent with the fact that the texture of staled, cooked, milled rice was softer than that of IR64 (Tables I and II).

IR8 (low GT) had the highest initial G′ among the three high-amylose starch gels. Both IR62 and IR32 (intermediate GT, soft gel) increased in G′ faster than IR8 did during storage at 8°C (Table V).

The effect of GT on G′ during gel-staling (Table V) confirms the Instron hardness data for amylopectin-staling (Tables I and II). It would be worth studying the contribution of the molecular properties of rice amylopectin to the differences in rate and extent of amylopectin-staling of cooked rice starch.

The role of starch lipids on amylopectin-staling is still not well understood. During staling, starch lipids tie up the amylose, reducing the increase in G′. Although starch lipids were highest in intermediate-GT, intermediate-amylose IR64 and C4-63G starches, and higher in IR62 and IR32 than in IR8 among high-amylose rices, they were not high in high-GT Century Patna 231 when compared with other low-GT, low-amylose starches. IR36 *ae* mutant (48.4% amylose) had only 0.75% starch lipids. However, cooked, low-GT rice starch has amylose-lipid complex I; cooked intermediate- to high-GT rice starch produces the more crystalline, more amylase-resistant amylose-lipid complex II (Eggum et al, *in press*).

The similar effects of GT on amylopectin-staling in cooked milled rice (as measured by Instron hardness) (Tables I and II) and in 25% starch gels (as measured by G′) (Table V) are also reflected in the glycemic index and the in vivo and in vitro resistant starch of cooked milled rice. Among high-amylose rices, intermediate-GT, soft-gel IR62 had a lower glycemic index than that of low-GT, hard-gel IR42; intermediate-GT, medium-gel IR36 had values in between them (Panlasigui et al 1991). In addition, resistant starch was higher in cooked, intermediate-GT, intermediate-amylose IR64 and high-amylose IR62 than it was in low-GT, high-amylose IR74 in tests using growing rats with and without 0.7% Nebacitin to suppress hind-gut fermentation (Eggum et al, *in press*).

## CONCLUSIONS

This study demonstrated the varietal differences in amylopectin-staling among nonwaxy rices of similar amylose contents, regardless of GT, as indexed by Instron hardness in cooked rice and by G′ in starch gels. Samples that remained soft during aging were preferred by consumers. In addition, intermediate- to high-GT rices showed more amylopectin-staling based on cooked rice hardness in all amylose types; a similar trend is observed in waxy rice (Juliano et al 1991). Varietal differences in rate and extent of amylopectin-staling may help explain variations in texture during storage of heat-processed rice products.

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