Heat Treatments of Milled Rice and Properties of the Flours

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ABSTRACT

The effects of autoclave and oven treatments on the gelatinization of rice flour and on the rheological characteristics of its pastes were studied by differential scanning calorimetry (DSC), rapid viscoanalysis (RVA), and rotational viscometry. Flours from autoclave-treated rice (ATR) and oven-treated rice (OTR) were prepared, respectively, by heating at 120°C for 60 min and 160°C for 60 min followed by drying (ATR sample), and grinding at 2.2–12.9% moisture content. The rice flour dispersions were adjusted between pH 6.3 and 2.8 using 0.2*M* citrate buffer. The retort processing of rice flour in water pastes were done at 120°C for 20 min either once or twice. The gelatinization peak temperature (PT and T_o) and the peak temperature corresponding to the amylose-lipid complexes (T_{p3}) of ATR increased at pH 6.3 and 2.8 compared with OTR and UTR flour. This indicates that the internal structures of the starch granules in ATR became more stable to heat and acid, even though the damaged starch content of ATR was 23% compared with 16 and 7%, respectively, for untreated rice flour (UTR) and OTR. The OTR flour pastes showed a gel-like behavior at pH 4.5 after retort processing in water at 120°C for 20 min; however, the ATR mixture behaved more like a liquid paste. Decreases in the reducing sugar content of OTR and ATR pastes suggested that enzymes in the heat-treated rice were denatured, which retarded the hydrolysis of glucose chains and the rupture of starch granules during pasting.

Rice is an important grain. Most of it is consumed as milled rice. In Japan, expansion of rice consumption could allow feed and food cereal self-sufficiency on a national basis. Interest in rice-based products and their processing technologies has increased despite higher costs than for either corn or wheat. A rice flour paste changes drastically in viscosity during gelatinization and swelling, and it is difficult to control its rheological properties. Modified starches and cereal flours have become important in processed food because their functional properties are improved over those of native starches and cereal flours.

Chemical modifications such as cross-linking and acetylation (Takahashi et al 1989), and physical treatments such as high-pressure treatment (Stute et al 1996; Douzals et al 1998), microwave heating (Lewandwicz et al 2000), heat-shear extrusion processing (Bryant et al 2001; Kadan et al 2001), γ-irradiation (Bao and Corke 2002), and warm-water treatment (Yamamoto and Shirakawa 1999) are widely used to change starch properties. Heat-moisture treatment (HMT, heating at a restricted moisture level) is one method used to physically modify starches and cereal flours. Sair (1967) observed that physicochemical properties of starches dramatically changed after HMT. Heat-moisture treated starches and cereal flours are considered safe and have a preferred image with many consumers.

We previously reported (Takahashi et al 2002, 2003) physicochemical properties of autoclave-treated rice (ATR) and oven-treated rice (OTR) flours. The ATR flour paste showed a lower yield stress (τ_y) and apparent viscosity (η_{app}) than pastes from UTR (untreated rice) or OTR.

Numerous studies have explored physical properties of rice flour from treated kernels, but few studies have addressed modified rice flour's resistance to acid conditions in food and retort processing. The present study is intended to clarify the effects of ATR and OTR on resistance of rice flour to acid hydrolysis and retort processing.

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MATERIALS AND METHODS

Rice

Short-grain *japonica* nonglutinous-type rice was harvested in 1998 in Japan. Milling of the brown rice to give 90% (w/w) of milled rice was conducted on a friction-type rice whitener (VP-30T, Yamamoto Co. Ltd., Yamagata, Japan). The moisture content of milled rice was 12.4% (w/w) determined by the drying method, and its protein and lipid contents were 6.2 and 0.9% (w/w), respectively, all determined by AOAC (1999) standard methods. The amylose content was 17.7% (w/w), determined by the method of Juliano (1971).

Autoclave and Oven-Treated Rice Flour Preparation

Milled rice (300 g) was kept ≈10 mm deep in a stainless steel wire-mesh container (250 mm diameter, 120 mm height, with openings of 1.5 mm) and heated at 120°C for 60 min in an autoclave (SS-320, Tomy Seiko Co. Ltd., Wako, Saitama, Japan). The moisture content was 20.6% after autoclaving and 12.9% after drying at room temperature (25 ± 1°C) for 24 hr. The autoclave treatment in the present study is interpreted as a heat-moisture treatment because the rice kernels were heated at a limited moisture level (≈20%).

Milled rice (300 g) was placed ≈5 mm deep in a stainless steel wire-mesh container (300 mm × 200 mm wide, 50 mm high, with openings of 1.5 mm) and heated at 160°C for 60 min in an air oven (DN600, Yamato Scientific Co. Ltd., Tokyo, Japan). The moisture content was 2.2 % after oven treatment.

Treated and untreated kernels were ground with a grinder (ZM-1000, Retsch GmbH & Co. KG, Germany) equipped with a screen with 0.25-mm apertures; untreated rice flour (UTR), autoclave-treated rice flour (ATR), and oven-treated rice flour (OTR) were stored in airtight polypropylene bags at <4°C. The moisture contents of rice samples at grinding were 12.4% for untreated rice, 12.9% for autoclaved rice, and 2.2% for oven-treated rice. The damaged starch in UTR, ATR, and OTR was determined according to Approved Method 76-30A (AACC 2000). Table I shows moisture content, mean diameter, damaged starch content, and color of rice flours.

Rice Flour Paste Preparation

Rice flour suspensions were set to a solid contents of 10.0% (w/w, dry basis) by adding the calculated quantities of distilled water or 0.2*M* citric acid sodium salt buffer (pH 6.1, 4.4, and 2.7) in glass jars so that the total sample mass was constant at 120 g. The suspensions were kept for 15 min at room temperature, and heated at 95°C for 30 min in a water bath with continuous stirring

at 200 rpm using an agitator (Z-1110, Tokyo Rikakikai Co. Ltd., Tokyo, Japan), at which time the pastes were thick enough to prevent rice flour settling. Pastes were transferred to polypropylene bags that were sealed and held in a water bath at 50°C until measurement of rheological properties. We treated 10.0% (w/w) rice flour pastes in distilled water with pressurized heating (retort processing) using the autoclave at 120°C for 20 min. The retort processing was repeated at 120°C for 20 min, and viscosity measurements were recorded after each heat treatment.

Pasting Properties

Pasting properties of rice flour were studied using a Rapid Visco-Analyser (RVA, model 3-D, Newport Scientific Pty. Ltd., Warriewood, NSW, Australia) with Thermocline software. Rice flour (3.0 g, db) was mixed with 25.0 g of 0.2*M* citrate buffer (pH 6.1, 4.4, and 2.7) in an RVA sample cup. A programmed heating and cooling cycle was used in which the samples were held at 50°C for 3 min, heated to 95°C in 7.5 min, maintained at 95°C for 7 min, cooled to 30°C in 10.8 min, and maintained at 30°C for 7 min. Pasting temperature (PT), peak viscosity (PV), minimum viscosity (MV), final viscosity (FV), breakdown (BD), and setback (SB) were recorded. Viscosity parameters were expressed in rapid viscosity units (RVU). Tests were repeated at least three times.

Thermal Properties

We analyzed thermal properties of rice flour using differential scanning calorimetry (DSC120, Seiko Corp., Tokyo, Japan). Rice flour (9.0 mg, db) was weighed into a silver pan, then 21 mg of citrate buffer (pH 6.1 and 2.7) was added. The pan was hermetically sealed then heated at 5°C/min from 25 to 155°C. The DSC curve was recorded with distilled water as a reference. Onset (T_o), peak (T_p) temperatures, and enthalpy change (ΔH) of gelatinization were calculated using a software program (EXSTAR6000, Seiko Corp., Tokyo, Japan). Tests were repeated at least twice.

Rheological Measurement

Flow curves of rice paste were measured using a rotational viscometer (RS50, Haake GmbH, Karlsruhe, Germany) equipped with concentric cylinder geometry and covered with a thin coat of *n*-hexadecane to prevent evaporation of moisture from the surface of the 50°C sample. The flow curves were obtained by shearing the samples for 5 min at increasing rates (0–100/sec). Samples were sheared for 5 min at 100/sec, and then allowed to rest in the concentric cylinder for 20 min before flow-curve measurements. The flow curves were approximated by the Herschel-Bulkley model (1) and the power law model (2)

$$\tau = \tau_y + \eta_{app}\dot{\gamma}^n \quad (1)$$

$$\tau = \eta_{app}\dot{\gamma}^n \quad (2)$$

where τ is the shear stress, τ_y is the yield stress, η_{app} is the apparent viscosity, and $\dot{\gamma}$ represents the shear rate. Numerical analysis software (Origin v. 6.0, OriginLab Corp., Northampton, MA) was used for curve fitting of the flow curve. Tests were done at least three times.

Determination of Reducing Sugar Content

We added fivefold citrate buffer or distilled water to a paste and homogenized it using a mortar and pestle. This suspension was centrifuged for 10 min at 1,233 × *g* and 20°C, and the amount of reducing sugar in the supernatant was measured by the Nelson and Somogyi method (Somogyi 1952). The level of reducing sugar was calculated based on the dry weight of rice flour. Tests were done at least three times.

Statistical Analysis

Results of rheological characteristics of the rice pastes were analyzed using the analysis of variance (ANOVA) procedure of a statistical analysis system software package (STATISTICA 5.1J,

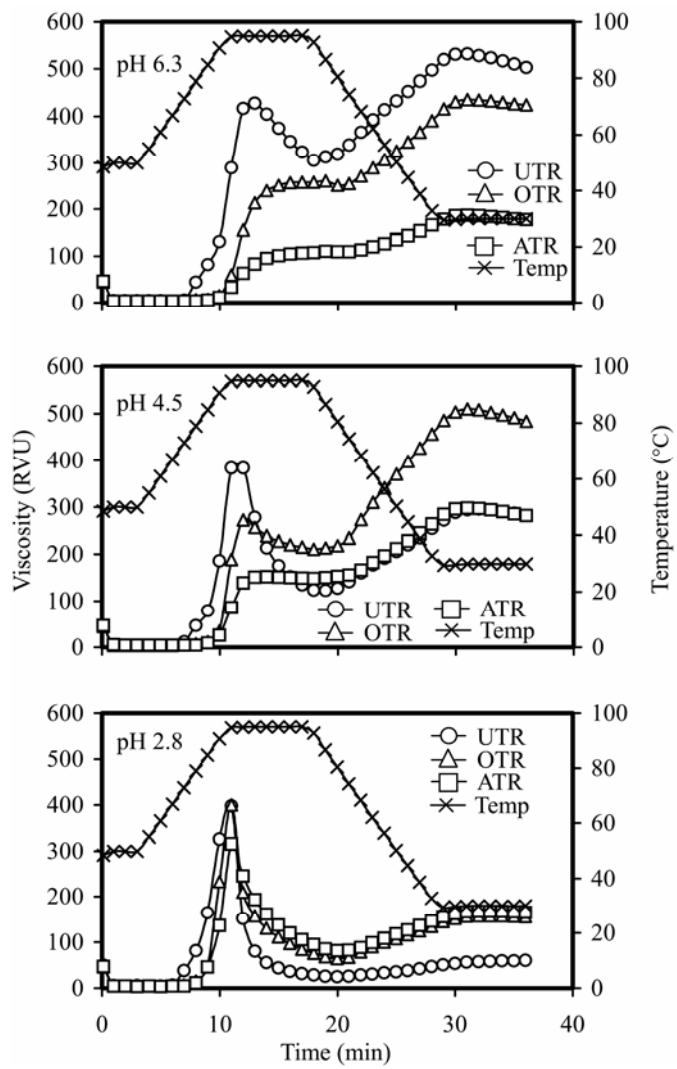

Fig. 1. Effect of pH (0.2*M* citrate buffers) on RVA viscosity curves (10.7%, w/w) of flours prepared from untreated rice flour (UTR), oven-treated rice flour (OTR), and autoclave-treated rice flour (ATR).

TABLE I
Moisture Content, Mean Diameter, Damaged Starch Content, and Color of Rice Flours

Samples[a]	Moisture Content (%, wb)	Mean Diameter[b] (μm)	Damaged Starch Content (%, wb)	Color		
				L	*a*	*b*
UTR	12.4 ± 0.2	128.9 ± 1.7	15.7 ± 0.2	93.2 ± 0.1	–2.1 ± 0.1	5.2 ± 0.1
OTR	2.0 ± 0.3	78.1 ± 7.4	6.6 ± 0.2	89.2 ± 0.1	–0.9 ± 0.1	12.2 ± 0.1
ATR	10.0 ± 0.3	126.3 ± 9.4	23.1 ± 0.2	88.8 ± 0.1	–0.8 ± 0.1	11.2 ± 0.1

[a] UTR, untreated rice flour; OTR, oven-treated rice flour; ATR, autoclave-treated rice flour. Mean ± standard deviation (n = 3).
[b] Volume-weighed mean diameter.

StatSoft Japan, Inc., Tokyo, Japan) including Tukey's significant difference test at the 5% significance level.

RESULTS AND DISCUSSION

Gelatinization Properties of Rice Flours and Physicochemical Properties of Rice Flour Pastes Under Acidic Conditions

Figure 1 shows RVA viscograms of 10.7% rice flour suspensions at various pH values. The pH values of the rice pastes after RVA measurements were 2.7–2.8, 4.4–4.5, and 6.2–6.3, which are described as pH 2.8, 4.5, and 6.3 hereafter.

The pasting temperatures (PT) of UTR, ATR, and OTR shifted to higher temperature as pH increased, as shown in Table II. This indicates that sodium citrate salt restricted granule swelling. Several salts suppress granule swelling and retard gelatinization (Jane 1993; Ahmad and Williams 1999; Shi and BeMiller 2000). Peak viscosity (PV) of UTR decreased with decreasing pH. This behavior indicates that citric acid leads to breakdown of UTR starch granules. On the other hand, the PV of ATR and OTR increased at lower pH. Pasting of ATR and OTR starches at pH 4.5 and 2.8 appeared to promote granule swelling and inhibit granule breaking under acidic conditions. Heat-moisture treated wheat starch was less susceptible to acid hydrolysis by 2.2*M* HCl (Hoover and Manuel 1996). Also, it was reported that the PV values of hydroxypropylated wheat starch pastes (Takahashi et al 1989) and γ-irradiated rice starch pastes (Bao and Corke 2002) increased in acidic medium.

Table III shows yield stresses (τ_y) and apparent viscosities (η_{app}) of 10.0% (w/w) rice flour pastes prepared at different pH values. Flow-curves at pH 6.3 and 4.5 exhibited pseudo-plastic flow approximated by the Herschel-Bulkley flow equation of the scaling law model, and at pH 2.8, quasi-viscous flow according to the power-law model. The η_{app} of each sample decreased sharply at pH 2.8. ATR pastes at pH 6.3 and 4.5 showed more liquid-like behavior than OTR and UTR pastes because the τ_y and η_{app} values were the lowest. Increases in τ_y were found for all samples when the pH was between 4.5 and 6.3. This increase indicates that the paste was more of a gel at pH 4.5 compared with pH 6.3. Hirashima et al (2004) reported that a 3.0% (w/w) corn starch paste formed a weak gel at pH 5.0 and 4.0, as indicated by the relative constancy of the storage modulus during a frequency sweep at a constant strain.

The results of the DSC experiments of 30% (w/w) rice flour suspensions at pH 6.3 and 2.8 are shown in Fig. 2 and Table IV. Decreases for gelatinization temperatures (T_o, T_{p1}, and T_c) were observed at pH 2.8 in all rice flours. The results corresponded to the decrease in PT values observed at pH 2.8 versus 6.3 in the RVA. The PT of OTR was greater than that of UTR at pH 2.8 and 6.3, but the differences in T_o, T_{p1}, and T_c were not significant. The PT of ATR flours also was greater than UTR flours, but the ATR flours had gelatinization temperatures 6–10°C higher than UTR flours (Table III). Those results indicate heat-moisture treatment in the ATR flours caused "perfecting" of crystals, which did not occur during dry heating of rice in OTR. Furthermore, heat treatment of rice caused the swelling properties of OTR and ATR flours to change as indicated by PT in the RVA.

Other endothermic peaks (T_{p2} and T_{p3}) in the DSC corresponding to amylose-lipid complexes were observed at 100–120°C (Fig. 2 and Table IV). That endotherm transition for ATR was higher (115–119°C) than for UTR and OTR (101–107°C). Previously, temperature increases in gelatinization (T_o) and the amylose-lipid complex (T_{p2}) were observed in DSC curves of physically modified (hydrothermally treated) rice flour (Lai 2001a). It was also reported that the amylose-lipid complex peak shifted to higher temperature by heat-moisture treatment (Miyoshi 2002) and parboiling (Biliaderis et al 1993). Changes in DSC parameters of ATR indicate rearrangement of amylose-lipid complex as well as starch chains occurs during heat-moisture treatment, which leads to the formation of crystallites of different stabilities (Hoover and Manuel 1996). Therefore, the changes in PT and T_o of ATR are attributed to more thermally stable crystallites in starch after autoclave-treatment.

TABLE II
Effect of Slurry pH on Pasting Characteristics[a] of Rice Flours[b] (10.7% solids)

Samples[c]	PT (°C)	PV (RVU)	MV (RVU)	FV (RVU)	BD (RVU)	SB (RVU)
UTR						
pH 2.8	67.9 ± 0.3a	398 ± 2d	25 ± 1a	59 ± 3a	374 ± 2g	34 ± 3a
pH 4.5	71.8 ± 0.2b	423 ± 1e	122 ± 2e	295 ± 3d	301 ± 2e	173 ± 1d
pH 6.3	74.2 ± 0.0d	445 ± 14f	314 ± 8i	546 ± 3g	131 ± 8c	232 ± 6e
OTR						
pH 2.8	72.9 ± 0.4c	397 ± 7d	60 ± 4b	146 ± 10b	337 ± 5f	86 ± 6b
pH 4.5	77.0 ± 0.3f	272 ± 0b	206 ± 5g	503 ± 6f	66 ± 5b	298 ± 1f
pH 6.3	82.5 ± 1.6g	nd[d]	261 ± 3h	437 ± 2e	nd	176 ± 3d
ATR						
pH 2.8	76.6 ± 0.3e	316 ± 1c	74 ± 6c	155 ± 13b	242 ± 7d	80 ± 7b
pH 4.5	82.8 ± 0.5g	151 ± 12a	146 ± 11f	298 ± 16d	5 ± 1a	152 ± 5c
pH 6.3	86.3 ± 0.8h	nd	104 ± 3d	183 ± 4c	nd	79 ± 2b

[a] PT, pasting temperature; PV, peak viscosity; MV, minimum viscosity; FV, final viscosity; BD, breakdown; SB, setback. Values followed by the same letter in the same column are not significantly different ($P < 0.05$). Mean ± standard deviation ($n = 3$).
[b] Rice samples ground through a 0.25-mm screen before determining pasting properties.
[c] UTR, untreated rice flour; OTR, oven-treated rice flour; ATR, autoclave-treated rice flour.
[d] Not detectable.

TABLE III
Effect of pH on Yield Stress (τ_y) and Apparent Viscosity (η_{app}) for 10.0% (w/w) Rice Flour Pastes at 50°C[a]

	τ_y (Pa)			η_{app} (Pa·sec)		
Samples[b]	pH 2.8	pH 4.5	pH 6.3	pH 2.8	pH 4.5	pH 6.3
UTR	nd[c]	16.9 ± 3.1b	11.1 ± 2.1b	0.5 ± 0.0a	15.0 ± 0.7b	16.8 ± 1.4b
OTR	nd	21.1 ± 2.0c	16.6 ± 2.5b	1.2 ± 0.0b	19.0 ± 1.1c	24.6 ± 1.3c
ATR	nd	3.9 ± 0.8a	0.6 ± 0.3a	1.3 ± 0.1c	10.5 ± 0.3a	9.2 ± 0.3a

[a] Flow curves of rice flour paste were analyzed based on the Herschel-Bulkley model at pH 6.3 and 4.5, and on the power law model at pH 2.8. Values followed by the same letter in the same column are not significantly different ($P < 0.05$). Mean ± standard deviation ($n = 3$).
[b] UTR, untreated rice flour; OTR, oven-treated rice flour; ATR, autoclave-treated rice flour.
[c] Not detectable.

Reducing sugar content of a 10.0% (w/w) UTR paste was higher than that for ATR and OTR at pH 6.3 and 4.5 (Fig. 3). Amylase enzymes would be denatured and not active in ATR and OTR where reducing sugar levels were low in their pastes at pH 4.5 and 6.3. Reducing sugar content of ATR flour was lower than that of UTR flour at pH 6.3 and 4.5, even though damaged starch content of ATR flour was greater than UTR flour (Table I). Lu et al (1996) reported that degradation of amylopectin in rice starch occurred during hydrothermal treatment of milled rice. Using gel-permeation chromatography (GPC), they found a decrease in the number of large molecules but an increase in the number of smaller molecules. Therefore, the suggestion of more thermally stable crystallites in starch granules after autoclave treatment is supported by a decrease in the reducing sugar content. Other support includes the increase in PT in the RVA of ATR flour and its increased gelatinization temperature in the DSC.

The reducing sugar content of OTR and ATR increased sharply at pH 2.8, although they were lower than for UTR. This indicates that acid-catalyzed hydrolysis of starch chain is occurring and that short chains leach out from the starch granules. Moreover, acidification could also accelerate rupture of starch granules as shown by the decreases in final viscosities (FV) in the RVA curves (Fig. 1 and Table II).

Effects of Retort Processing of Rice Flours in Water

Flow-curves of aqueous pastes of UTR, ATR, and OTR flours were determined after retort processing of flour-water mixtures in an autoclave at 120°C for 20 min. All the pastes demonstrated typical shear-thinning behaviors that approximated the Herschel-Bulkley equation of the scaling law model (Table V). The τ_y and η_{app} were affected by retort heating. The τ_y and η_{app} of ATR after reheating were higher than those of the control sample heated at

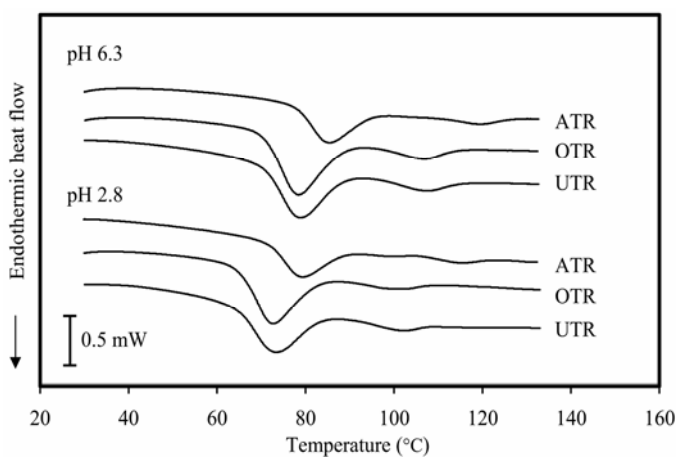

Fig. 2. Differential scanning calorimetry (DSC) curves of 30% (w/w) rice flours in 0.2*M* citrate buffers. Untreated rice flour (UTR), oven-treated rice flour (OTR), autoclave-treated rice flour (ATR).

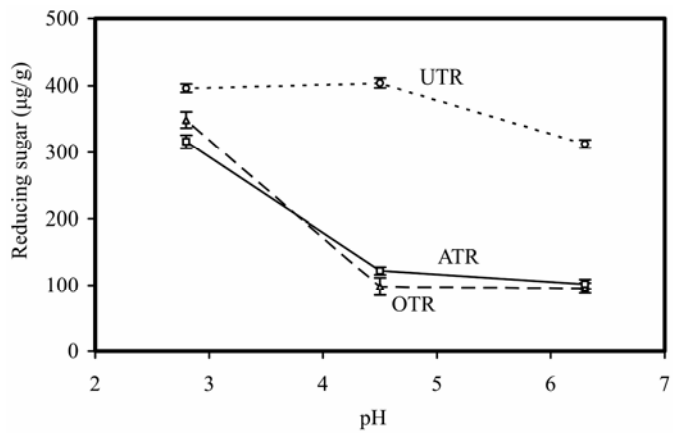

Fig. 3. Effect of pH on reducing sugar content of 10% (w/w) pastes from untreated rice flour (UTR), oven-treated rice flour (OTR), autoclave-treated rice flour (ATR). Point and bars indicate mean ± standard deviation, respectively ($n = 3$).

TABLE IV
Effect of pH on Differential Scanning Calorimetry (DSC) Characteristics[a] of Sample Flours in Excess Water[b]

	Gelatinization				Amylose-Lipid Complex			
Samples[c]	T_o (°C)	T_{p1} (°C)	T_c (°C)	ΔH (kJ/kg)	T_{p2} (°C)	ΔH_2 (kJ/kg)	T_{p3} (°C)	ΔH_3 (kJ/kg)
UTR								
pH 2.8	64.3 ± 0.6a	73.1 ± 0.2b	83.1 ± 0.5a	9.1 ± 0.1b	101.1 ± 0.3a	1.2 ± 0.1a	nd[d]	nd
pH 6.3	70.0 ± 0.5b	78.5 ± 0.1c	89.3 ± 0.6b	9.8 ± 0.3bd	107.2 ± 0.4b	1.7 ± 0.1b	nd	nd
OTR								
pH 2.8	64.7 ± 0.5a	72.1 ± 0.3a	82.6 ± 0.4a	10.2 ± 0.2cd	100.5 ± 1.3a	1.1 ± 0.1a	nd	nd
pH 6.3	70.6 ± 0.2b	78.3 ± 0.4c	88.3 ± 0.6b	10.9 ± 0.2c	106.3 ± 0.5b	1.6 ± 0.1b	nd	nd
ATR								
pH 2.8	72.0 ± 0.6c	79.1 ± 0.3d	88.2 ± 0.7b	6.2 ± 0.5a	nd	nd	115.3 ± 0.8a	0.6 ± 0.1a
pH 6.3	77.6 ± 0.1d	85.0 ± 0.2e	94.8 ± 0.4c	6.3 ± 0.1a	nd	nd	119.1 ± 0.5b	0.9 ± 0.1b

[a] T_o, onset temperature; T_p, peak temperature; T_c, conclusion temperature; ΔH, gelatinization enthalpy.
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$). Mean ± standard deviation ($n = 3$).
[c] UTR, untreated rice flour; OTR, oven-treated rice flour; ATR, autoclave-treated rice flour.
[d] Not detectable.

TABLE V
Effect of Retort Heating of Rice Flour-Water Mixtures (10.0%, w/w) on Yield Stress (τ_y) and Apparent Viscosity (η_{app}) at 50°C[a]

	τ_y (Pa)			η_{app} (Pa·sec)		
Samples[b]	Control Heat Once 95°C, 20 min	Heat Once 120°C, 20 min	Heat Twice 120°C, 20 min	Control Heat Once 95°C, 20 min	Heat Once 120°C, 20 min	Heat Twice 120°C, 20 min
UTR	11.5 ± 2.1b	3.3 ± 0.7a	3.2 ± 0.5a	17.2 ± 1.4b	11.7 ± 0.3a	10.1 ± 0.0a
OTR	16.2 ± 2.5c	22.0 ± 1.3b	11.5 ± 2.0b	24.1 ± 1.3c	17.5 ± 1.6b	16.3 ± 0.7c
ATR	0.8 ± 0.3a	4.1 ± 1.4a	3.6 ± 0.9a	9.7 ± 0.3a	16.3 ± 1.1b	12.3 ± 0.4b

[a] Flow curves of rice flour pastes were analyzed based on the Herschel-Bulkley model. Values followed by the same letter in the same column are not significantly different ($P < 0.05$). Mean ± standard deviation ($n = 3$).
[b] UTR, untreated rice flour; OTR, oven-treated rice flour; ATR, autoclave-treated rice flour.

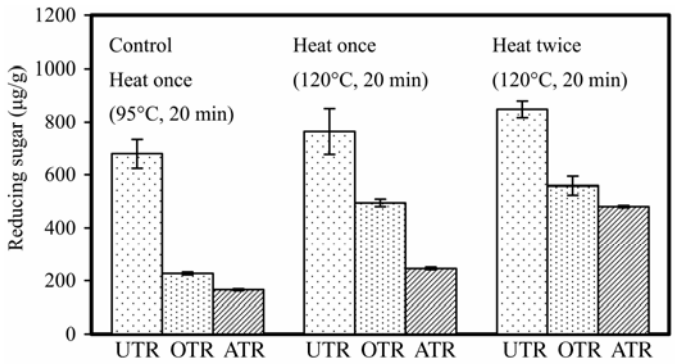

Fig. 4. Effect of retort processing at 120°C for 20 min on reducing sugar content of 10% (w/w) pastes from untreated rice flour (UTR), oven-treated rice flour (OTR), autoclave-treated rice flour (ATR). Bars indicate mean ± standard deviation (n = 3).

95°C for 20 min. This suggests that the starch granule swelling in ATR was retarded compared with that of the control. The τ_y and η_{app} values of OTR and ATR flour slurries heated at 120°C for 20 min were both higher than those of the UTR. Few glucose chains were hydrolyzed by enzymes in the OTR and ATR samples compared with UTR, so retort heating produced less reducing sugar in the OTR and ATR samples than in the UTR (Fig. 4). Thus, the collapse of the starch granules in the OTR and ATR samples was inhibited during retort heating.

The OTR flour paste showed gel-like behavior; the τ_y of OTR was greater than that of the other samples at pH 4.5 (Table III) and after retort heating (Table V). Therefore, it is feasible that the use of OTR may improve the food texture of rice pasta (Lai 2001b) and pancakes (Seguchi 1990). The ATR flour in acid medium pH 2.8 (Table III) and in water after retort heating at 95°C for 20 min behaves as a liquid (Tables III and V). This fluid property of ATR flour pastes may be caused in part by the high level of damaged starch in ATR flour (Table I). Decreases in the viscosity of a starch paste alters the food texture of a filling paste (Lorenz and Kulp 1981). Moreover, ATR after retort heating could be used as a stabilizer and thickener in soups because the final ATR paste hardly formed a gel at pH 6.4 and 4.5 in the presence of salts (Tables II, III, and V). The low starch damage in the OTR flour (≈7%) versus the starch damage in the ATR (23%) and UTR (≈16%) flour was attributed to the low moisture content of ≈2% for OTR versus ≈12.5% for ATR and UTR. The extra dry endosperm was friable and quickly reduced in particle size.

CONCLUSIONS

Rice flours prepared by dry heating (oven-treated) rice kernels and by moisture heating (autoclaved) rice kernels exhibit different rheological properties in 0.2*M* citrate buffer at pH 2.8, 4.5, and 6.3. The gelatinization swelling properties of the rice starch in ATR and OTR flours are altered by the heat treatments of milled rice. These findings suggest that heat-treated rice can expand the use of rice flour in foods.

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