

Effect of storage temperature on cooking behaviour of rice

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Abstract

The differences in the properties of residual cooking water and the textural profile of cooked rice grain following storage at 4 °C and 37 °C were examined. The higher temperature storage led to greater water uptake, reduced pH and turbidity of residual cooking liquid. The solids content in the residual cooking water also significantly ($p < 0.001$) decreased following storage at 37 °C compared to 4 °C storage. Textural profile of the cooked rice grain also differed for rice grains under the two storage temperatures. Hardness increased ($p < 0.01$) and adhesiveness reduced ($p < 0.01$) following storage at 37 °C compared to 4 °C. Moreover, analysis of the hot-water soluble fraction suggested that storage at 37 °C decreased the leaching of starch components, particularly amylose. The cooked rice grains were also visualized using scanning electron microscopy, and the cooked rice following storage at 4 °C showed smoother surfaces than that of the cooked rice following storage at 37 °C.

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1. Introduction

Cultivated rice (*Oryza sativa* L.) is typically consumed as cooked rice with only a small amount being used to make ingredients for processed foods. This pattern of usage results in the need to store rice over varying periods. Storage results in numerous changes in rice chemical and physical properties (Noomhorm, Kongseree, & Apintanapong, 1997; Patindol, Wang, & Jane, 2005; Perdon, Siebenmorgen, Buescher, & Gbur, 1999; Singh, Kaur, Sandhu, Kaur, & Nishinari, 2006; Sodhi, Singh, Arora, & Singh, 2003; Sowbhagya & Bhattacharya, 2001; Suzuki et al., 1999; Zhou, Robards, Helliwell, & Blanchard, 2002) and these changes impact rice cooking and eating quality (Teo, Abd, Cheah, Norziah, & Seow, 2000).

The texture of the cooked rice grain has been shown (Okabe, 1979; Sesmat & Meullenet, 2001; Tsugita, Ohta, & Kato, 1983) to describe the ultimate acceptance of rice

by consumers when consumed as the whole grain. Although, texture is multidimensional, hardness and stickiness are critical, with hardness being the most important and most commonly measured parameter (Meullenet, Gross, Marks, & Daniels, 1998). As rice aged, texture of the cooked rice grain became harder and less sticky than cooked fresh rice and the aged rice showed increased volume expansion and water absorption during the cooking process (Noomhorm et al., 1997; Pushpamma & Reddy, 1979). The changes in textural properties of aged rice have been associated with the protein content (Zhou, Robards, Helliwell, & Blanchard, 2003a) and, in particular, with oxidation of the proteins in the external layers of the grains (Ohno & Ohisa, 2005). In this connection, it is interesting to compare the effects of storage on other cereal grains (McDonough, Floyd, Waniska, & Rooney, 2004).

Rice cooking properties are largely related to the gelatinization properties of its starch granule (Juliano, 1985). During the cooking process, starch granules become swollen and release exudates of starch molecules. Cooking loss and soluble amylose content in the residual cooking water

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of rice samples has been used (Nardi, Dellungo, & Bellopede, 1997) to assess rice quality. A reduction in the amount of extractable solid for aged rice was reported by Villareal, Resurreccion, Suzuki, and Juliano (1976). These results probably reflect the increase in water-insolubility of rice starch and proteins during ageing, resulting in a slower cooking rate. The changes in rice pasting and thermal properties during storage have been studied in our previous publications (Zhou et al., 2003a, Zhou, Robards, Helliwell, & Blanchard, 2003b), and these changes were assumed to finally influence rice cooking properties. Thus, in this study, the effect of storage on the changes in rice cooking properties including residual cooking water and cooked rice grain texture are determined.

2. Materials and methods

2.1. Experimental materials and rice storage

Three varieties of milled rice grain (Koshihikari, medium grain with 18% amylose content; Kyeema, aromatic long grain with 20% amylose content; Doongara, high amylose long grain with 29% amylose content) were used for this study. The varieties were grown in the Murrumbidgee Irrigation Area (MIA) of New South Wales, Australia.

Previous studies suggest that storage at 37 °C accelerated the ageing process, whilst storage at 4 °C retarded the process and that samples stored at these two temperatures provide a valid comparison of the rice ageing process (Tsugita et al., 1983; Rajendra & Zakiuddin, 1991; Suzuki et al., 1999). Thus, the present study was conducted using the two storage temperatures, 4 °C and 37 °C. The milled rice was placed in air-tight glass bottles and stored in the dark at 4 °C and 37 °C in thermostatically controlled incubators for 16 months which was considered as the maximum storage period encountered in normal commercial practice. After storage, samples were withdrawn and the cooking properties were determined using the whole rice grains. For the determination of amylose/starch content of rice and scanning electron microscopy, the rice grains were ground using a Cyclone Sample Mill (UDY Corporation, Fort Collins, CO) through a 1.0 mm sieve screen immediately prior to analysis. Moisture was determined by drying at 110 °C to constant weight and analytical results were expressed on a dry matter basis. All analyses were performed using triplicate samples.

Isoamylase enzyme and starch analysis kit were purchased from Megazyme (Vic., Australia). Chemicals and solvents used in this study were either analytical or high performance liquid chromatography (HPLC) grade.

2.2. Amylose content of rice

Rice flour (0.10 g) was combined with aqueous dimethylsulfoxide (5 mL; 90:10, DMSO/water). The mixture was incubated in a boiling water bath for 60 min and then cooled to room temperature. The solution (250 µL) was

diluted to 1 mL using 0.05 M sodium acetate – acetic acid buffer (pH 5.0) and 10 µL of isoamylase (2 units) was added. The mixture was incubated at 50 °C for 19 h and then treated in a boiling water bath for 10 min and centrifuged at 10,000 g for 10 min. The supernatant (40 µL) was used for HPLC determination of amylose and fractions of amylopectin. The HPLC system comprised a Waters 2690 pump equipped with autosampler and differential refractive index detector (Waters, Model 410, Milford, MA). An Ultrahydrogel™ 250 column (Waters, 7.8 mm × 300 mm), guard column (Phenomenex Inc., Sydney, Australia) and detector were maintained at 37 °C and injection was at 25 °C. A sodium acetate – acetic acid buffer (0.05 M; pH 5.0) containing 0.02% sodium azide was used as mobile phase at a flow rate of 0.4 mL min⁻¹. Amylose content was calculated as percent amylose peak area relative to the total peak area (amylose + amylopectin fractions).

2.3. Cooking method

Rice grain (1.0 g, dry basis) was combined with 10 mL of distilled water in a quick-fit conical flask fitted with a glass stopper. The flask was immersed in a boiling water bath for 15 min after which it was placed in an ice bath for 5 min. The properties of the excess residual cooking water and the texture of the cooked rice grain were analyzed.

2.4. Rice cooking properties

2.4.1. Water uptake capacity of cooked rice grain

The excess residual cooking water was withdrawn using pipette after the cooking process and the volume was measured. Water uptake capacity of the cooked rice grain was calculated from the difference between the total cooking water and residual cooking water after the cooking process and expressed as mL g⁻¹ grain. The residual cooking water was used for subsequent analysis of solids content, pH and turbidity.

2.4.2. Solids content in residual cooking water

An aliquot of residual cooking water (0.5 mL) was transferred into a test tube and dried at 110 °C to constant weight. The solids content of the residual cooking water was measured by weighing and expressed as mg mL⁻¹.

2.4.3. pH of residual cooking water

The pH of the residual cooking water was determined using a digital pH meter (John Morris Scientific Pvt. Ltd., Sydney, Australia) at room temperature (20 °C).

2.4.4. Turbidity of residual cooking water

The residual cooking water was left to stand overnight at room temperature (20 °C) to allow the large particles in the water to settle. The aqueous layer was used for the determination of turbidity which was measured using a UV/VIS Spectrophotometer (Unicam 8625, Melbourne,

Australia). Turbidity was expressed as the absorbance at 600 nm.

2.4.5. Amylose in residual cooking water

Residual cooking water (800 μL) was combined with 600 μL of 0.05 M sodium acetate-acetic acid buffer (pH 5.0) and 10 μL of isoamylase and incubated at 50 $^{\circ}\text{C}$ for 19 h. The mixture was then incubated in a boiling water bath for 10 min and centrifuged at 10,000 g for 10 min. The supernatant was used for HPLC determination of amylose and amylopectin. On the basis of HPLC, amylose content in the residual cooking water was calculated as percent amylose peak area relative to the total peak area (amylose + fractions of amylopectin). The amount of amylose in the residual cooking water was calculated from the total soluble starch (Enzyme Kit Method) and amylose content in the leachate.

2.5. Textural profile of cooked rice grains

Textural profile of the cooked rice grain was determined using a Texture Analyser (TA.XT2i, Stable Micro System, Surrey, UK). A two-cycle compression, force-versus-distance program was used to allow the plate to travel 9.0 mm, return, and repeat at the same speed. The test speed was 2.0 mm s^{-1} , and a probe with a 10 mm diameter was used. Parameters recorded from test curves included hardness, adhesiveness and cohesiveness.

2.6. Scanning electron microscopy (SEM)

Visualisations were performed on a Cambridge S360 Scanning Electron Microscope with an attached Oxford CT 1500 Cryotrans cold-stage/coating unit. After air dried, the rice samples were glued onto a sample holder, plunged into liquid nitrogen slush (at -230°C) and transferred immediately onto the SEM cold-stage. The specimens were warmed to a controlled -80°C to sublimate off ice crystals. Rice samples were then transferred into the cryotrans and coated with approximately 10 nm of pure gold. The coated specimens were then observed at -180°C on the cold-stage of the SEM.

2.7. Statistical analysis

Experimental data were subjected to analysis of variance using Genstat 5 (release 4.1). Treatment means were tested

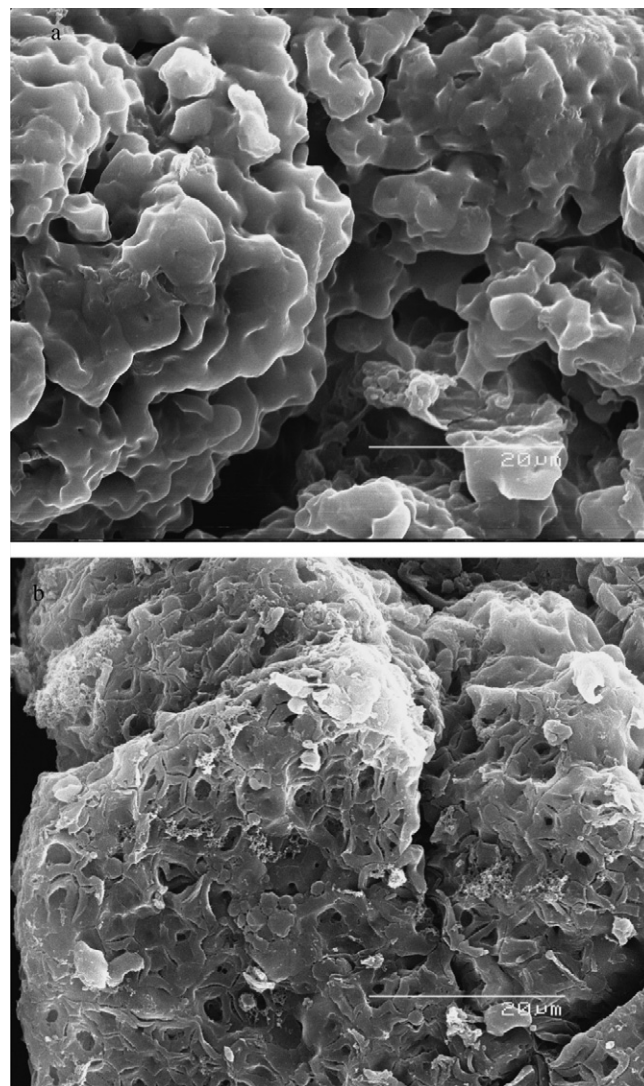


Fig. 2. A representative scanning electron micrograph showing the transverse structure of cooked rice grain (Doongara) following storage at (a) 4 $^{\circ}\text{C}$ and (b) 37 $^{\circ}\text{C}$ for 16 months.

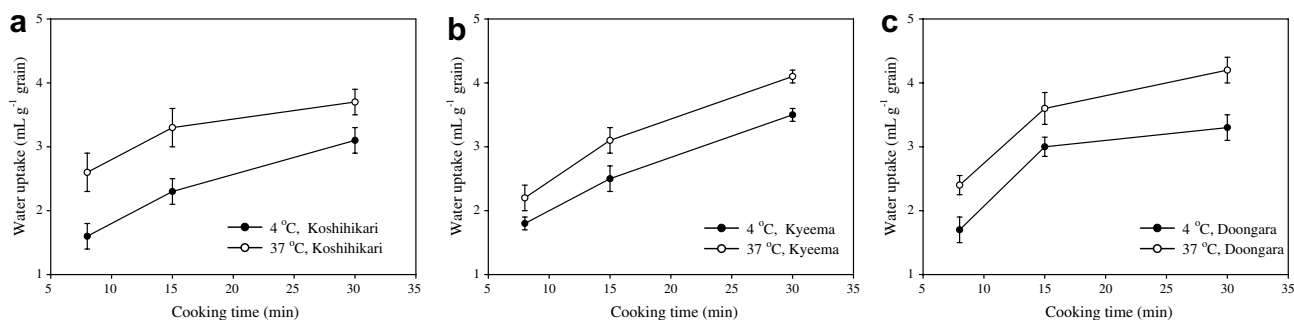


Fig. 1. The differential water uptake of cooked rice grain following storage for 16 months at 4 $^{\circ}\text{C}$ and 37 $^{\circ}\text{C}$.

separately for least significant difference (lsd) at a 5% level of probability.

3. Results and discussion

The cooking method used in the present study conforms to the definition of cooking with a large amount of water (Juliano, 1985). Using cooking times of 8, 15 and 30 min, the storage temperature had a significant effect on cooking behaviour as assessed by changes in the texture of cooked rice grains and the properties of residual cooking water.

3.1. Effect of storage on water uptake of cooked rice grain

Higher temperature storage (37 °C) led to a time-dependent increase in water uptake by the rice grains during cooking compared to lower temperature storage (Fig. 1). Moreover, the three varieties showed different water uptake. Koshihikari, with the lowest amylose content had the lowest water uptake (Fig. 1a), while Doongara, with the highest amylose content had the highest water uptake (Fig. 1c) consistent with previous observations (Mohapatra & Bal, 2006). Our previous studies (Zhou et al., 2003a,

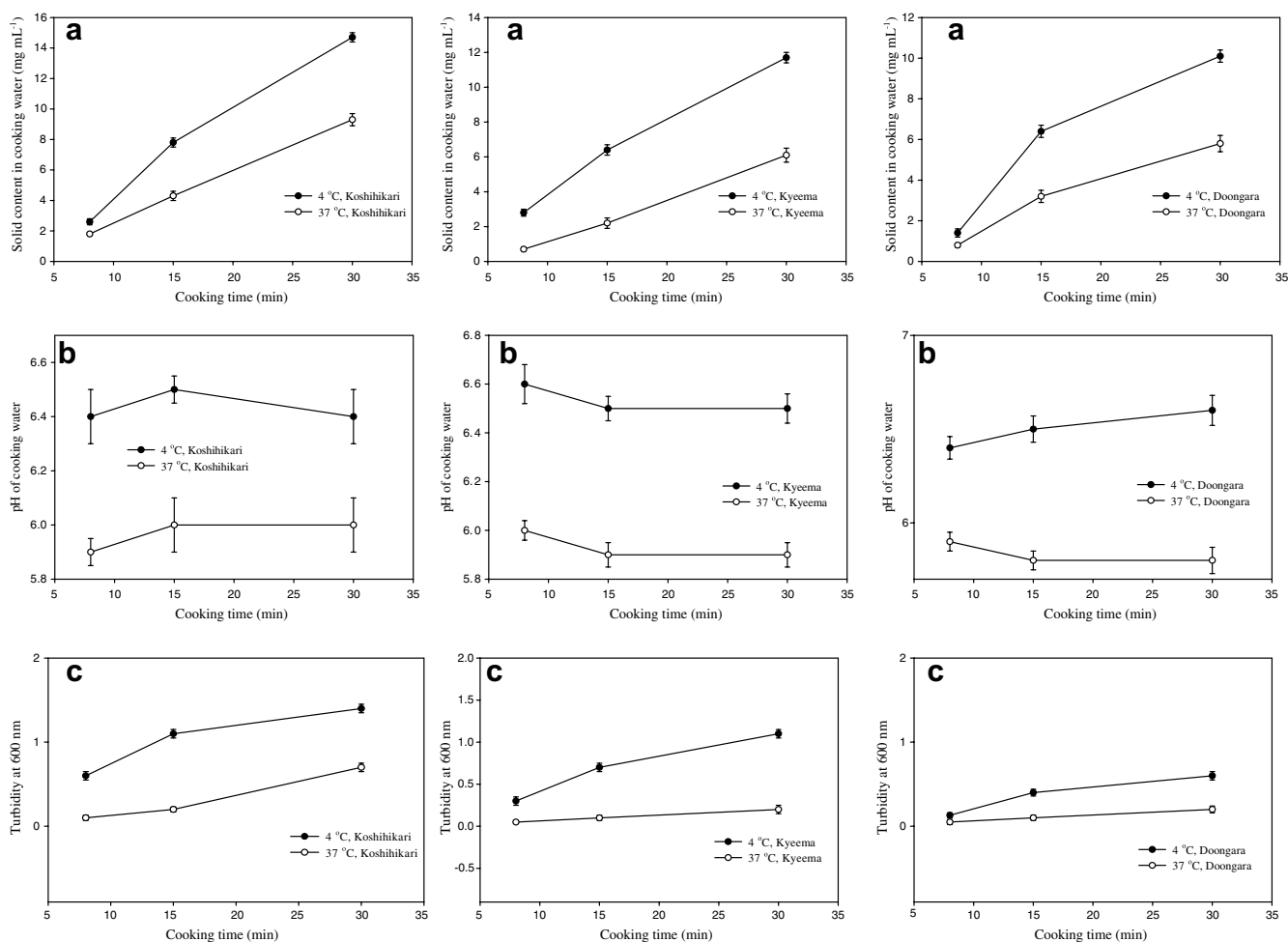


Fig. 3. The differential properties of residual water after cooking of rice grain following storage for 16 months at 4 °C and 37 °C. (a) Solid content in residual cooking water; (b) pH of residual cooking water and (c) Turbidity of residual cooking water.

Table 1
Starch and amylose contents of rice following storage for 16 months at 4 °C and 37 °C

Variety	Koshihikari		Kyeema		Doongara	
	4 °C	37 °C	4 °C	37 °C	4 °C	37 °C
Starch content (% per dry grain) ^a	83.7 ± 0.5	83.3 ± 0.7	83.5 ± 0.6	83.0 ± 0.8	82.9 ± 0.8	82.5 ± 0.5
Amylose proportion (%) ^b	17.8 ± 0.8	17.2 ± 0.7	20.3 ± 0.7	21.0 ± 0.5	28.8 ± 0.8	28.6 ± 0.8

^a Starch content of rice grain was determined using the Megazyme starch kit, according to the manufacturer's instructions.

^b Amylose proportion of the rice grain was determined using HPLC and amylose proportion was calculated as per cent amylose peak area relative to the total starch peak area (amylose + amylopectin).

2003b) of pasting and thermal behaviour suggest that hydration of rice grains stored at 37 °C is more difficult with greater resistance to hydrothermal disruption than for rice stored at 4 °C. It is proposed that after cooking, the leached starch components and the swollen starch granule of rice stored at 4 °C interact with each other to form a homogeneous paste, in which the moisture held in the cooked rice is mainly involved in the starch hydration. In contrast, the moisture in the cooked rice grain following storage at 37 °C is partially involved in starch gelatinization, but some of the moisture is simply entrapped in the cooked grain because of greater volume expansion (Pushpamma & Reddy, 1979; Noomhorm et al., 1997) during cooking. The different texture of the two cooked rices (4 °C storage versus 37 °C storage) is presented in Fig. 2, and shows that cooked rice following storage at 4 °C has a smoother surface than cooked rice following storage at 37 °C.

3.2. Effect of storage on the properties of residual cooking water

The properties of residual cooking water differed significantly between the two storage temperatures (Fig. 3). For example, rice grains stored at 37 °C had significantly lower ($p < 0.05$) solids content of the residual cooking water compared to the rice grains stored at 4 °C. It appears that storage at 37 °C led to changes in the rice grain structure such that the components became more difficult to extract from the granules. Higher temperature storage also decreased the pH and reduced the turbidity of residual cooking water (Fig. 3). These differences are consistent with the inhibition of leaching of rice components, particularly starch components, during the cooking process resulting from the more organized rice structure formed following higher temperature storage.

3.3. Effect of storage on amylose leaching during cooking

Because starch is the major constituent in residual cooking water and amylose plays an important role in the control of rice properties, the leaching behaviour of starch components, particularly amylose was investigated. Although, there were no differences in the amylose proportion (ratio of amylose to total starch) and total starch of rice grain between the two storage temperatures (Table 1), the proportion of amylose relative to the leached starch in residual cooking water was significantly affected by storage temperature ($p < 0.01$) with samples stored at 37 °C containing a lesser proportion of amylose than those stored at 4 °C (Fig. 4a). Amongst the three varieties, Doongara, with the highest amylose content, showed the greatest reduction in proportion of amylose in leachate following storage at 37 °C. This change in the proportion of leached amylose for the sample stored at higher temperature supports the observation of decreased amylose to amylopectin ratio following storage (Patindol et al., 2005). For each variety,

higher temperature storage (37 °C) also led to significant reduction in the amount of leached amylose in the residual cooking water compared to lower temperature storage (4 °C) ($p < 0.01$) (Fig. 4b). Thus, starch and in particular, amylose became more insoluble following the higher temperature storage (Rajendra & Zakiuddin, 1991). It seems that ageing-induced changes in rice might be irreversible and that the resulting changes in cooking properties cannot be eliminated by regulating cooking time (Fig. 4).

3.4. Effect of storage on the texture of cooked rice grain

The important parameters for the evaluation of the texture of the cooked rice grain include hardness, adhesiveness, and cohesiveness. Hardness is defined as the maximum force that occurs at any time during the first compression cycle (Smewing, 1999). Higher temperature

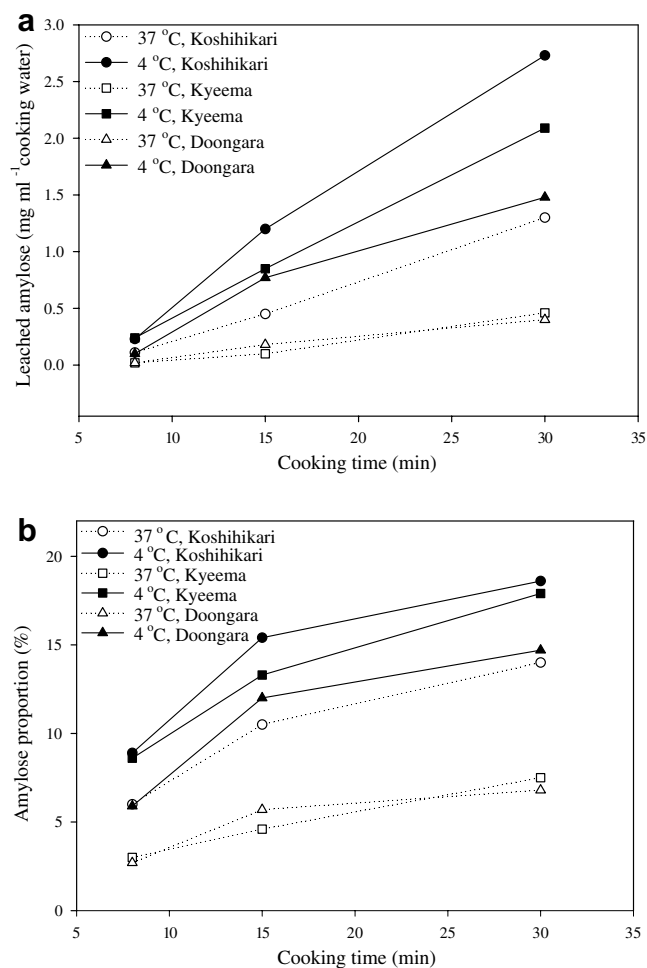


Fig. 4. Amylose leaching behaviour during cooking of rice grain following storage for 16 months at 4 °C and 37 °C. (a) The amount of leached amylose in residual cooking water calculated from the total soluble starch and amylose proportion in the leachate. The total soluble starch was determined using starch kit according to the manufacturer's instruction and (b) the proportion of leached amylose in residual cooking water calculated as percent amylose peak area relative to the total peak area of starch.

Table 2
Changes in the texture of cooked rice grain following rice storage for 16 months at 4 °C and 37 °C determined by Texture Analyser

Variety	Storage temperature	Hardness (g)	Adhesiveness (g s ⁻¹)	Cohesiveness
Koshihikari	4 °C	373 ± 59	4.1 ± 2.0	0.37 ± 0.03
	37 °C	891 ± 228	2.5 ± 1.4	0.47 ± 0.03
Kyeema	4 °C	354 ± 67	4.0 ± 1.2	0.38 ± 0.06
	37 °C	685 ± 114	2.9 ± 1.0	0.47 ± 0.02
Doongara	4 °C	561 ± 97	1.7 ± 1.1	0.40 ± 0.07
	37 °C	872 ± 153	1.0 ± 1.1	0.46 ± 0.03

Data are reported as means ± SD (standard deviation) for 16 determinations.

storage resulted in significant increase in hardness ($p < 0.001$) compared to lower temperature storage (Table 2). Following the first compression cycle, the force is removed from the sample as the probe moves back to its original position. The area of this negative peak is taken as a measure of the adhesiveness of the materials (Smewing, 1999). High temperature storage (37 °C) led to a significant decrease in adhesiveness ($p < 0.01$) compared to lower temperature storage. The higher hardness and lower adhesiveness are likely associated with the lower hydration process of starch granules in aged rice grains stored at higher temperature.

Cohesiveness is measured by taking the total work done on the sample during the second cycle and dividing it by the work done during the first cycle (Smewing, 1999). Work is measured as the area under the respective curves. Higher temperature storage led to an increase in cohesiveness (Table 2) compared to lower temperature storage, which suggested that aged rice grains demonstrated higher resistance to the first compression of the probe. This increase may be related to an increase in the resistance to the hydrothermal disruption of starch granules and the increase in insoluble materials (i.e. starch and proteins) contents as the samples that are very cohesive will be perceived as tough and difficult to break up in the mouth. Tsugita et al. (1983) and Meullenet, Marks, Hankins, Griffin, and Daniels (2000) also reported that increasing storage temperature increased rice hardness and decreased rice adhesiveness, and storage temperature and duration significantly affected adhesion to lips, an indicator of rice cohesiveness (Tamaki, Tashiro, Ishikawa, & Ebata, 1993).

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