New Perspectives in Science Education
International Conference
NEW PERSPECTIVES in SCIENCE EDUCATION

Effects of Different Storage Conditions on Polished Rice After Cooking and Freezing

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Abstract

Rice is a globally essential staple food. During storage, it undergoes a process of aging over time, resulting in physical and chemical changes that lead to quality deterioration. Texture measurements of cooked rice stored at various temperatures revealed that as the storage time increases, the rice tends to become harder and less adhesive compared to fresh rice (0 months) [1]. However, these changes were minimized as temperatures dropped within freezing environments, demonstrating that differences in storage temperature significantly influence the suppression of the aging process.
In this study, we stored rice at four different temperatures, including ultra-low temperature (-80°C), and examined the effects of storage temperature through physical property analysis, sugar content measurement, and internal structural observation. Furthermore, we evaluated the effectiveness of ultra-cryopreservation and focused on the increasingly popular practice of freezing cooked rice. Cooked rice from various storage conditions was frozen for one week, thawed, and then subjected to the same measurements to investigate the impact on frozen rice.
While there were no significant differences in sugar content across the different storage temperatures over a maximum of six months, distinct differences were observed in hardness values. By scientifically demonstrating the effects of storage temperature on rice quality through applied multifaceted approach —chemical, physical, engineering, and morphological—this finding suggest provides educational materials for Life Science by viewing daily life through a scientific lens. Moreover, it aims to be applicable to science education as a subject for inquiry-based learning regarding food deterioration and preservation technologies.

Keywords: *polished rice, cooking rice, freezer storage, ultra-low-temperature*

1. Introduction

Long-term storage of rice leads to a process known as "aging" (staling), where physiological, physical, and chemical changes cause a decline in quality. As these aging progresses, the interplay of various factors also reduces the palatability and consumer appeal of the rice. In cold regions of Japan, ultra-low temperature storage—which utilizes natural cold air to maintain brown rice at sub-zero temperatures—has been shown to preserve quality and flavor over extended times [2].
Previous research on the physical properties of cooked polished rice (it is raw rice) stored at 10°C, -20°C, -40°C, and -60°C has reported that physical changes intensify as the storage time lengthens. While significant changes were observed at 10°C, these effects diminished at lower temperatures of -20°C and -40°C. At -60°C, the properties remained nearly identical to those measured before storage.
In this study, polished rice was stored at four different temperatures: 25°C (representing room temperature), 4°C (refrigeration), -20°C (standard freezing), and -80°C (an ultra-low temperature even lower than those in previous reports). Every two months, the rice was cooked and subjected to texture profile analysis, sugar content measurement, and X-ray internal observation to assess the impact on the cooked rice.
Furthermore, as freezing cooked rice for later consumption has become a widespread lifestyle choice to improve household efficiency, the frozen storage of cooked rice is receiving increased attention. Therefore, this experiment also involved freezing the rice (previously stored under various conditions and then cooked) for one week. After thawing, the same measurements were conducted. Overall, the study evaluated the effects of storage temperature and duration on the physical properties and characteristics of cooked rice, as well as how subsequent freezing and thawing influence the properties of the resulting "frozen rice."

2. Materials and Methods

2.1 Material and Sample Preparation

The sample used was polished Koshihikari rice produced in Uonuma, Niigata Prefecture, in 2024 (Reiwa 6). Portions of 300 g of polished rice were placed in resealable plastic bags and stored in an incubator set at 25°C, a refrigerator at 4°C, a freezer at -20°C, and an ultra-low temperature freezer at -80°C. Measurements were conducted every two months for the rice stored at each temperature.

2.2 Cooking Procedure

For each sample, 250 g of rice was weighed and washed. The washing process involved stirring the rice by hand 10 times followed by a water change, repeated three times. After washing, the rice was drained in a colander, transferred to a rice cooker pot, and water was added until the total weight reached 625 g. The rice was then cooked using a domestic induction heating (IH) rice cooker (Zojirushi NW-SA10).

2.3 Frozen Storage of Cooked Rice

After cooking, 150 g portions of rice were wrapped in plastic film and shaped into rectangles (approximately 11 cm × 8 cm, with a thickness of 1.5 cm). These samples were then stored in a freezer at -20°C for one week.

2.4 Texture Analysis

After cooking or thawing, the samples were allowed to cool at room temperature for one hour. The hardness stress, cohesiveness, and adhesiveness were then measured using a creep meter (Yamaden RE2-3005C). Each 5 g sample was packed into a stainless steel petri dish (30 mm in diameter and 15 mm in height). The measurement conditions were set as follows: a cylindrical plunger with a diameter of 30 mm was used, the compression speed was 1.0 mm/s, the strain rate was 85%, and the number of compressions was two[1]. Each sample was measured 10 times per point, and the entire procedure was repeated three times for each specimen.

2.5 Measurement of Sugar Content

Sugar extract solutions were prepared from cooked rice, thawed rice, and raw rice stored at each temperature. For raw rice, 5 g samples were used, while for cooked rice, a weight calculated based on the cooked weight ratio (approximately 11 g) was measured. To each sample, 25 mL of 80% ethanol was added, followed by homogenization. The mixture was shaken for one hour and then subjected to suction filtration to separate the supernatant from the residue. Another 25 mL of 80% ethanol was added to the residue, shaken for an additional hour, and filtered again.
The two supernatants were combined, and the ethanol was removed using a rotary evaporator (EYELA N-1300). Distilled water was added to the remaining liquid to bring the total volume to 20 mL. This solution was then passed through a 0.45 µm filter to obtain the final sugar extract.
The sugar content (D-glucose, maltose, and sucrose) was determined by measuring the absorbance of the prepared extracts using an enzymatic method with the E-kit (Enzytec Liquid), and the values were calculated accordingly.

2.6 Internal Observation Via X-ray Microscopy

Internal observations of both polished and cooked rice were conducted using an X-ray microscope (Bruker SkyScan 1272). To prevent the samples from drying out during the measurement, they were sealed with a thin film. The acquired images were subsequently reconstructed using specialized software to facilitate detailed internal analysis.

3. Results and Discussions

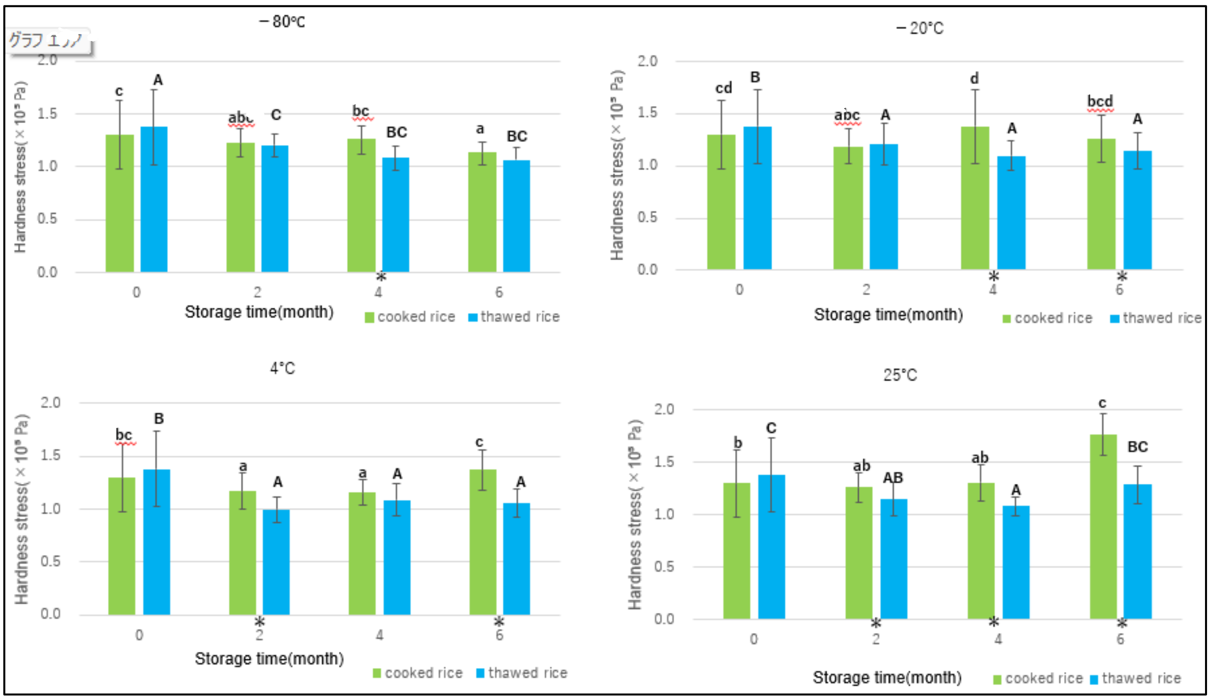
3.1 Physical Property Measurement Results

Figure 1(a) shows the hardness stress results for cooked and thawed rice stored at different temperatures and durations, measured after cooling at room temperature for one hour. At storage temperatures of -80°C and -20°C, no specific trend was observed for either cooked or thawed rice; however, the -80°C condition showed minimal changes. For the 4°C storage, the hardness of cooked rice increased from the 4th to the 6th month of storage, while no consistent trend was found after thawing.At 25°C, the hardness of cooked rice remained stable until the 4th month but increased sharply after 6 months. Regarding the thawed rice, although no single trend was observed, a discrepancy between the cooked and thawed states emerged starting at 2 months, with this difference tending to widen as the storage time lengthened. Across all temperatures, for samples showing significant differences between cooked and thawed states, the thawed rice tended to be softer with lower numerical values. These results suggest that lower storage temperatures minimize changes in cooked rice, whereas higher temperatures lead to more pronounced hardening over long-term storage. Conversely, for the frozen-then-thawed rice[1], the duration of raw rice storage did not appear to significantly impact the increase in hardness.

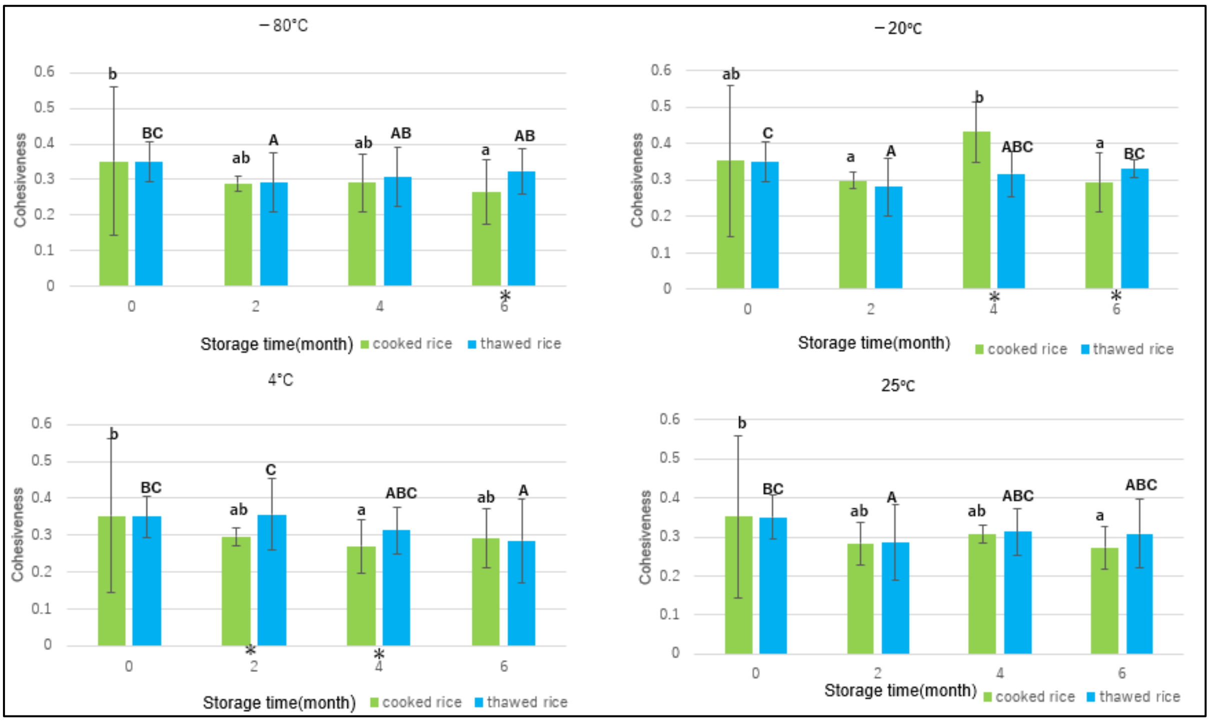
Figure 1(b) shows the Cohesiveness. No consistent trend related to storage duration was observed at any storage temperature for either cooked or thawed rice. While no remarkable differences were found between the cooked and thawed states in most cases, those with significant differences showed a tendency for higher cohesiveness after thawing. The fact that storage duration and temperature had little effect on cohesiveness aligns with previous studies. This suggests that cohesiveness is relatively resilient to storage conditions, allowing for a consistent mouthfeel during mastication regardless of the storage time.

Figure 1(c) shows the results for Adhesiveness. Fo r cooked rice, no major changes were observed over time at any temperature. When comparing cooked and thawed rice, although no consistent trend in significant differences was found, the thawed rice tended to exhibit higher adhesiveness when differences did occur. Since no major shifts in adhesiveness were observed across any storage temperature over the six-month time, these results suggest that the characteristic "stickiness" of rice is not significantly affected by storage within a half-year timeframe.

(a)



(b)



(c)

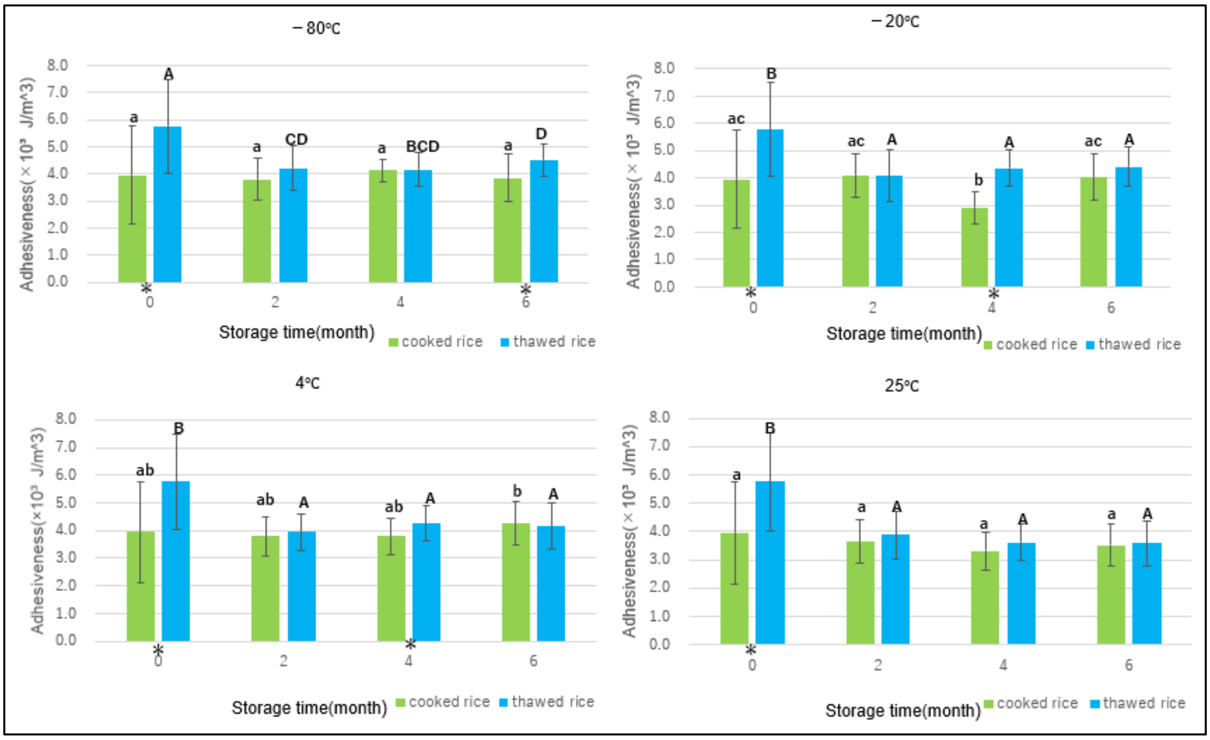


Fig.1 . Effect of Storage Temperature and time on the Texture Properties of Cooked Rice.
a) Hardness stress value; b) Cohesiveness; c) Adhesiveness
Defferent small letters indicate significantly different between storage times of the same storage temperature for cooked rice ($p<0.05$)
Different capital letters indicate significantly different between storage times of the same stotage temperature for thawed rice ($p<0.05$)
*)This mark indicates that there is a significant difference between cooked rice and thawed rice stored at the same temperature and storage times($p<0.05$).

3.2 Measurement of Sugar Content

The amounts of maltose, sucrose, and D-glucose per 100 g of raw rice were calculated using an enzymatic method for polished, cooked rice, and thawed rice stored at various temperatures and durations(Table 1).

Table 1. Measured mean values of maltose, sucrose, and D-glucose content in various rice samples (polished, cooked, and thawed) stored at different temperatures and times(mg/100 g raw rice).

	Maltose〔mg/100 g raw rice〕											
	−80°C			−20°C			4°C			25°C		
Storage time (month)	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice
0	64.01	62.90	59.23	64.01	62.90	59.23	64.01	62.90	59.23	64.01	62.90	59.23
2	59.78	54.67	51.66	41.50	37.64	44.35	40.03	44.62	42.33	47.74	43.35	50.59
4	57.16	49.41	53.57	60.24	49.30	55.55	60.12	51.61	59.03	56.17	48.85	49.91
6	53.61	47.50	53.55	56.02	46.71	53.30	61.32	53.47	56.16	51.37	49.59	46.63

	Sucrose〔mg/100 g raw rice〕											
	−80°C			−20°C			4°C			25°C		
Storage time (month)	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice
0		32.34			32.34			32.34			32.34	
2		23.34			14.63			18.31			24.89	
4		22.72			20.55			23.22			16.91	
6		31.51			28.36			26.10			20.88	

	D-Glucose〔 mg/100 g raw rice〕											
	−80°C			−20°C			4°C			25°C		
Storage time (month)	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice	cooked rice	raw rice	thawed rice
0	41.71	17.78	45.69	41.71	17.78	45.69	41.71	17.78	45.69	41.71	17.78	45.69
2	42.24	16.71	40.88	42.51	24.87	42.51	42.83	20.85	45.90	36.78	18.57	41.91
4	43.47	18.33	38.38	41.43	17.41	41.32	40.26	18.65	36.00	41.36	18.60	42.68
6	46.04	15.71	40.83	42.15	16.03	41.74	43.15	15.18	45.16	44.31	15.74	46.67

Based on these results, the contents of maltose, sucrose, and D-glucose in the rice did not show any significant changes across different storage temperatures or durations. This indicates that a storage times of up to six months does not influence the sugar content, regardless of the storage environment.
Regarding the sucrose content in both cooked and thawed rice, the levels in this experiment were below the detection limit, making it impossible to detect sucrose. Previous studies report that the amount of sucrose in 100 g of cooked rice is approximately 25 mg/100 g[3], and the amount of glucose is about 110 mg/100 g; however, the detection levels in the present study were substantially lower than these values. Possible factors for this discrepancy include insufficient extraction during the sugar extraction process or procedural errors during the operation of the detection kit.
While various sugar detection methods exist, the enzymatic method used in this study is a relatively simple and convenient approach. However, its convenience comes with certain limitations in detection sensitivity. These results suggest the necessity of carefully evaluating detection methods for use in educational settings, where reproducibility is a critical requirement.

3.3 Internal Observation Via X-ray Microscopy

In this experiment, internal observations were conducted using an X-ray microscope for both polished rice and cooked rice stored at 25°C, which is considered an extreme temperature for rice preservation(Fig. 2).

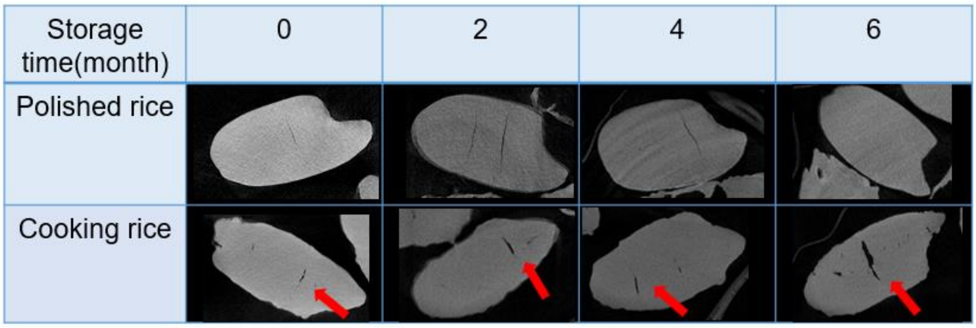


Fig. 2. X-ray microscopic observation: A comparison of internal structural images between polished rice and cooked rice samples stored at 25°C. The red arrow points the cavity.

For the sectional internal image observation, the central portion of the grain, which has the largest surface area, was selected for analysis. Regarding the internal structure of the polished rice, although cracks were observed in the center, no significant changes over time were found.
In contrast, focusing on the cross-sections of the cooked rice, cavities were observed in the central part of the rice grains (as indicated by the arrows), and these cavities tended to enlarge as the storage times lengthened. This phenomenon suggests that swelling and gelatinization did not fully reach the interior of the rice grains during cooking. It can be inferred that the duration of storage affects this process, with insufficient swelling and gelatinization becoming more apparent over time.
Previous studies have reported the existence of cavities in the cross-sections of cooked rice and have shown that the water absorption rate of rice decreases during storage[1],[4]. Therefore, in this experiment as well, it is presumed that the storage times led to a decline in water absorbency, resulting in insufficient water penetration to the core of the grain and the appearance of these cavities in the central cross-section of the cooked rice.

4. Conclusions

When polished rice was stored at -80°C, -20°C, 4°C, and 25°C for six months, texture analysis revealed that for both freshly cooked and thawed rice, no consistent trend in hardness stress was observed at -80°C and -20°C. In particular, changes over time were minimal at -80°C. In contrast, rice stored at 25°C showed a sharp increase in hardness after six months. These results suggest that lower storage temperatures minimize texture changes in cooked rice, while higher temperatures promote hardening over extended times. However, for frozen-stored cooked rice, the duration of the initial raw rice storage did not appear to affect the increase in hardness. Regarding cohesiveness and adhesiveness, no significant changes were observed in freshly cooked rice across different storage durations or temperatures, suggesting that a six-month storage time has little impact on these properties. Notably, in cases where differences did occur, thawed rice tended to be more cohesive and adhesive.
In terms of sugar content, no clear trends related to storage temperature or duration were identified. However, the detected amounts were substantially lower than those reported in previous studies, with sucrose remaining below the detection limit. This discrepancy may be attributed to procedural errors, suggesting that while simple enzymatic methods are advantageous, it is essential in educational settings to consider more highly reproducible techniques.
X-ray microscopic observation of the internal structure of rice stored at 25°C showed no temporal changes in raw polished rice. However, in cooked rice, the central cavity tended to enlarge as the storage time lengthened. This is likely because the storage duration led to a decline in water absorbency, resulting in insufficient water penetration to the core and, consequently, incomplete swelling and gelatinization during cooking.
This study applied a multifaceted approach to everyday life science, integrating chemical analysis through component extraction and reagents, physical and engineering measurements using a creep meter, statistical analysis of measured data, and morphological observation. By combining these interdisciplinary methods, the research presents a learning model that enables students to connect specialized knowledge across domains and to understand scientific phenomena from multiple perspectives. The findings suggest that this approach can serve as a practical and transferable framework for STEM education, supporting interdisciplinary understanding and inquiry-based learning in contemporary science education contexts.

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