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RICE STORAGE BELOW ICE POINT USING NATURAL COLDNESS TO PRESERVE ITS QUALITY

by

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Summary:

We developed a technique for storing rice below ice point using natural coldness. We conducted a basic study to examine the effect of storage temperature on the overall quality of Japonica rice. Rice storage experiments on a laboratory scale were carried out at environment temperature, low temperature (below 15°C), ice point and at –15°C. The results showed that the rice storage at –15°C preserved rice quality. Next, a rice storage experiment on a farm scale was conducted. A total of 378 metric tons of rough rice was stored in a farm-scale silo and aerated for 113 hours in February. The temperature of the rough rice in the silo fell below ice point. The temperature of the rough rice in the middle of the silo remained below ice point until July. The quality of the stored rice was consequently preserved at a level similar to that of freshly harvested rice even after 9 months of storage. A combination of rice storage below ice point and natural coldness in winter could be used as a new technique to preserve the rice quality without the need of a cooling unit or electricity.

Keywords:

Rice, Storage below ice point, Natural coldness, Quality preservation, Super-low-temperature storage

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INTRODUCTION

There are two commercial rice storage systems in Japan: the environment-temperature storage system, in which the temperature during storage is not controlled; and the low-temperature storage system, in which the temperature is kept below 15°C during storage. The low-temperature storage system can minimize insect activity and mold growth, and therefore fumigants are not required during storage. However, this system requires electricity to cool the stored rice. The total capacity for storing dried brown rice in Japan in 1998 was about 12 million metric tons. About 50% of the storage structures are equipped with cooling units, and the number of storage structures with cooling units is increasing every year.

Hokkaido, the northernmost island of Japan, has the highest yield of rice in Japan. The winter in Hokkaido is very cold, with the temperature being always below ice point. Sapporo, the capital of Hokkaido, has about 60 ice-days (maximum daily temperature is below ice point) in a year.

It may be possible to apply natural coldness in winter to a new technique for storing rice without electric energy consumption. However, little is known about the changes in the quality of rice that is stored at a temperature below ice point. Therefore the objectives of this study were (1) to examine the effect of storage temperature on the overall quality of rice, and (2) to develop a new farm-scale rice storage technique using natural coldness.

EFFECT OF STORAGE TEMPERATURE ON OVERALL QUALITY OF RICE (LABORATORY EXPERIMENT)

MATERIALS AND METHODS

RICE SAMPLES

A rice-storage experiment was carried out using a Japonica rice variety (Kuiku 125), and the experiment was repeated in the following year using another Japonica variety (Kirara 397).

STORAGE CONDITIONS

About 15kg of brown rice was stored in a polyethylene container with a screw lid under the following conditions:

1. Environment-temperature storage; i.e., the rice sample was stored in a commercial rice warehouse without any temperature control system;
2. Low-temperature storage; i.e., the rice sample was stored in a commercial rice warehouse equipped with a cooling unit and insulated walls, and kept below 15°C;
3. Ice-point temperature storage; i.e., the rice sample was stored in a refrigerator and kept at ice point;
4. Minus 15°C storage; i.e., the rice sample was stored in a refrigerator and kept at −15°C.

The period of each storage experiment was 9 months for Kuiku 125 and 11 months for Kirara 397.

QUALITY ASSESSMENT

The quality of each rice sample was examined after storage.

Moisture content was determined by the official method of the Japan Food Agency. Ground rice (5 g) was placed in a forced-air oven at 105°C for 5 hours, and moisture was computed on a wet basis.

Brown rice samples (at least 3kg per sample) were milled in a friction mill (model MCM-250, Satake Engineering, Tokyo, Japan) to obtain milled rice samples. The milling procedure consisted of passing the rice through the friction mill four times while adjusting the back pressure on the rice in the milling chamber to maintain the milling degree at 90.5% (±0.1%). The milling degree was defined as the ratio of the weight of milled rice to that of the brown rice.

A sensory test was twice carried out according to the official Japanese rice taste testing method standardized by the Japan Food Agency. The sensory test was a multiple comparison test.

RESULTS AND DISCUSSION

GRAIN TEMPERATURE

The temperature of the brown rice during the environment-temperature storage and the low-temperature storage experiments decreased from November (at the beginning of storage experiments) to the middle of January (Fig. 1). The minimum grain temperature in the environment-temperature storage experiment was about 0°C. After that, the grain temperature increased. When the grain temperature reached 15°C in May, a cooling unit began to cool the warehouse, and the grain temperature was kept at about 13°C in the low-temperature storage experiment. However, in the environment-temperature storage experiment, the grain temperature continued to increase, reaching about 19°C at the end of the storage experiment.

The grain temperature in the ice-point storage and minus 15°C storage experiments was kept constant at 0°C (±1°C) and –15°C (±1.5°C), respectively.

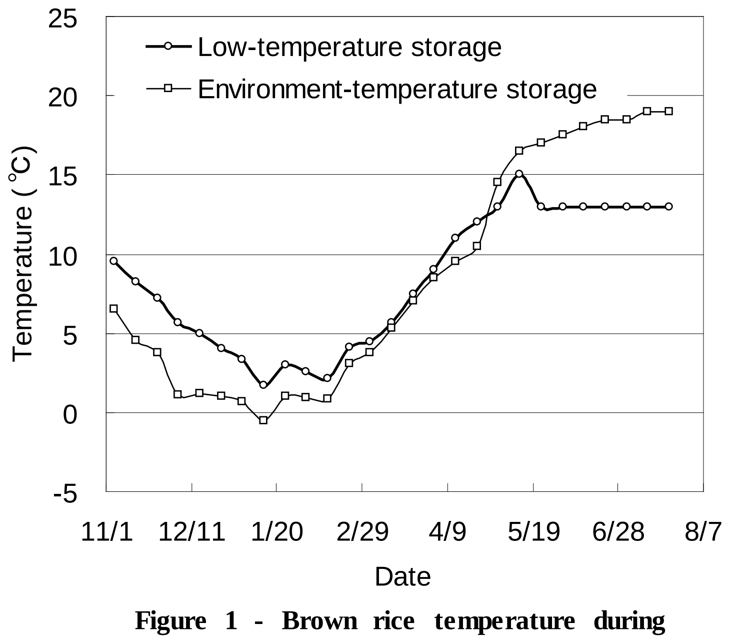

Figure 1 - Brown rice temperature during environment-temperature storage and low-temperature storage experiments (Kuiku 125).

QUALITY ASSESSMENT

The moisture contents of Kuiku 125 and Kirara 397 before storage were 16.2% and 15.2%, respectively. There was little change in moisture content during storage because the samples were kept in containers with lids.

Sensory evaluations of Kuiku 125 after storage for 9 months (Fig. 2) showed that there were significant differences in the appearance of the milled and the cooked rice, aroma and overall flavor according to storage conditions. The appearance of the milled and the cooked rice, aroma and overall flavor of the sample stored at −15°C were significantly better than those of the sample stored at environment temperature. The sensory evaluations of Kirara 397 (Fig. 3) after storage for 11 month were almost the same as those of Kuiku 125. These results proved that the storage of rice below ice point could preserve the quality of rice during storage.

DEFINITION OF SUPER-LOW-TEMPERATURE STORAGE

We designated the storage of rice below ice point as “super-low-temperature storage” due to the fact that the storage temperature was much lower than that of low-temperature storage. In this experiment, the temperature of the rice in the super-low-temperature storage was maintained at –15°C. However, –15°C is too low for farm-scale storage. Farm-scale super-low-temperature storage was then defined as storage in which the grain temperature is always kept below 15°C and below ice point for at least one month during storage.

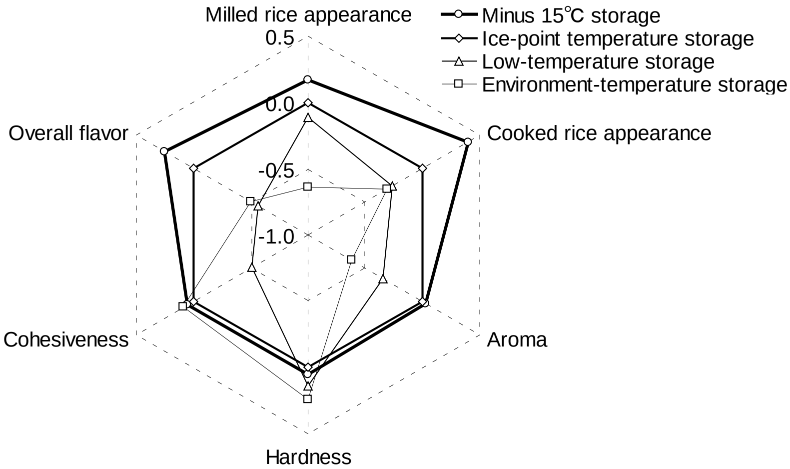

Figure 2 - Taste evaluation after 9-month storage (Kuiku 125).

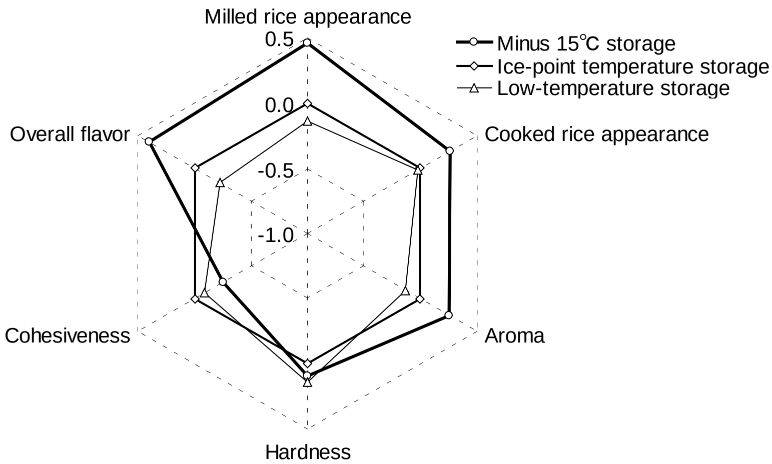

Figure 3 - Taste evaluation after 11-month storage (Kirara 397).

RICE STORAGE BELOW ICE POINT USING NATURAL COLDNESS TO PRESERVE ITS QUALITY (ON-FARM EXPERIMENT)

MATERIALS AND METHODS

RICE SAMPLE

Kirara 397 (a Japonica rice variety) was used for the on-farm rice storage experiment.

STORAGE CONDITIONS

A round silo with a diameter of 6.4 m, a height of 26 m, and a capacity of 417 metric tons of rough rice was used for the on-farm experiment. The silo had a hopper bottom and was made of steel with a 50-mm layer of insulation on the walls. It was also equipped aeration systems throughout. A total of 378 t of rough rice was stored in the silo. The storage period was from the end of November until the middle of August of next year (9 months).

Three control experiments were also carried out simultaneously: a room-temperature storage experiment, in which the rice sample was stored in a laboratory room; a low-temperature storage experiment in which the rice sample was stored in a commercial rice warehouse and kept below 15°C; and a minus 5°C storage experiment, in which the rice sample was stored in a refrigerator and kept at −5°C. About 15 kg of rough rice was stored in a polyethylene container with a lid in each control experiment.

QUALITY ASSESSMENT

Moisture content, germination rate, free fat acidity and texturogram property were determined, and a sensory test was twice conducted before and after storage to assess rice quality.

Moisture content was determined by the official method of the Japan Food Agency. Germination rate was measured according to the standard method of the Japan Food Agency; one hundred sound brown rice kernels were soaked in a hydrogen peroxide solution (1% [w/w] concentration) and placed in an incubator at 20°C. Germination rate was determined by the number of kernels that germinated within seven days. Free fat acidity was determined by the rapid method of the American Association of Cereal Chemists (AACC, method 02-02); free fat acid was extracted in a benzene solution and the extracted solution was then titrated with potassium hydroxide solution. Texturogram property (hardness/stickiness ratio) was defined as the ratio of the first positive peak to the first negative peak of the texture profile as measured by a texturometer (Zenken, Tokyo, Japan). The sensory test was carried out according to the official Japanese rice taste testing method.

RESULTS AND DISCUSSION

AMBIENT TEMPERATURE DURING ON-FARM STORAGE

The minimum daily temperature was below ice point from the end of November until the end of April (Fig. 4). The lowest minimum daily temperature was −22°C in February and the highest maximum daily temperature was 33°C in July.

AERATION AND GRAIN TEMPERATURE

Rough rice in the silo was aerated at the beginning of February. Aeration was performed when the temperature of inlet air was below −5°C and it was continued until the cooling front had moved throughout the rough rice in the silo. The airflow rate was 0.11 $m^3/(min \cdot t)$, static pressure was 270 mmAq, air velocity at the grain surface was 0.022 m/s, and total aerating time (fan time) was 113 h.

The temperature of the rough rice was measured at the center of silo and at 10 cm from the silo wall by thermocouples set at every 3 m from the bottom to the top of the silo. Grain temperature distribution in vertical direction was less than 2°C. The sets of temperatures recorded at the center and wall of the silo, respectively, were then averaged, and were used to indicate changes in temperature of the rough rice during on-farm storage (Fig. 5).

The temperature of the rough rice was 7°C at the beginning of storage. The wall temperature gradually decreased as the ambient temperature fell. The minimum grain temperature at the wall was −7°C in the middle of February. From the beginning of March until the end of storage (in the middle of August), the grain temperature at the wall gradually increased. The maximum temperature at the wall was 19°C at the end of July. The temperature of the rough rice at the center of silo fell to −3°C when aerated. The center temperature was kept at −3°C until the end of April and kept below ice point until the middle of July. The center temperature was 2°C at the end of storage. After the aeration in February, the temperature of the rough rice throughout the silo remained below ice point until the end of March. Super-low-temperature storage was therefore realized in a farm-scale silo using aeration and natural coldness in winter.

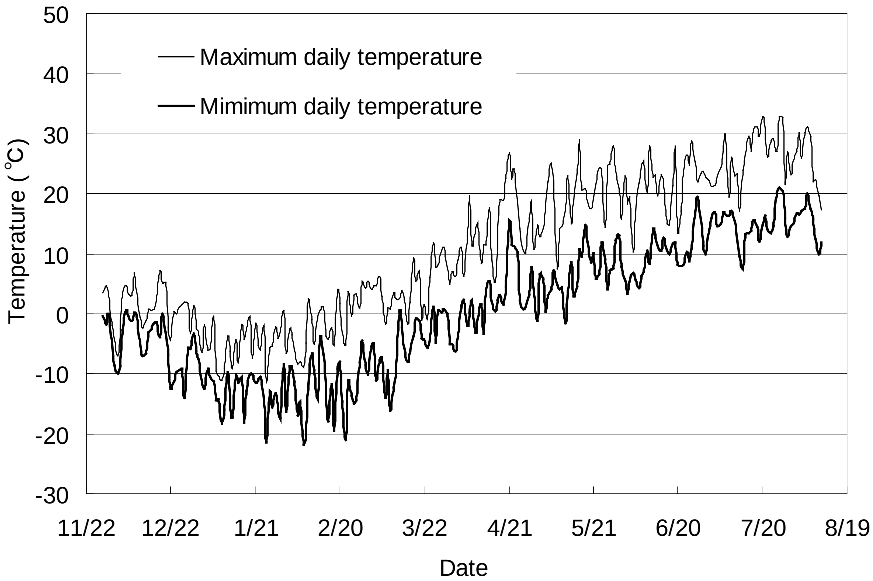

Figure 4 - Ambient temperature during on-farm storage.

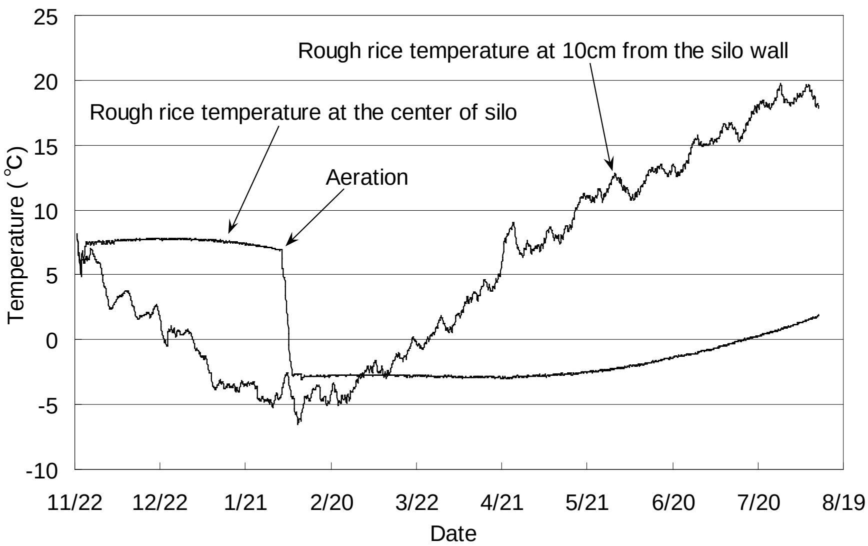

Figure 5 - Rough rice temperature during on-farm storage.

MOISTURE MIGRATION

The rough rice was sampled and inspected every month during storage. Rough rice samples were taken from the center and 10 cm from the wall at four points. Sampling depths below surface were 0.1, 0.5, 1, 2 and 4 m.

The moisture content of each sample was almost the same at the beginning of storage (Fig. 6). The moisture contents of surface grain and grain around the walls decreased by the end of storage (Fig. 7). Rewetting of grain did not occur during storage. Moisture did not migrate during winter because the grain temperature was low. Moisture migration started from when the grain temperature rose to more than 5°C. A ventilation system in the top of the silo was used to avoid moisture condensation on inside surface of the silo. The system worked automatically whenever the air temperature in the vacant space at top of the silo was 3°C higher than the ambient temperature. The moisture content of surface grain decreased mainly due to the ventilation of this vacant space.

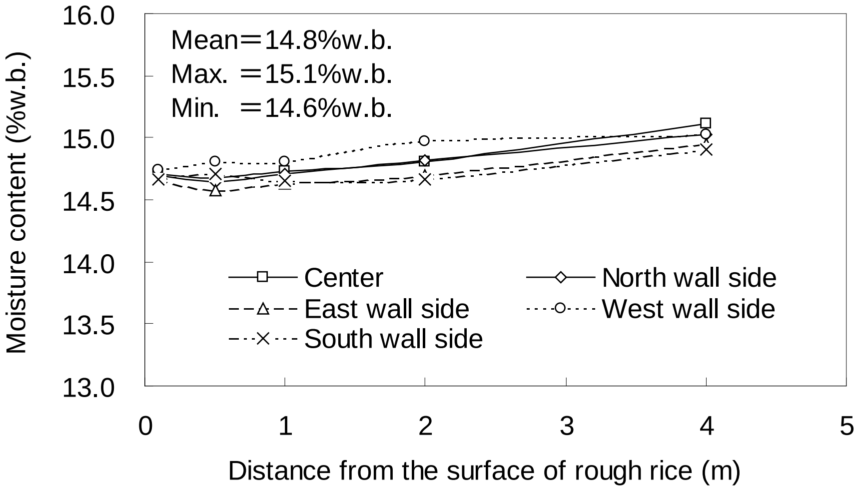

Figure 6 - Moisture content distribution of rough rice stored in the silo at the beginning of storage.

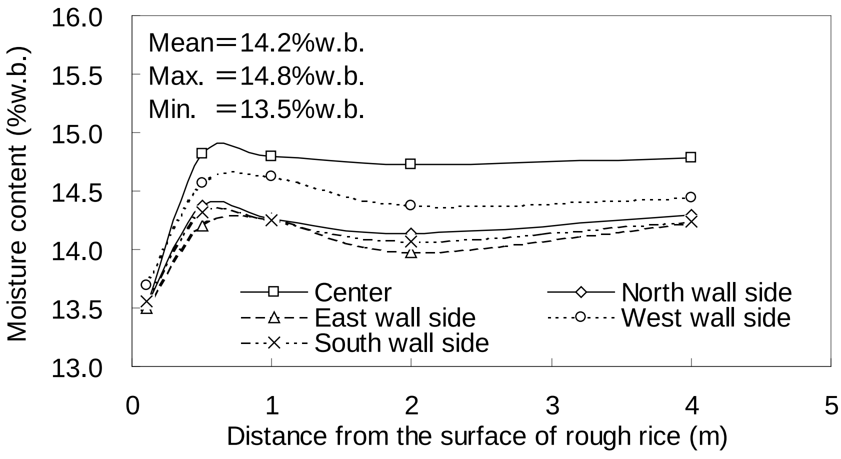

Figure 7 - Moisture content distribution of rough rice stored in the silo at the end of storage.

REWARMING PROCESS

During the unloading of grain in spring and summer, warm humid air comes in contact with the cooled grain and may condense into moisture on the surface of grain. If warm humid air touches cooled rough rice, the hulls first absorb the resultant condensation and then the moisture slowly permeates into the kernel. If the air comes into direct contact with cooled brown rice, on the other hand, the condensation may cause the kernel to crack. Accordingly, cooled rough rice needs to be rewarmed to a temperature above the dew point temperature of the surrounding air before shelling.

Three types of rewarming process were used to prevent the kernels from cracking in this on-farm experiment (Fig. 8).

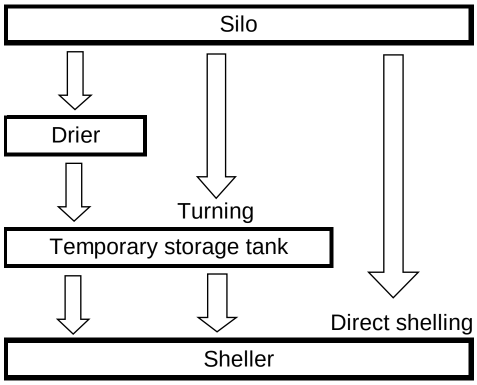

Figure 8 - Rewarming process from silo to sheller.

TEMPERATURE OF GRAIN AND TEMPERATURE AROUND SHELLER DURING UNLOADING, REWARMING AND SHELLING

The stored rough rice was unloaded in the middle of August. At the beginning of unloading, the temperature of the unloaded rough rice was below 5°C (Fig. 9). If the temperature of the rough rice was lower than the dew point temperature around the sheller, the rough rice was passed through a drier and a temporary storage tank, and shelled (Fig. 8). The unheated forced-air drier was used for rewarming. After rewarming using the drier, the temperature of the rough rice before shelling increased to near ambient temperature (Fig. 9). If the temperature of the rough rice after unloading was close to the dew point temperature around the sheller, the rough rice was turned into a temporary storage tank and shelled (Fig. 8). After turning, the temperature of the rough rice before shelling rose above the dew point temperature (Fig. 9). To simplify the rewarming process after unloading, the rough rice was directly shelled if the temperature of the rough rice was close to the dew point temperature around the sheller (Fig. 8). During passage along the belt conveyers and bucket elevators, the temperature of the rough rice rose above the dew point temperature around the sheller (Fig. 9).

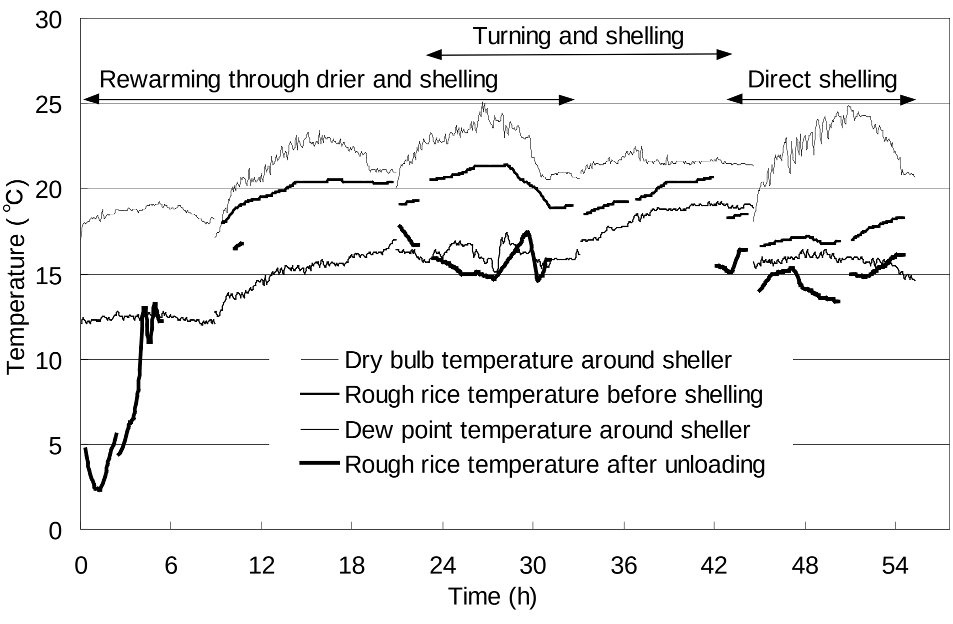

Figure 9 - Temperature of grain and temperature around sheller during unloading, rewarming and shelling.

MOISTURE CONTENT OF ROUGH RICE DURING UNLOADING AND REWARMING

During unloading, rewarming and shelling process, a sample was taken from every 10 t of grain in order to measure moisture content and to check for cracked kernels. Judging from the moisture content of the rough rice after unloading, there was no wet point in the silo (Fig. 10). The samples of rough rice taken at the beginning and at the end of unloading were found to have a low moisture content because the rough rice in the hopper bottom of the silo was dried by the aeration in February. The low-moisture grain was mixed with other grain during the rewarming, shelling and shipping process, and therefore the low moisture content of the grain did not result in any problems.

The mean moisture content before loading (before storage) was 14.9%, which decreased to 14.8% after unloading (after storage) because the moisture content of the rough rice at the surface, around the walls, and in the hopper bottom of the silo had decreased. However, the volume of rough rice with a low moisture content was very small compared to the total volume in the silo. Consequently, the total moisture decrease of the rough rice during storage was only 0.1%. By the time of shelling, the mean moisture content had returned to 14.9% due to the condensation during rewarming.

CRACKED KERNELS

The proportion of cracked kernels observed before storage was 1.0% (Table 1). None of the rewarming processes increased this percentage of cracked kernels. This result proves that condensation on rough rice does not give rise to any problems.

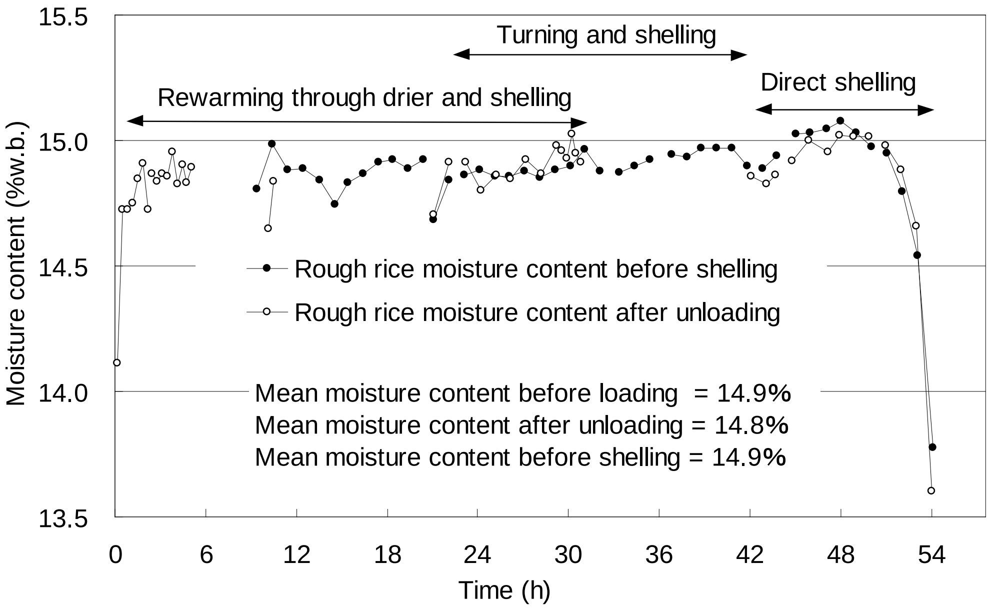

Figure 10 - Moisture content of rough rice during unloading and rewarming.

Table 1. Cracked kernels (%)

	After storage		Rewarming process from silo to sheller					
			Rewarming using drier and shelling		Turning and shelling		Direct shelling	
Before storage	Before shelling	After shelling	Before shelling	After shelling	Before shelling	After shelling	Before shelling	After shelling
1.0	0.8	1.0	1.2	1.0	1.0	1.0	1.2	1.2

QUALITY ASSESSMENT

The temperature of the rough rice during on-farm and the control storage are indicated in Fig. 11. The mean temperatures of the rice during room-temperature, low-temperature, on-farm silo and minus 5°C storage were 18.6°C, 5.0°C, 0.8°C and –5.1°C, respectively.

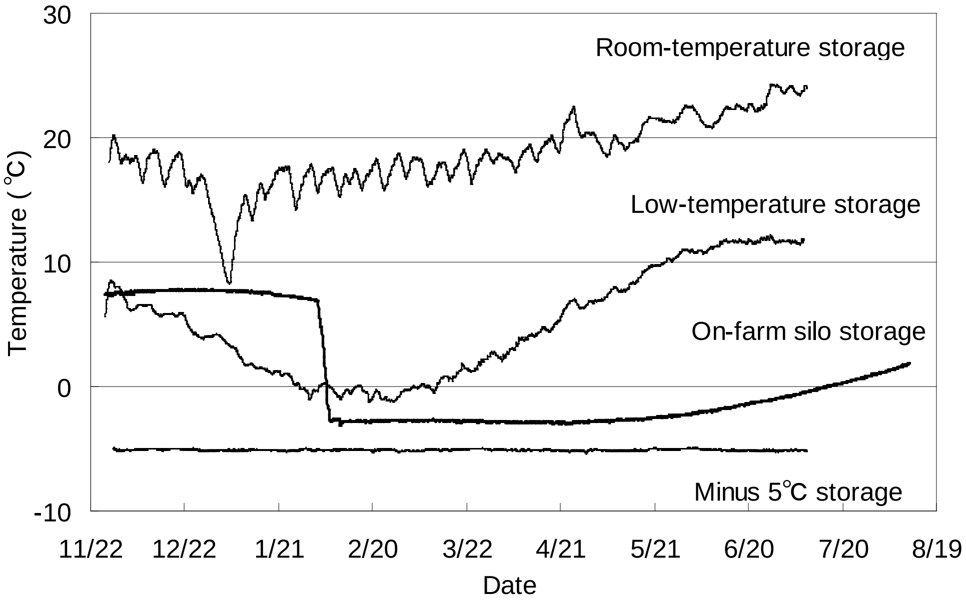

Figure 11 - Rough rice temperature during on-farm storage and control storage.

The germination rates of rice subjected to silo, minus 5°C and low-temperature storage were as high as that of the sample taken before storage (Fig. 12). On the other hand, the germination rate of rice subjected to room-temperature storage was very low (10%). This means that the rice lost vitality during high-temperature storage.

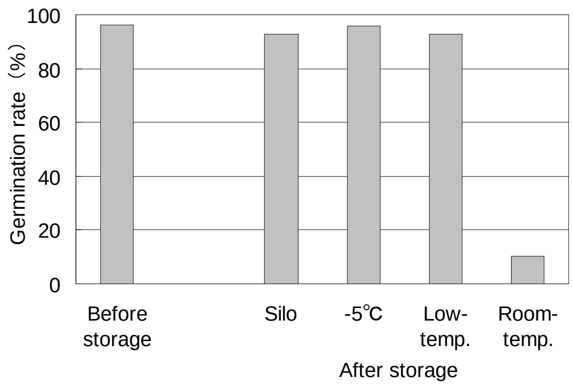

Figure 12 - Germination rate of brown rice.

Free fat acidity increased during each type of storage (Fig. 13). However, the rate of increase was lowest in rice subjected to minus 5°C storage, increasing in rice subjected to silo and low-temperature storage, to be highest in rice subjected to room-temperature storage. This result indicates that the low temperature of the stored grain controlled the decomposition process of fat.

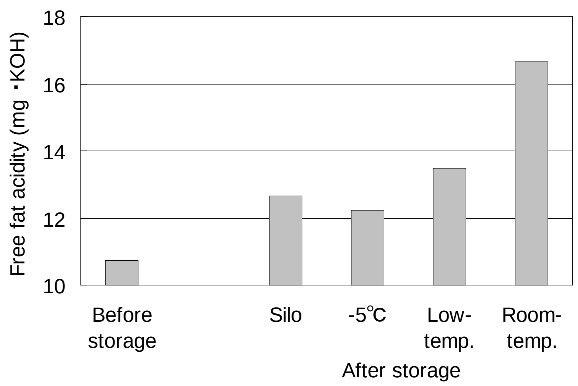

Figure 13 - Free fat acidity of brown rice.

The hardness of cooked rice increased and the stickiness of cooked rice decreased after storage (Fig. 14). The changes in the texture of cooked rice were caused by the deterioration of rice starch. The deterioration was minimized by silo storage and minus 5°C storage because of the low temperature.

The overall flavor of the rice subjected to silo and minus 5°C storage was a little better than that before storage (Fig. 15). The sensory test was a multiple comparison test. The reference sample for the test before storage was kept in a refrigerator (3-5°C). The same reference sample was used for the test after storage. The reference sample also deteriorated during storage in the refrigerator. The samples subjected to silo and minus 5°C storage deteriorated less than the reference sample because of the lower storage temperature.

The quality assessments indicate that rice storage below ice point (silo storage and minus 5°C storage), which we designated as super-low-temperature storage, minimized deterioration and preserved rice quality much better than did storage at higher temperatures.

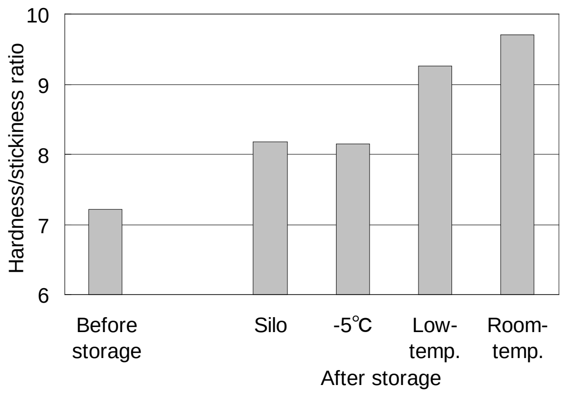

Figure 14 - Texturogram property of cooked rice.

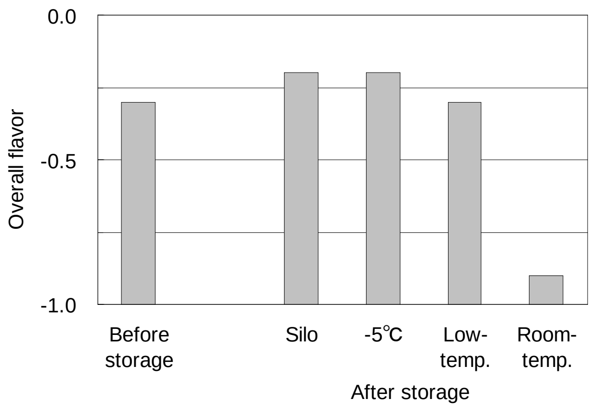

Figure 15 - Overall flavor of sensory test.

CONCLUSION

We developed a technique for storing rice below ice point using natural coldness in winter. The quality of the rice stored below ice point was preserved at a level similar to that of freshly harvested rice. A combination of rice storage below ice point and natural coldness in winter could be used as a new technique to preserve rice quality without the need of a cooling unit (expense) or electricity (energy). This new rice storage technique has been increasingly applied throughout the colder regions of Japan.