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Development of On-farm Storage Technique for Rice at Temperature below Ice Point Using Ambient Naturally Cold Air in Winter

Shuso Kawamura, Associate Professor

Agricultural Process Engineering Lab. Hokkaido University, Sapporo 060-8589, Japan shuso@bpe.agr.hokudai.ac.jp

Kazuhiro Takekura, Graduate Student

Agricultural Process Engineering Lab. Hokkaido University, Sapporo 060-8589, Japan Takekura@bpe.agr.hokudai.ac.jp

Kazuhiko Itoh, Professor

Agricultural Process Engineering Lab. Hokkaido University, Sapporo 060-8589, Japan kazu@bpe.agr.hokudai.ac.jp

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Abstract. *The objective of this project was to develop a new on-farm storage technique for rice at a temperature below ice point using ambient naturally cold air in winter. In an on-farm storage experiment, 994 tons of rough rice was stored in two silos from the end of November 1999, and the rough rice was aerated from the bottom to the top of each silo for 91 hours in January 2000. The rough rice temperature in each silo fell down below ice point (minus 1.5 degrees Celsius on average). At the end of storage (end of July 2000), the temperature of rice grains in the center of each silo was kept still below ice point (minus 0.5 degrees Celsius). The quality of the rice stored in the silos was thereby preserved at a level similar to that of freshly harvested rice. A combination of rice storage at a temperature below ice point and utilization of ambient cold air in winter enables the quality of rice to be preserved at a high level without the requirement of a cooling unit or electricity.*

Keywords. Rice, Quality, Super-low-temperature storage, Cold air, Aeration, Farm size

Introduction

Currently, there are two commercial rice storage systems in Japan: an environment-temperature storage system, in which the temperature during storage is not controlled; and a low-temperature storage system, in which the temperature is maintained below 15 °C during storage. The low-temperature storage system minimizes insect activity and mold growth, and fumigants are therefore 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 1999 was 12.7 million metric tons. Fifty seven percent of the storage structures in Japan in 1999 were equipped with cooling units, and the number of storage structures equipped with cooling units has been increasing every year.

Our previous basic studies revealed that dried rice (with a moisture content of about 15% w.b.) does not freeze even at a temperature of –80 °C (Kawamura et al., 2000) and that the quality of rice stored at a temperature below ice point is comparable to that of newly harvested rice (Kawamura et al., 1997, 1999). The results of our study indicated that a temperature below ice point minimized the physiological activities in rice and hence minimized the deterioration of rice quality. We called rice storage at a temperature below ice point "super-low-temperature storage".

In 1996, a grain elevator (GE), called Kamikawa Grain Elevator, was constructed in Hokkaido, the northernmost island of Japan, the temperature in winter is always below ice point. The Kamikawa GE was the first grain elevator to be constructed in Hokkaido.

Based on the results of our studies mentioned above, an on-farm experiment was conducted at Kamikawa GE from 1996 to 1998 in order to develop a new rice storage technique for cold regions such as Hokkaido (Kawamura et al., 1999). In the experiment, rough rice was cooled to a temperature below ice point by aerating it in a silo with chilly fresh air in winter, and super-low temperature storage on a farm size was thus realized. The quality of rough rice that had been stored by super-low-temperature storage was higher than those of rice samples that had been stored by conventional low-temperature storage and room-temperature storage. Various techniques were used in the on-farm experiment at Kamikawa GE, such as automatic ventilation in the upper vacant space of the silo during storage to avoid moisture condensation on the inside surface of the silo, aeration through the silo to cool the rice grains, rewarming of the rice grains after storage, and safe hulling conditions to prevent the occurrence of fissures in brown rice.

One problem with the on-farm super-low-temperature storage system was that the temperature of the rice grains near the inner silo wall gradually increased in spring and summer, whereas the temperature of rice grains in the center of the silo remained below ice point. However, it was not clear whether these differences in the temperature of rice grains in the silo affected the rice quality.

In 1999, a new grain elevator, called Uryuu GE, started operation in Hokkaido. The second on-farm experiment was conducted in this grain elevator from 1999 to 2000 to try to establish a new rice storage technique at a temperature below ice point using ambient naturally cold air in winter. In this experiment, the super-low temperature storage technique that had been developed in Kamikawa GE was used, and the effect of the difference in the temperatures of rice grains near the silo wall and in the center of the silo on rice quality was investigated.

Materials and methods

Storage structure

Figure 1 shows a grand plan of Uryuu GE, constructed in 1999, and Figure 2 shows a photograph of the GE. Two of the 12 silos of Uryuu GE were used for the on-farm experiment. The two silos used in the experiment are marked “S1” and “S2” in Figure 1. Each silo was round in shape with a hopper bottom and had a diameter of 7.4 m, a height of 26 m, and a capacity of 480 metric tons of rough rice. Each silo was made of steel with a 75-mm layer of insulation on the outside of the wall. An automatic system for aeration from the bottom through to the top of the silo and an automatic system for ventilation in the upper vacant space of the silo were installed.

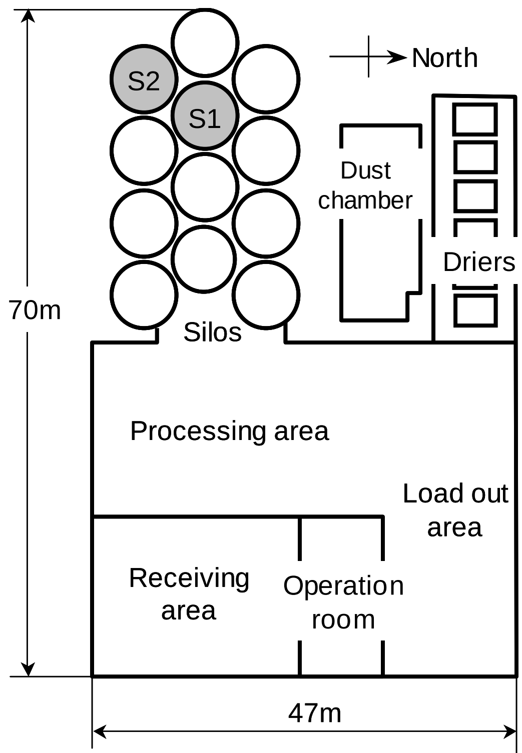

Figure 1. Grand plan of Uryuu grain elevator.

Figure 2. Photograph of Uryuu grain elevator.

Rice samples

Kirara397 and Hoshinoyume, which are very popular Japonica rice varieties, were used for the storage experiment.

Storage conditions

Five hundred t of Kirara397 rough rice was stored in the S1 silo, and 494 t of Hoshinoyume rough rice was stored in the S2 silo. The storage period was about 8 months, from the end of November 1999 until the end of July 2000. The rough rice in the two silos was simultaneously aerated at the end of January 2000. Aeration from the bottom to the top of the silo was automatically carried out when the temperature of fresh air was below −7°C and it was continued until the cooling front had moved through all of the rough rice in the silo. The static pressure of the air was 260 mmAq, air velocity at the grain surface was 0.03 ms^{-1}, volume quantity of airflow was 160 m^3min^{-1}, airflow rate was 0.16 $m^3min^{-1}t^{-1}$, and total aerating time (fan time) was 91 h.

Three control storage experiments were also carried out at the same time: a room-temperature storage experiment, in which rice samples were stored in a laboratory room; a low-temperature storage experiment, in which rice samples were stored in a commercial rice warehouse and kept at a temperature below 15°C; and a storage experiment at –5°C, in which rice samples were stored in a refrigerator and kept at –5°C. About 15 kg each of rough rice and brown rice were stored in polyethylene containers with lids in each control experiment.

Temperature measurement, sampling and quality assessment

The temperatures of rough rice in the center of silo and at 10 cm from the silo wall were measured by thermocouples set at 2.2-meter intervals from the bottom to the top of the silo. The temperatures of rough rice and brown rice in each container in the control storage experiments were also measured.

The rice was sampled and tested for quality before, during and after storage. Rough rice samples were taken from the center of the silo and at four points 15 cm from the silo wall (north, west, south and east in the silo) at the end of storage. Sampling depths below the surface of the rough rice were 0.1, 0.5, 1.0, 2.0 and 4.0 m.

The rate of rough rice flow during unloading after storage was 30 t/h. A sample was taken from every 10 t of rough rice (every 20 min) during unloading

Moisture content, germination rate, free fat acidity and texturogram property were determined to assess rice quality. Moisture content was determined by the standard method of the Japanese Society of Agricultural Machinery (JSAM); about 10 g of a whole-grain rice sample was placed in a forced-air oven at 135°C for 24 h, and the moisture content was computed on a wet basis. Germination rate was measured according to the standard method of the Japan Food Agency; three hundred sound brown rice kernels were soaked in a hydrogen peroxide solution (0.5% [w/w] concentration) and placed in an incubator at 20°C. Germination rate was determined by the number of kernels that had 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 measured by a texturometer (Zenken, Tokyo, Japan).

Results and discussion

Grain temperature during storage

The range of grain temperatures in the vertical direction in each silo was less than 3°C, and there was no tendency in the grain temperature distribution. The temperatures recorded in the center and near the wall of each silo were then averaged and were used as indicators of changes in grain temperature during on-farm storage (Figure 3).

The grain temperature in each silo was 10°C at the beginning of storage. The temperature of rice grains near the wall gradually decreased as the ambient temperature fell. The minimum temperature of rice grains near the wall in the middle of February was −2°C. From the end of March until the end of storage (at the end of July), the temperature of rice grains near the wall gradually increased. The maximum temperature of rice grains near the wall in the middle of July was 21°C. The temperature of the rice grains in the center of silo remained constant (10°C) at the beginning of storage and fell to −2°C when aerated at the end of January. The temperature of rice grains in the center remained below ice point until the end of July. After aeration, the grain temperature throughout the silo remained below ice point until the end of March. These results showed that super-low-temperature storage of rice in a farm-scale silo can be achieved by using aeration and chilly fresh air in winter.

The thermal conductivity of rough rice (0.09 $Wm^{-1}K^{-1}$) is nearly equal to that of lumber (0.15 $Wm^{-1}K^{-1}$) and glass wool (0.04 $Wm^{-1}K^{-1}$) and is smaller than that of steel (80 $Wm^{-1}K^{-1}$) and concrete (1 $Wm^{-1}K^{-1}$). This means that rough rice is a thermal insulating material. On the other hand, the specific heat of rough rice (1.7 $JK^{-1}g^{-1}$) is larger than that of lumber (1.3 $JK^{-1}g^{-1}$), concrete (0.8 $JK^{-1}g^{-1}$) and steel (0.5 $JK^{-1}g^{-1}$). This means that rough rice is also a refrigerant material. Because of these physical properties of rough rice, the grain temperature in the center of each silo remained below ice point until the end of July despite the increase in outside temperature in summer.

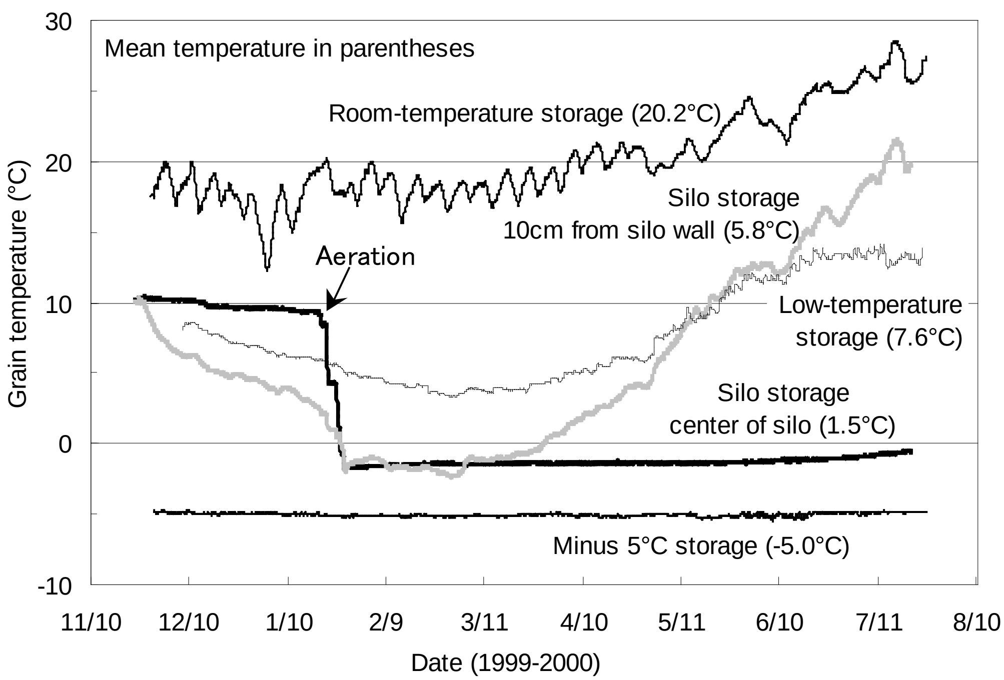

Figure 3. Rice grain temperatures during on-farm silo storage and control storage (Kirara397).

In our experiments, the mean temperatures of the rice grains during room-temperature storage, during low-temperature storage, at 10 cm from the silo wall during on-farm silo storage, in the center of the silo during on-farm silo storage, and during storage at –5°C were 20.2°C, 7.6°C, 5.8°C, 1.5°C and –5.0°C, respectively (Figure 3).

Quality of rice grains sampled from different parts of the silo at the end of storage

The germination rates and free fat acidities of rice samples taken from different parts of each silo at the end of storage are shown in Figures 4 and 5, respectively. The germination rates of all samples were more than 97%. Free fat acidities of all samples ranged from 12 mg to 15 mg. Rice grains that have a germination rate of more than 90% and free fat acidity of less than 20 mg means no deterioration in the quality.

The temperature of rice grains near the wall of each silo increased to about 20°C in July. However, the temperature of rice grains near the wall was below ice point for two months during winter, and the mean temperature of rice grains near the silo wall was 5.8°C. The results of the measurements of germination rates and free fat acidities showed that there was no deterioration in the quality of rice grains near the silo wall.

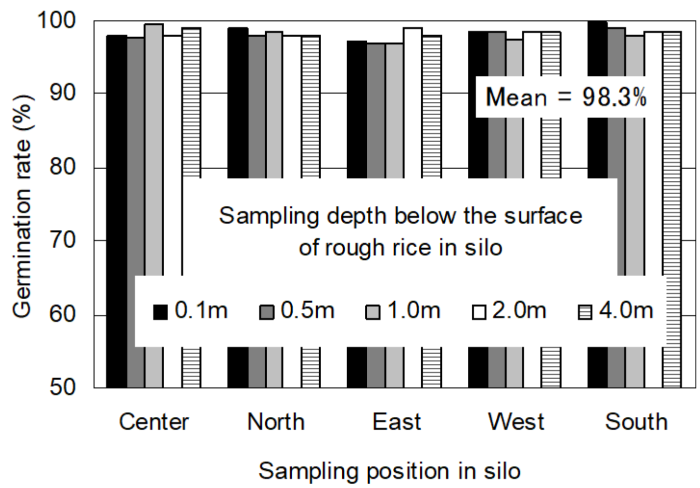

Figure 4. Germination rates of rice grains sampled from different parts of the silo (Hoshinoyume).

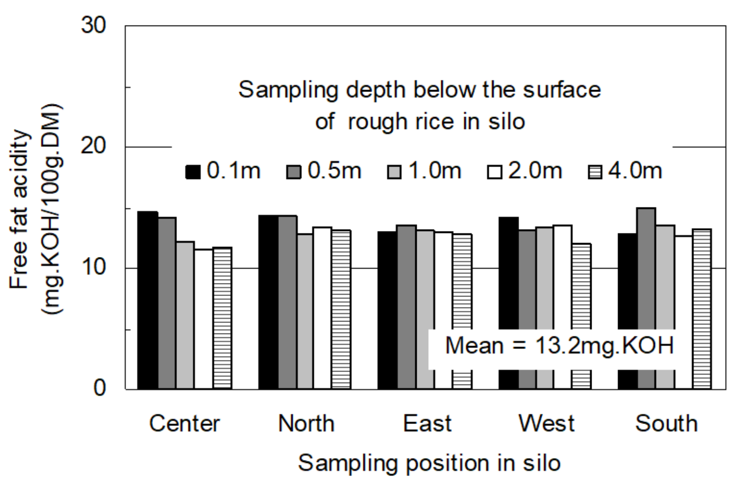

Figure 5. Free fat acidities of rice grains sampled from different parts of the silo (Hoshinoyume).

Grain temperature during unloading and quality of unloaded rice

Grain temperature at the beginning of unloading was 15°C, soon after the beginning of unloading, it decreased to 2 °C and then remained at about 2 °C for 2 h (60 t of rough rice). The grain temperature increased to about 18 °C at 4 to 6 h after the start of unloading and then fluctuated in the range of 5 °C to 15 °C until the end of unloading (Figure 6). The fluctuations in the grain temperature during unloading indicated that the low-temperature grains in the center of the silo and the high-temperature grains near the silo wall were mixed together when unloaded.

The germination rates and free fat acidities of rice samples taken during unloading are shown in Figures 7 and 8, respectively. The germination rates of all samples were more than 95%. Free fat acidities of the samples ranged from 12 mg to 15 mg. These results indicate that the quality of the rice grains was uniform and that there was no deterioration in quality.

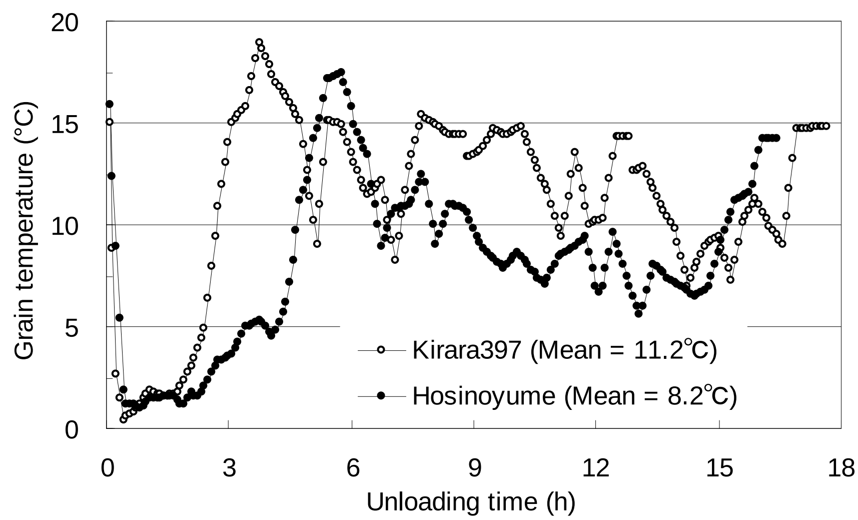

Figure 6. Rough rice temperature just after unloading from the silo.

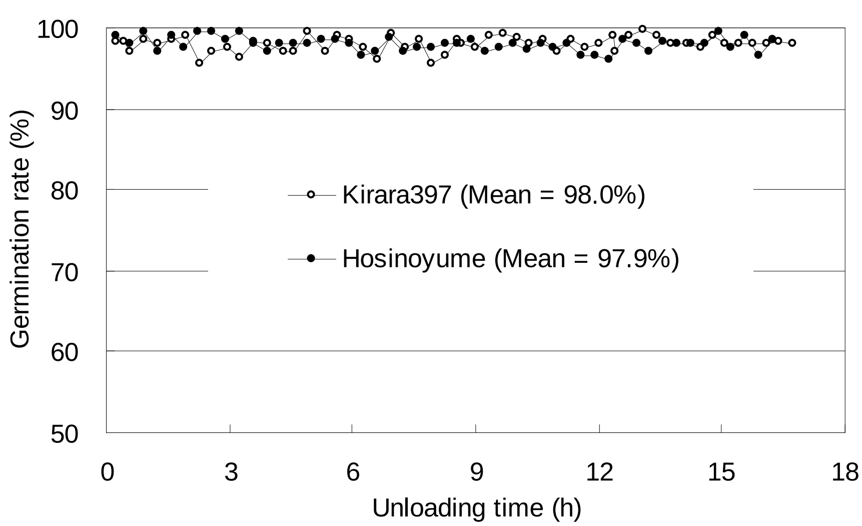

Figure 7. Germination rates of rice grains unloaded from the silo.

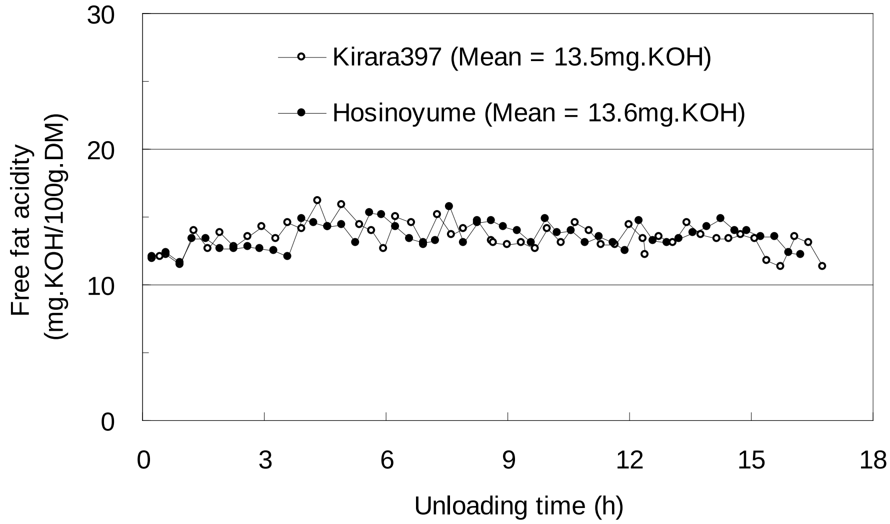

Figure 8. Free fat acidities of rice grains unloaded from the silo.

Moisture contents of rice grains before and after storage

The moisture contents of Kirara397 and Hoshinoyume were both 15.4% before loading (before storage). The moisture contents of Kirara397 and Hoshinoyume just after unloading from each silo (just after the end of storage) were 14.9% and 15.0%, respectively. An automatic system for ventilation of the upper vacant space of the silo was used to avoid moisture condensation on the inside surface of the silo. The moisture content of grain at the top decreased mainly due to the ventilation of this vacant space during storage, and the moisture content of grain at the bottom of the hopper of the silo decreased due to the aeration in January. However, by the time of shelling, the moisture contents of Kirara397 and Hoshinoyume had increased to 15.4% and 15.3%, respectively, due to moisture condensation during the rewarming process of cold rough rice after unloading.

The proportion of cracked kernels did not increase after the rewarming process, indicating that the moisture condensation on rough rice during the rewarming process did not cause any problems.

Quality assessment

The germination rates of rice subjected to silo, minus 5°C and low-temperature storage were more than 98%, as high as that of the sample taken before storage (Figure 9). On the other hand, the germination rate of rice subjected to room-temperature storage had decreased to about 50%, indicating that the rice had lost vitality during room-temperature storage.

The free fat acidities of rice increased in all of the storage experiments (Figure 10). However, there were differences in the rates of increase in free fat acidity: the rate of increase of rough rice storage was less than that of brown rice storage. Moreover, the rate of increase in free fat acidity was highest for rice stored at room-temperature, next-highest for rice stored at low-temperature and in the silo, and lowest for the rice stored at –5°C. These results indicate that the decomposition process of fat is slower in rice stored in rough rice and at a low temperature.

Generally, the hardness of cooked rice increases and the stickiness of cooked rice decreases after storage. The hardness/stickiness ratio increases as rice ages. The changes in the texture of cooked rice are caused by a deterioration in rice starch. Figure 11 shows that this deterioration was minimized by silo storage and minus 5°C storage, and rough rice storage.

The results of quality assessment indicate that storage of rice below ice point (silo storage and minus 5°C storage in this study), which we have called super-low-temperature storage, preserves the quality of rice at a much higher level than at higher temperatures.

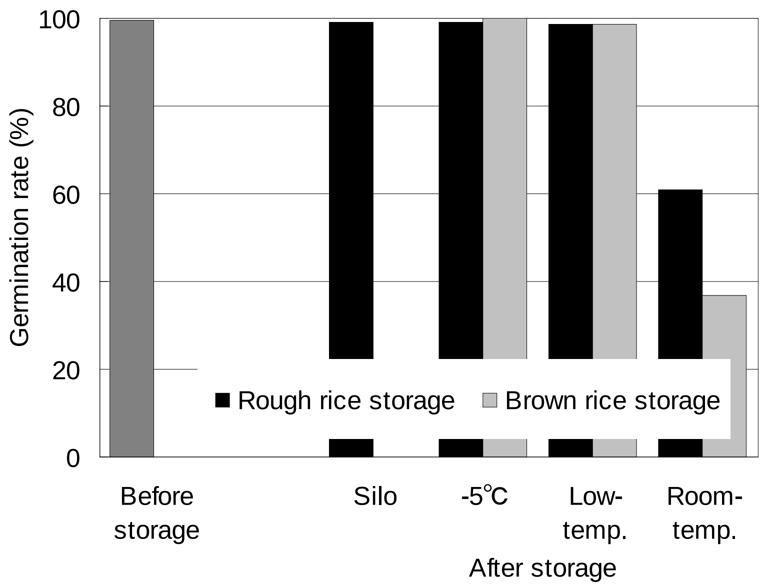

Figure 9. Germination rates of rice before and after storage (Kirara397).

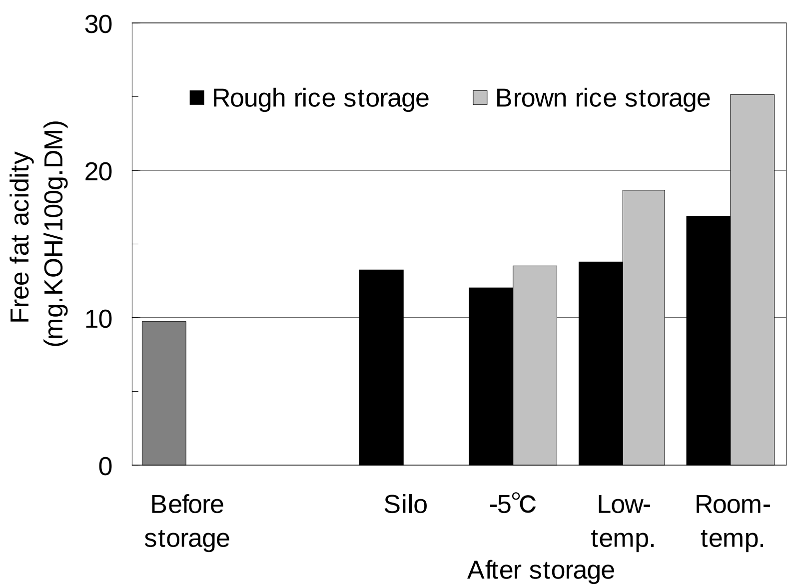

Figure 10. Free fat acidities of rice before and after storage (Kirara397).

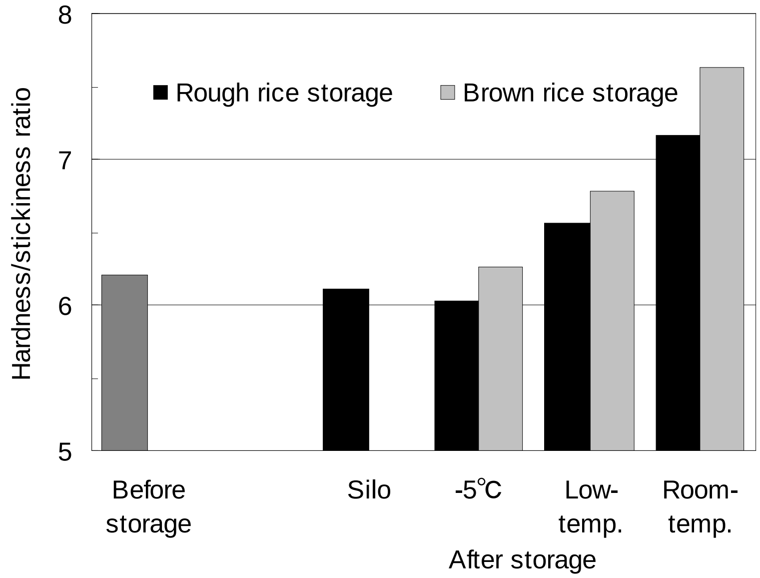

Figure 11. Texturogram properties of cooked rice before and after storage (Hoshinoyume).

Conclusions

We developed a new technique for storing rice at a temperature below ice point using ambient naturally cold air 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 at a temperature below ice point and the utilization of chilly fresh air in winter enables the quality of rice to be preserved at a high level without the requirement of a cooling unit or electricity. The use of this new rice storage technique in cold regions of Japan has been increasing in recent years. In Hokkaido, for example, 18 grain elevators have been constructed since 1996, and another 4 grain elevators are currently under construction in 2001. It is estimated that the storage capacity of rough rice in Hokkaido will be 100,000 t at the end of 2001.

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