



## XVII<sup>th</sup> World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)  
Québec City, Canada June 13-17, 2010



### **ROUGH RICE STORAGE BELOW FREEZING POINT BY USING RENEWABLE ENERGY FROM FRESH CHILLY AIR IN WINTER**

SHUSO KAWAMURA<sup>1</sup>, KAZUHIRO TAKEKURA<sup>2</sup>

<sup>1</sup> S. Kawamura, Graduate School of Agricultural Science, Hokkaido University, Sapporo, Hokkaido 060-8589, Japan, shuso@bpe.agr.hokudai.ac.jp

<sup>2</sup> K. Takekura, National Agricultural Research Center, Tsukuba, Ibaraki 305-8666, Japan, takekura@affrc.go.jp

#### **CSBE100685 – Presented at Section II: Farm Buildings, Equipment, Structures and Livestock Environment Conference**

**ABSTRACT** A project was conducted to develop a new on-farm storage technique for rough rice at a temperature below freezing point by using renewable energy from fresh chilly air in winter. One thousand tons of rough rice was stored in two on-farm silos from the end of November and it was aerated through [rough rice] from bottom to top of the silos for 91 hours in January. The rough rice temperature in the silo fell below freezing point (minus 1.5°C on average). At the end of the storage period (end of July in the next year after harvesting) the temperature of rough rice in the center of the silo was still below freezing point (minus 0.5°C). The quality of the rice stored below freezing point was preserved at a level similar to that of freshly harvested rice. A combination of rice storage at a temperature below freezing point and utilization of renewable energy from fresh chilly air in winter enables the quality of rice to be preserved at a high level without the requirement of a cooling system or electricity. The new technique for storing rough rice below freezing point was named as super-low-temperature storage system. The use of this storage technique in cold regions of Japan has been increasing in recent years. In Hokkaido, the northernmost island of Japan, 28 rice grain elevators have been constructed for super-low-temperature storage since 1996. The storage capacity of rough rice in Hokkaido was 124,000 t at the end of 2007.

**Keywords:** Super-low-temperature storage, natural cold renewable energy, rice quality, germination rate, free fat acidity, texturogram property.

**INTRODUCTION** The temperature and moisture content of rice grains greatly affect the quality of rice during storage. In Japan, the moisture content of brown rice during storage is maintained at a level of 16% (w.b., 10 g, whole-grain, 135°C, 24 h). There are two commercial brown 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 activities and mold growth, and fumigants are therefore not required during storage. However, this system requires electricity to cool the stored brown rice. The total capacity of brown rice storage

structures equipped with cooling units is about 6.6 million t, almost 70% of rice consumption in Japan.

A previous basic study (Kawamura et al., 1997) revealed that the quality of rice stored at a temperature below freezing point is comparable with that of newly harvested rice. Kawamura et al. (2000) reported that rice with moisture content of less than 17.8% does not freeze at a temperature of  $-80^{\circ}\text{C}$  and that a temperature below freezing point minimizes the physiological activities in rice and hence minimizes the deterioration of rice quality. Rice storage at a temperature below freezing point was named “super-low-temperature storage” by Kawamura et al. (1997, 1999) because the storage temperature was much lower than that of the low-temperature storage.

In 1996, a grain elevator was constructed in Hokkaido, the northernmost island of Japan, where the temperature in winter is always below freezing point. This grain elevator was the first grain elevator to be constructed in Hokkaido. Based on the results of the studies (Kawamura et al., 1997, 1999, 2000), an on-farm experiment was conducted at the grain elevator from 1996 to 1998 in order to develop a new rice storage technique for cold regions such as Hokkaido. In the experiment, rough rice was cooled to a temperature below freezing point by aerating it in a silo with renewable cold energy from chilly fresh air in winter, and super-low-temperature storage of rice on a farm scale was thus realized (Kawamura et al., 1999; Takekura et al., 2003a, 2003b, 2003c). The quality of rough rice that had been stored at a super-low temperature was higher than the quality of rice samples that had been stored at a conventional low temperature and at room temperature. Various techniques were used in the on-farm experiment at the grain elevator. These techniques included 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 freezing point. However, it was not clear whether this difference in the temperatures of rice grains in the silo affected the rice quality.

Based on the results of the experiment mentioned above, another on-farm experiment was conducted in a newly constructed grain elevator to establish the super-low-temperature storage technique at a temperature below freezing point using ambient naturally cold renewable energy in winter. In this experiment, the effect of the difference in temperatures of rice grains near the silo wall and in the center of the silo on rice quality was investigated. In this paper the results of the experiment is reported.

## **MATERIALS AND METHODS**

**Storage Structure** Figure 1 shows a grand plan of Uryuu grain elevator used for this experiment and Figure 2 shows a side view of the grain elevator. Two of the 12 silos of Uryuu grain elevator were used for the on-farm experiment. The two silos used for 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 23.2 m, and a capacity for rough rice storage of 480 t. Each silo was made of steel with a 75-mm insulation layer on the

outside of the silo wall. An automatic system was installed in each silo for aeration from the bottom through to the top of the silo, and an automatic system was installed in each silo for ventilation in the upper vacant space of the silo.

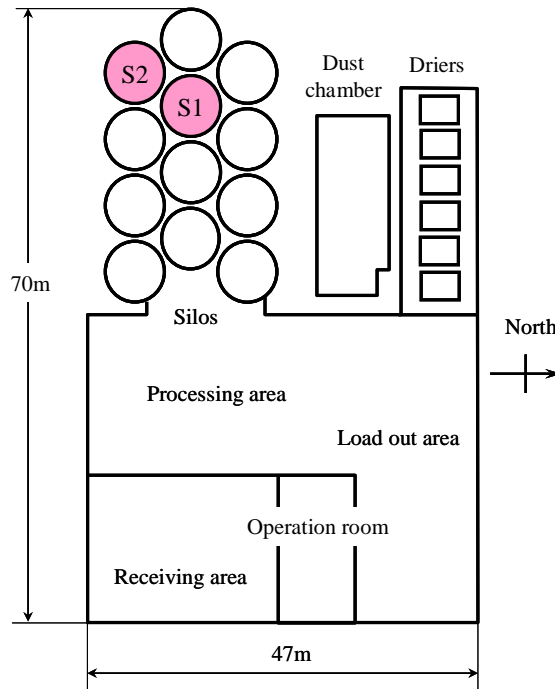


Figure 1. Grand plan of Uryuu grain elevator used for the experiment.



Figure 2. Side view of Uryuu grain elevator. (The silo on the left is one of the silos used for the experiment.)

**Rice Samples** Kirara397 and Hoshinoyume, popular Japonica type rice varieties in Japan, were used for the on-farm storage experiment. The moisture content of each rough rice sample was 15.4%.

**Storage Conditions** Five hundred tons 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 until the end of July in the next year. The

rough rice in the two silos was simultaneously aerated in January. Aeration from the bottom to the top of each silo was automatically carried out when the temperature of fresh air was below  $-7^{\circ}\text{C}$  and it was continued until the cooling front had moved through all of the rough rice in the silos. The static pressure of the air was 260 mmAq, air velocity at the grain surface in the silo was 0.03 m/s, volume quantity of airflow was  $160\text{ m}^3/\text{min}$ , airflow rate was  $0.16\text{ m}^3/\text{min}/\text{t}$ , 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 storehouse and kept at a temperature below  $15^{\circ}\text{C}$ ; and a storage experiment at  $-5^{\circ}\text{C}$ , in which rice samples were stored in a refrigerator and kept at  $-5^{\circ}\text{C}$ . About 15 kg each of rough rice and brown rice were stored in polyethylene containers with lids in each control experiment.

**Temperature Measurement and Sampling** 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 examined for quality before, during and after storage. Rough rice samples (100 g each) 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 the storage period. 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 (100 g) was taken from every 10 t of rough rice (every 20 min) during unloading.

**Quality Assessment** Moisture content, germination rate, free fat acidity and texturogram property were determined to assess rice quality. Moisture content (m.c.) 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  $135^{\circ}\text{C}$  for 24 h, and the moisture content was calculated on a wet basis. Germination rate was determined according to the standard method of the Japan Food Agency (JFA): three hundred sound brown rice grains were soaked in a hydrogen peroxide solution (0.3% [w/w] concentration) and placed in an incubator at  $20^{\circ}\text{C}$ . The germination rate was calculated by counting the number of grains that had germinated within a period of 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 from ground brown rice in a benzene solution, and the extracted solution was then titrated with potassium hydroxide solution. Texturogram property (hardness/stickiness ratio) of cooked rice 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 DISCUSSIONS

**Grain Temperature during Storage** The range of grain temperatures in the vertical direction in each silo was less than  $3^{\circ}\text{C}$ , and there was no tendency in the grain temperature distribution. The temperatures recorded in the center and near the wall of each silo were averaged respectively, and the average values 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 the storage period (at the end of July in the next year after harvesting), 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 the 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 of the silo remained below freezing point until the end of July. After aeration, the grain temperature throughout the silo remained below freezing point until the end of March. These results indicate that super-low-temperature storage of rice in a farm-scale silo can be achieved by using aeration and renewable cold energy from chilly fresh air in winter.

The thermal conductivity of rough rice (about 0.09 W/m/K, Seno et al., 1976) is nearly equal to that of lumber (0.15 W/m/K) and glass wool (0.04 W/m/K) and is smaller than that of steel (80 W/m/K) and concrete (1 W/m/K). This means that rough rice is a thermal insulating material. On the other hand, the specific heat of rough rice (about 1.7 J/K/g, Morita et al., 1979) is larger than that of lumber (1.3 J/K/g), concrete (0.8 J/K/g) and steel (0.5 J/K/g). 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 freezing point until the end of July despite the increase in outside temperature in summer.

In the experiments, the mean temperatures of 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 -5°C storage were 20.2°C, 7.6°C, 5.8°C, 1.5°C and -5.0°C, respectively (Figure 3).

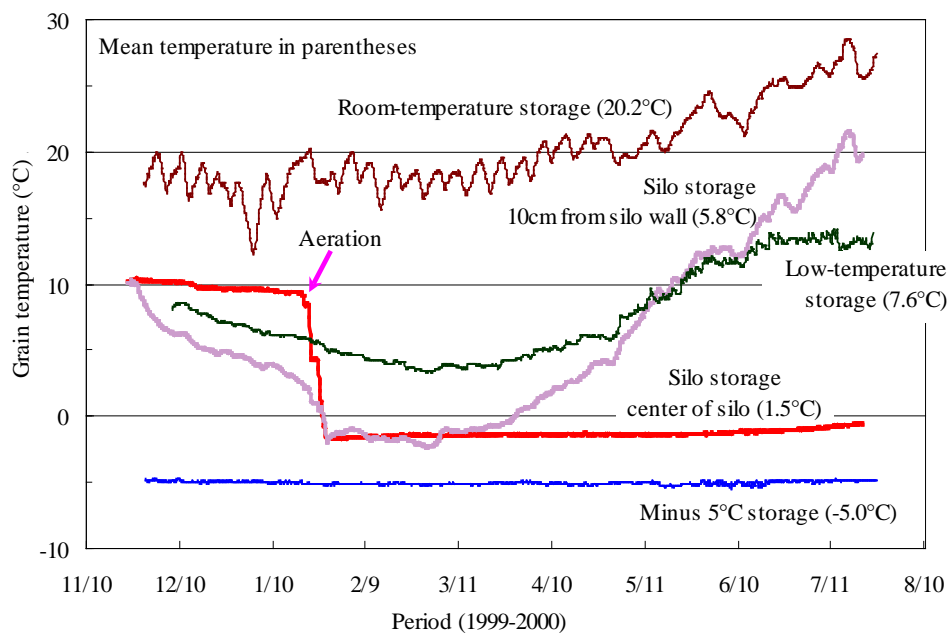


Figure 3. Rice grain temperatures during on-farm silo storage and control storage (Kirara397).

**Quality of Rice Grains Sampled from Different Parts of the Silo at the End of the Storage Period** The germination rates and free fat acidities of rice samples taken from different parts of the silo at the end of the storage period 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. A germination rate of rice grains of more than 90% and free fat acidity of rice grains of less than 20 mg means that there has been no deterioration in the quality of the rice. The temperature of rice grains near the silo wall increased to about 20°C in July. However, the temperature of rice grains near the wall was below freezing point during winter, and the mean temperature of rice grains near the silo wall during storage was 5.8°C. The results of measurements of germination rates and free fat acidities showed that there was no deterioration in the quality of rice grains near the silo wall.

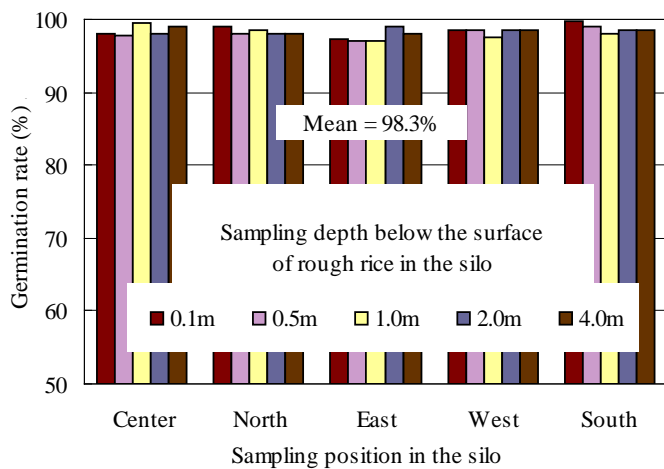


Figure 4. Germination rates of rice grains sampled from different parts of the silo (Hoshinoyume).

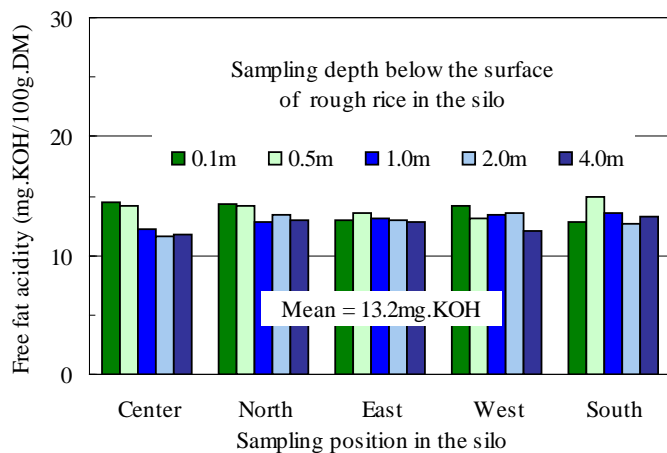


Figure 5. Free fat acidities of rice grains sampled from different parts of the silo (Hoshinoyume).

**Grain Temperature during Unloading and Quality of Unloaded Rice** The rough rice samples stored was unloaded in the end of July in the next year after harvesting. Grain temperature at the beginning of unloading was 15°C. Soon after the beginning of unloading, it decreased to 1°C and then remained at 1 - 3°C for 2 h (60 t of rough rice). The grain temperature increased to about 18°C from 4 h to 6 h after the start of unloading and then fluctuated in the range of 5 - 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 in the silo was uniform and that there was no deterioration in the quality.

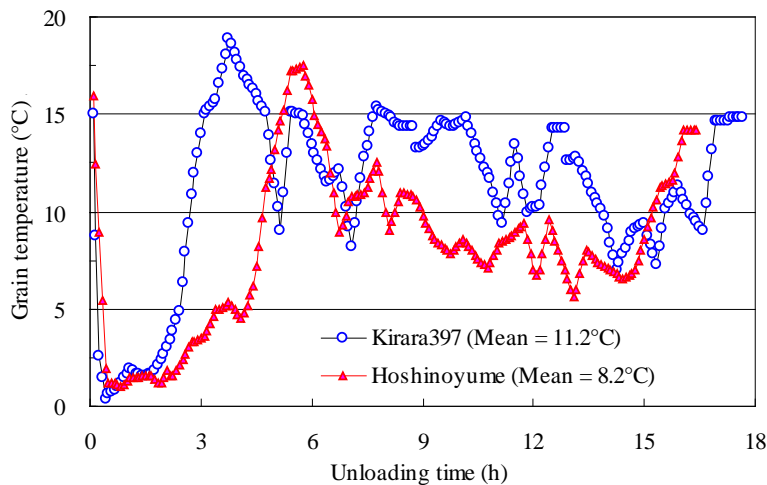


Figure 6. Rough rice temperature just after unloading from the silos.

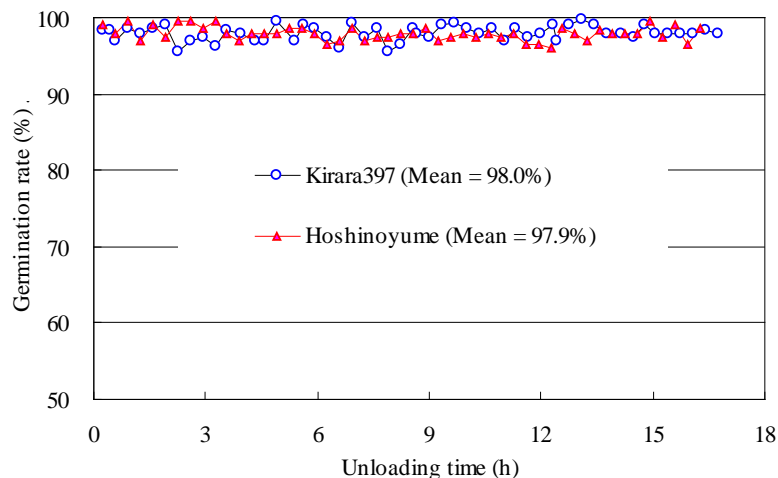


Figure 7. Germination rates of rice grains unloaded from the silos.

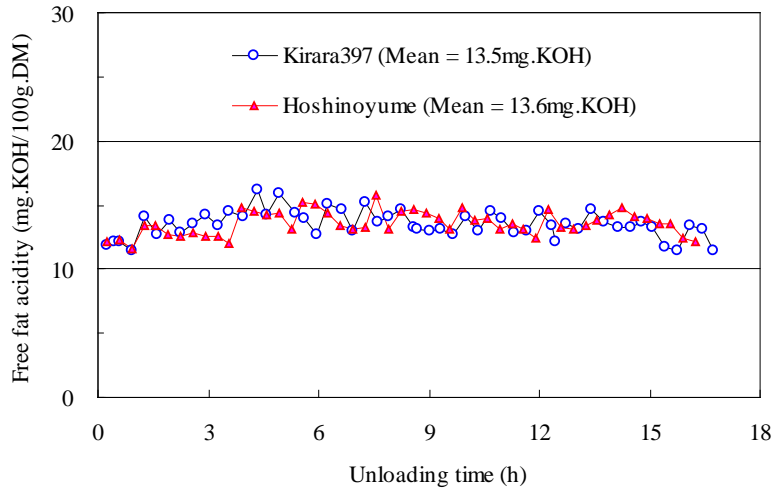
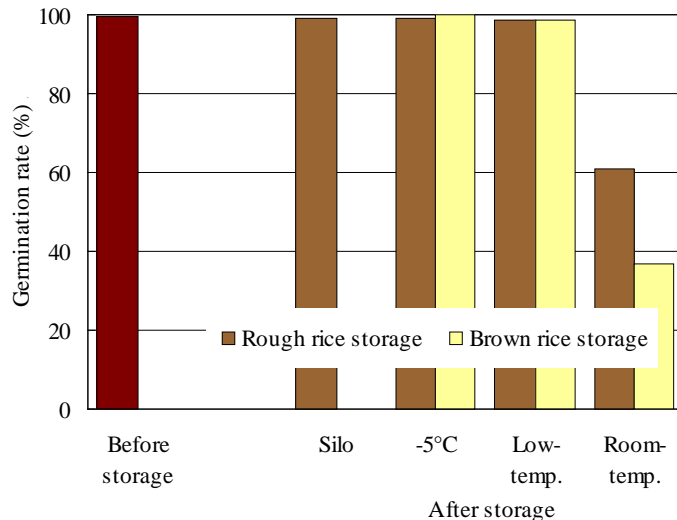


Figure 8. Free fat acidities of rice grains unloaded from the silos.

**Quality Assessment of Rice before and after Storage** The germination rates of rice subjected to silo,  $-5^{\circ}\text{C}$  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 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 in rough rice during storage was less than that of brown rice during storage. Moreover, the rate of increase in free fat acidity was highest for rice stored at a room temperature, next-highest for rice stored at a low temperature and in the silo, and lowest for rice stored at  $-5^{\circ}\text{C}$ . These results indicate that the decomposition process of fat is slower in rough rice during storage and in rice during storage at lower temperatures. Figure 11 shows that changes in the texture of cooked rice were minimized by silo storage and  $-5^{\circ}\text{C}$  storage and by storage of rough rice.



The results of quality assessment indicate that storage of rice at temperatures below freezing point (silo storage and  $-5^{\circ}\text{C}$  storage in this study), which is called super-low-temperature storage, preserves the quality of rice at a much higher level than that of rice stored at higher temperatures.



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

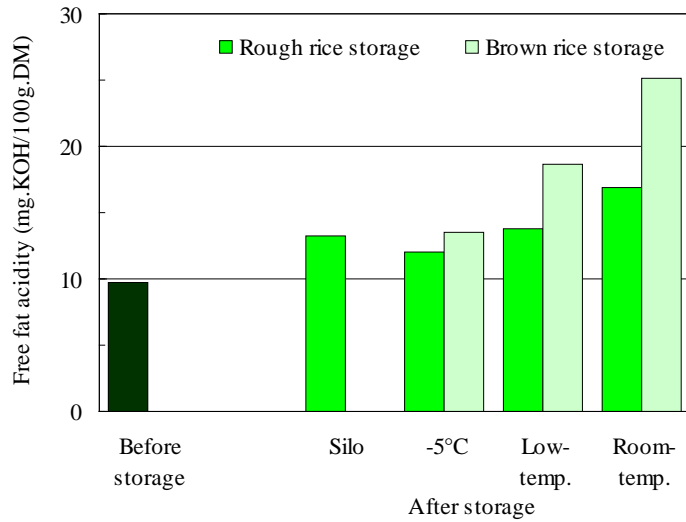


Figure 10. Free fat acidities of rice before and after storage (Kirara397).

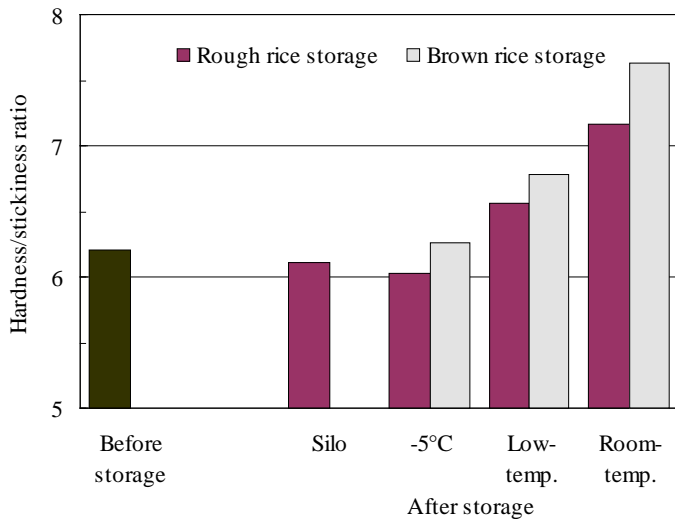


Figure 11. Texturogram properties of cooked rice before and after storage (Hoshinoyume).

**DISCUSSION** A new technique for storing rice at a temperature below freezing point by using renewable energy from ambient fresh chilly air in winter was developed. A combination of rice storage at a temperature below freezing point and utilization of renewable cold energy from chilly fresh air enables the quality of rice to be preserved at a high level without the requirement of a cooling unit or electricity.

The use of the super-low-temperature storage technique has been increasing in cold regions of Japan in recent years. In Hokkaido, the northernmost island in Japan, 28 grain-elevators have been constructed for super-low-temperature storage since 1996. The storage capacity of rough rice in Hokkaido was 124,000 t at the end of 2007.

## CONCLUSIONS

- Rice storage at a temperature below freezing point in farm-scale silos can be achieved by using renewable energy from fresh chilly air in winter. The temperature of all rice grains in the silo fell below freezing point. At the end of the storage period, the temperature of rice in the center of the silo was still below freezing point.
- The rice quality stored in the silo was uniform and preserved at a level similar to that of freshly harvested rice. A combination of rice storage at a temperature below freezing point and utilization of renewable cold energy from fresh chilly air enables the quality of rice to be preserved at a high level without the requirement of a cooling unit or electricity.
- The use of the new rice storage technique has been increasing in cold regions after the on-farm experiment. In Hokkaido, the northernmost island in Japan, 28 grain-elevators have been constructed since 1996. The storage capacity of rough rice in Hokkaido was 124,000 t at the end of 2007.

**Acknowledgements** The on-farm rice storage project was supported by Hokkaido Agricultural Structures Council, Japan. We are also grateful to Uryuu Agricultural Cooperatives for their cooperation in conducting the project.

## REFERENCES

- Kawamura, S., M. Natsuga, S. Kouno, and K. Itoh. 1997. Super-low Temperature Storage for Preserving Rice Quality. In Proc. Joint International Conference on Agricultural Engineering & Technology, Dhaka, Bangladesh, Volume III, 820-824.
- Kawamura, S., K. Takekura, N. Numata, T. Ogawa, and K. Itoh. 1999. Rice Storage below Ice Point Using Natural Coldness to Preserve Its Quality. ASAE Paper No. 996044. St. Joseph, Mich.: ASAE.
- Kawamura, S., K. Takekura, T. Ogawa, and K. Itoh. 2000. Long-Term Storage of Rough Rice at Temperatures below Ice Point. ASAE Paper No. 006041. St. Joseph, Mich.: ASAE.
- Morita, T., and P. R. Singh. 1979. Physical and thermal properties of short-grain rough rice. *Trans. ASAE*, 22, 630-636.
- Seno, T., T. Yamaguchi, Y. Aihara, and S. Kohara. 1976. Studies on grain storage by steel silo (2) On the physical properties of grains (in Japanese with English abstract). *J. Society of Agric. Structures, Jpn*, 6(1): 10-18.
- Takekura, K., S. Kawamura, K. Itoh. 2003a. Development of Techniques for Storing Rough Rice in Cold Regions (Part 1) (in Japanese with English abstract). *J. Jpn Society of Agric. Machinery*. 65(4): 57-64.
- Takekura, K., S. Kawamura, K. Itoh. 2003b. Development of Techniques for Storing Rough Rice in Cold Regions (Part 2) (in Japanese with English abstract). *J. Jpn Society of Agric. Machinery*. 65(4): 65-70.
- Takekura, K., S. Kawamura, K. Itoh. 2003c. Development of Techniques for Storing

Rough Rice in Cold Regions (Part 3) (in Japanese with English abstract). J. Jpn Society of Agric. Machinery. 65(5): 40-47.