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LOW-TEMPERATURE BROWN RICE STORAGE BY USING RENEWABLE ENERGY FROM SNOW

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ABSTRACT A low-temperature storage system for brown rice in which grain temperature is maintained below 15°C during storage has been commercially used in Japan. However, the low-temperature storage system requires a cooling system and electricity to cool rice in summer. The objective of this study was to determine whether renewable energy generated from snow can be used to replace the cooling system and electricity for cooling a rice storehouse. At the beginning of March 2009, a snow pile was made next to a practical rice storehouse (capacity of 2500 t of brown rice). The shape of the snow pile was a trapezium, 17 x 23 m at the bottom and 4 x 10 m at the top and 5 m in height. The total amount of snow was 890 t. The snow pile was covered with wood chips of 200-300 mm in thickness acting as an insulation layer. About 27% of the energy for cooling the rice storehouse could be replaced by using the snow pile in summer. The quality of rice stored in the storehouse was preserved at a level almost similar to that of freshly harvested rice. The results of this study indicate that renewable energy generated from snow piles can be utilized for cooling a rice storehouse as a high-quality rice storage system without electric energy consumption.

Keywords: Rice storage, Grain temperature, Free fat acidity, Germination rate

INTRODUCTION Rice is one of the most important crop products in the world, especially in Asian countries. Long-term storage of grain crop products including rice is an important issue for stable food supply all year round. There are three forms of rice, rough rice, brown rice and white milled rice, and rice is stored in each form. Moisture content and grain temperature greatly influence the quality during rice storage (Sharp and Timme, 1986).

There are various types of storage system depending on the rice form and grain temperature during storage. In the case of rough rice storage systems in Japan, there is a super-low-temperature storage system in which grain temperature is maintained below ice point using natural cold fresh air in winter (Tekekura et al., 2004; Kawamura et al., 2003a, 2004a, 2004b). The super-low-temperature storage enables rice quality to be preserved at a high level similar to that of freshly harvested rice. Rough rice storage is more effective for quality preservation compared to brown rice storage. However, the most popular rice storage systems in Japan (about 80% of rice produced in Japan) have been brown rice storage systems because of some historic reasons. There are two commercial brown rice storage systems in Japan: an environment-temperature storage system and a low-temperature storage system. The environment-temperature storage system, in which grain temperature is not controlled during storage, encourages insect activities and mold growth may occur. On the other hand, the low-temperature storage system, in which grain temperature is maintained below 15°C during storage, minimizes insect activities and mold growth, and fumigants are therefore not required during storage. However, the low-temperature storage system requires an electric cooling system and electric energy to cool the rice storehouse.

Hokkaido, the northernmost island of Japan, has much snowfall during winter. Snow must be removed from streets in downtown areas for the security of pedestrian traffic and vehicle traffic. There have been many reports on utilization of natural cold renewable energy including that of snow, especially in snowfall regions (Nakamura and Osada, 2002; Saito, 2005; and Muramatsu, 1987). However, there has been no study on the utilization of snow removed from streets for cooling a commercial rice storehouse. The objective of this study was to determine whether snow piles removed from streets can be utilized to replace the electric cooling system and electric energy for cooling a rice storehouse.

MATERIALS AND METHODS

Snow pile and snow cooling system At the beginning of March 2009, a snow pile was made next to a storehouse designated by the Japanese government as a rice storehouse for low-temperature storage of rice. The rice storehouse is located in the outskirts of Sapporo, Hokkaido, Japan. Total capacity for storage is 45,000 t of brown rice, and there are 18 sections for brown rice storage. One section (capacity of 2,500 t of brown rice) of the storehouse was used for the experiment. Rice imported from California, USA (2,700 t of white milled rice) was stored in that section. That section of the storehouse has three refrigerators operated in summer (from June to September) for maintaining temperature below 15˚C.

The shape of the snow pile was a trapezium, 17 m by 23 m at the bottom and 4 m by 10 m at the top and 5 m in height (Fig. 1). The surface area of the snow pile was 483 m^2 and the total amount of snow was calculated to be 890 t. The snow pile was covered with wood chips of 200-300 mm in thickness as an insulator layer (Fig. 2).

A schematic diagram of the snow cooling system is shown in Fig. 3. Cold water from the melting snow pile was circulated through the storehouse by a pump and two radiators were used for heat exchanges from the cold water to cold air in the storehouse. The cold air was circulated through out the storehouse by a fan. In this experiment, the period for using the snow cooling system was from 21st July to 18th September in 2009, and cold energy from the snow pile was used together with electrically cooled energy by three refrigerators to cool the storehouse.

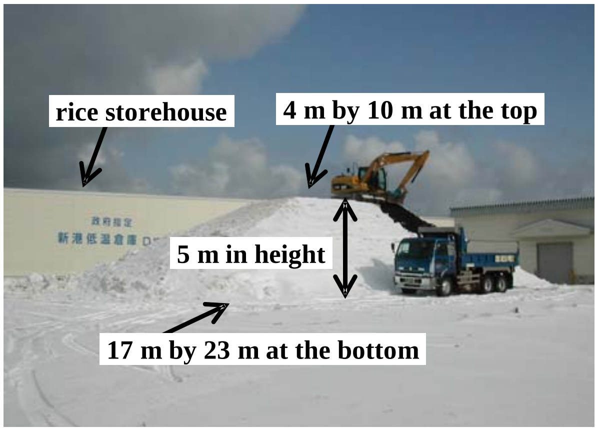

Fig.1. Snow pile made next to the storehouse.

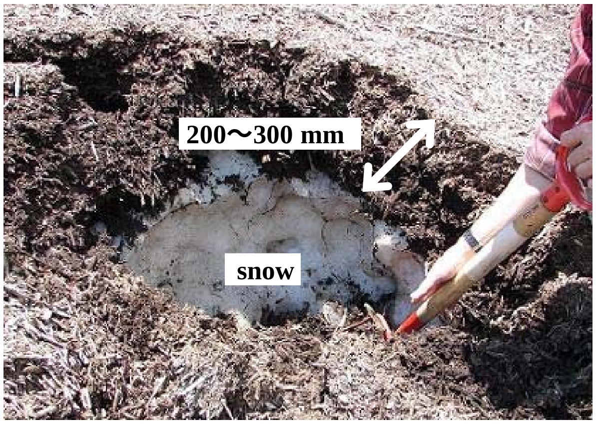

Fig.2. Snow and wood chips as an insulator layer.

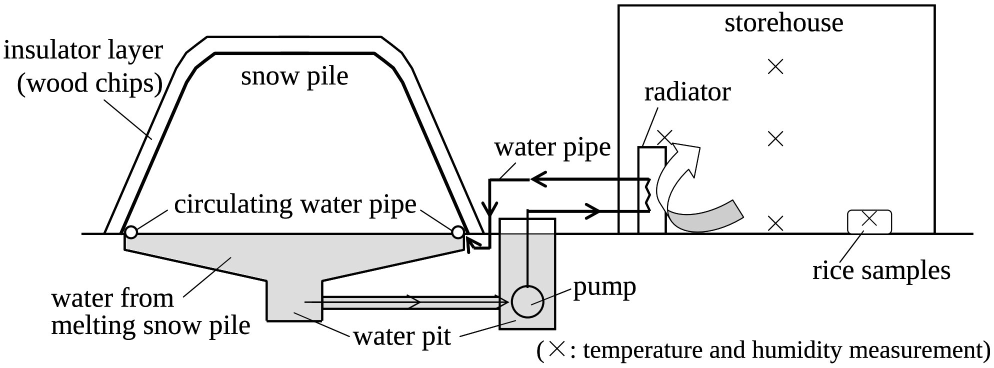

Fig.3. Schematic diagram of the snow cooling system.

Rice samples and storage conditions The rice sample used for the experiment was "Kirara397" (Japonica type rice) variety grown in Hokkaido in 2008. Two types of rice (rough rice and brown rice) were stored. Each rice sample was packaged in a paper bag and the paper bag containing the rice sample was packaged in triple plastic bags. Rice packaged in a paper bag is a popular packaging method for rice storage in Japan. However, paper bag packaging is affected by the humidity of surrounding air. To avoid the influence of humidity, the paper bag was packaged in plastic bags for the experiment purposes.

Three storage temperatures were used as experimental conditions: low-temperature storage in which rice samples were stored in the storehouse, room-temperature storage in which rice samples were stored in a laboratory room without temperature control, and super-low-temperature storage in which rice samples were stored in a refrigerator kept at -5˚C. About 20 kg of rough rice and 15 kg of brown rice were stored in each experimental condition.

The storage experiment was started in December 2008 and will be continued until December 2011.

Quality analysis Moisture content, free fat acidity and germination rate are used as indicators of rice quality during storage. Free fat acidity value was determined by the rapid method of the American Association of Cereal Chemists (AACC method 02-02), extracting free fat acid in benzene solution and titrating the extracted solution with potassium hydroxide solution. Germination rate was determined according to the standard method of the Japan Food Agency; 500 sound brown rice kernels were soaked in hydrogen peroxide solution (0.3% [w/w] concentration) and placed in an incubator at 20˚C. Germination rate was determined as percentage of kernels that germinated within seven days.

Grain temperatures were measured in each storage condition during storage. During the period in which the snow cooling system was used, temperature and humidity were measured in the storehouse and at the outlet of the radiator (Fig. 3).

RESULTS

Temperature and humidity at the outlet of the radiator and in the storehouse Temperature and humidity of the cold air at the outlet of the radiator are shown in Fig. 4. Minimum temperature, average temperature and maximum temperature at the outlet of the radiator were 7.6, 10.6 and 14.2˚C, respectively, and minimum humidity, average humidity and maximum humidity at the outlet of the radiator were 58, 79 and 97% RH, respectively, in August. Temperature and humidity in the center of the storehouse are shown in Fig. 5. Minimum temperature, average temperature and maximum temperature in the storehouse were 12.7, 14.1 and 14.9˚C, respectively, and minimum humidity, average humidity and maximum humidity in the storehouse were 57, 59 and 64% RH, respectively, in August.

These results indicate that air temperature at the outlet of the radiator and the storehouse temperature were maintained below 15˚C, the maximum temperature of the low-temperature storage system. Air humidity at the outlet of the radiator was sometimes beyond the maximum permissible level (i.e., 80% RH). However, the storehouse humidity was maintained at an appropriate level (i.e., 60% RH) because the outlet air temperature increased slightly in the storehouse and there was large amount of rice (2,700 t) in the storehouse.

The calculated cold energy supply to the storehouse from the snow cooling system in August was 2,928 kWh (=10.54 GJ). In this experiment, about 27% of the energy to cool the storehouse could be replaced by using the snow cooling system. In the experiment next year (2010), we are planning to make a snow pile three-times larger than that used in 2009, to increase cold-water flow rate and to install more radiators in the storehouse. As a result, we will try to achieve 100% replacement of electric energy except for energy for water pump and circulating fan with natural cold renewable energy from snow.

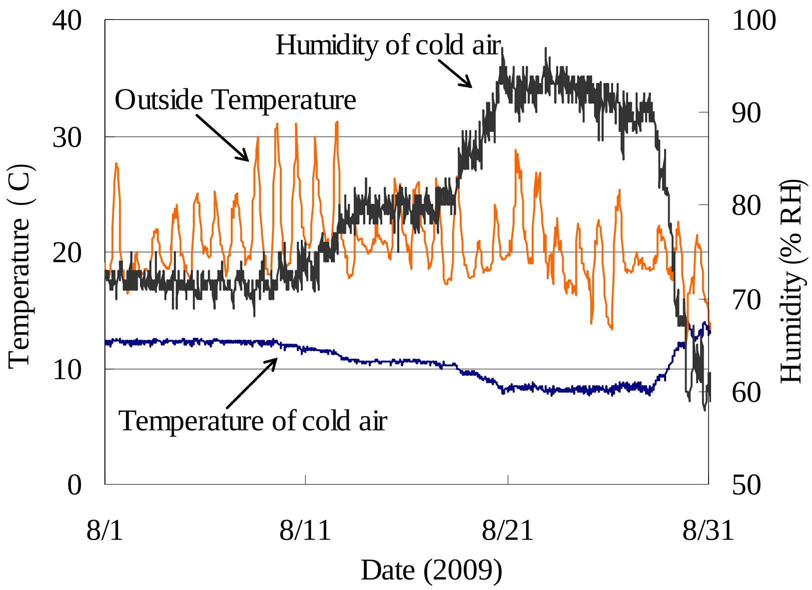

Fig.4. Temperature and humidity of the cold air at the outlet of the radiator, and outside temperature.

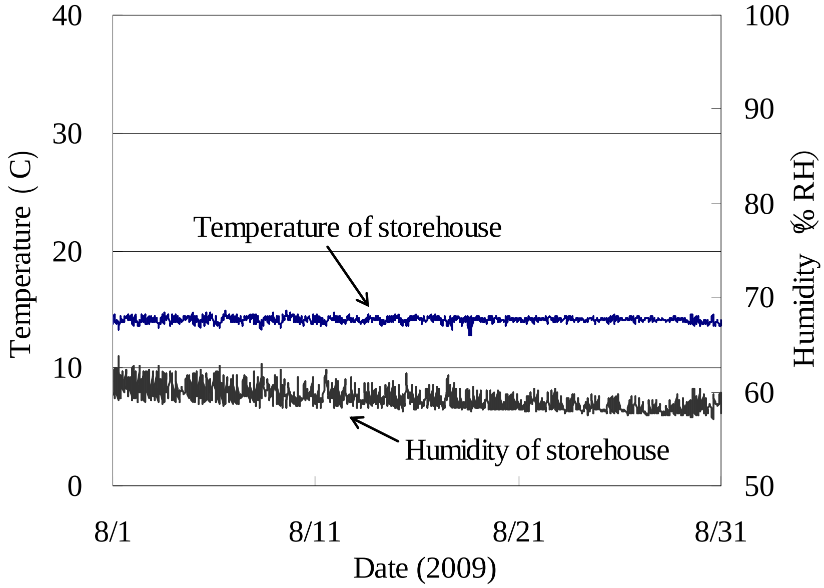

Fig.5. Temperature and humidity in the center of the storehouse.

Grain temperature during storage Grain temperatures during storage in the three storage conditions (i.e., room-temperature storage, low-temperature storage and super-low-temperature storage) are shown in Fig. 6. Grain temperature in room-temperature storage fluctuated due to the influence of outside temperature and of room heating in winter. Grain temperature in super-low-temperature storage was uniform at about -5˚C. Grain temperature in low-temperature (storehouse) storage did not vary to a great extent except for in May and June. At the beginning of May, rice stored in the storehouse was unloaded, and rice was loaded in the storehouse at the beginning of July. During unloading and loading of rice, the door of the storehouse was opened. During May and June, there was no rice in the storehouse except for the rice used in the experiment, and the refrigerators were turned off. Therefore, grain temperature in low-temperature storage fluctuated according to the outside temperature from the beginning of May until the beginning of July.

The mean temperatures during storage were 19.6˚C for room-temperature storage, 11.4˚C for low-temperature storage and -5.0˚C for super-low-temperature storage.

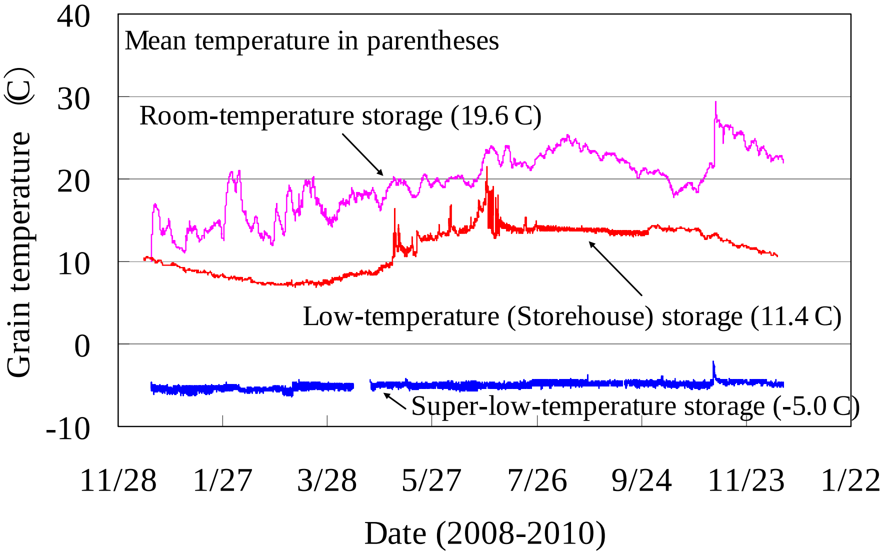

Fig.6. Rice grain temperatures during storage for 12 months.

Quality of rice The major constituent contents of rice are starch, moisture, protein and fat in that order. Moisture contents of each rice sample stored in each condition did not vary during storage because of the plastic bags.

Fat is quickly hydrolyzed by enzyme lipase into free fat acid; hence, free fat acidity is an indicator of deterioration of rice quality. Free fat acidities of rice stored in each condition after 12 months are shown in Fig. 7. Free fat acidities increased in all of the storage conditions. However, there were differences in the rates of increase in free fat acidity. The rate of increasing in rough rice was less than that in brown rice. The rate of increase in free fat acidity was highest in rice stored at room temperature, next-highest at low temperature and lowest in rice stored at super-low temperature. These results indicate that low storage temperature minimized enzyme activity and thus quality deterioration of rice.

Germination rate is an index of vitality and freshness of rice. High germination rate means that rice has vitality as rice seed and freshness as newly harvested rice. Therefore, germination rate can be an indicator of rice quality during storage. Germination rates of rice stored in each storage condition after 12 months are shown in Fig. 8. Germination rates of rice stored at low temperature and super-low temperature remained at almost 100%. However, germination rates of rice stored at room temperature decreased to about 85%. These results indicate that low storage temperature maintained vitality and quality of rice.

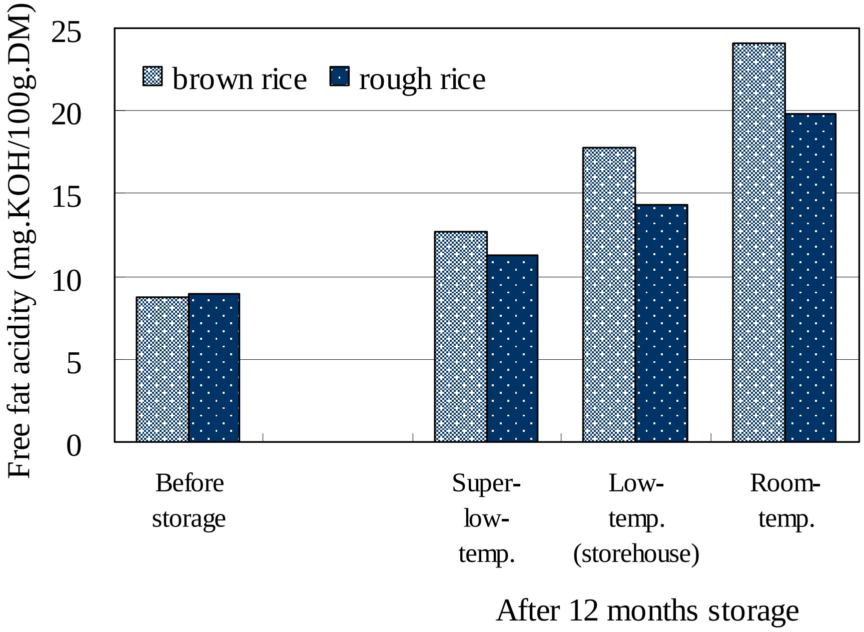

Fig.7. Free fat acidities of rice before and after 12 months of storage.

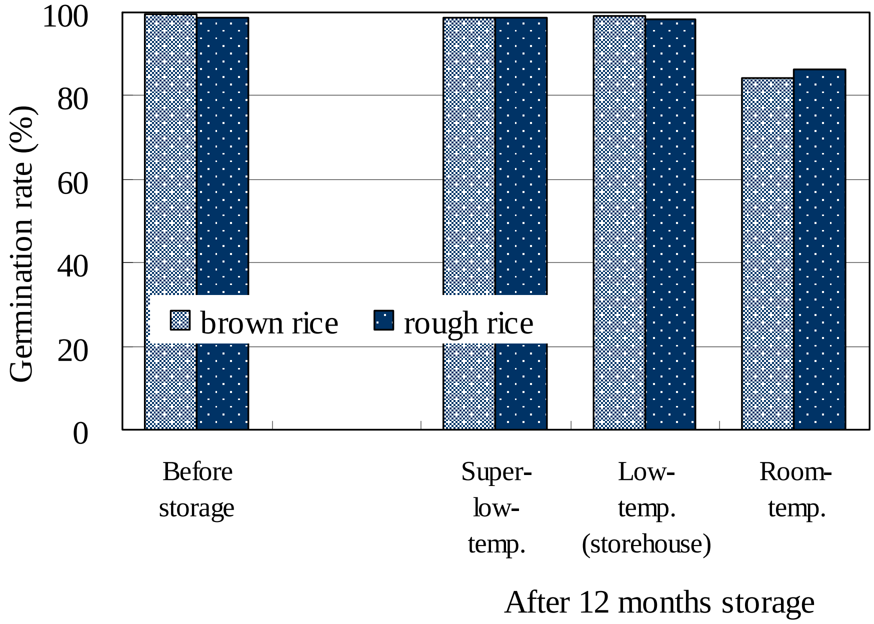

Fig.8. Germination rates of rice before and after 12 months of storage.

DISCUSSION A commercial rice storehouse could be cooled by using the snow cooling system in summer. About 27% of the energy to cool the storehouse could be replaced by using the snow cooling system in August.

There is no freezing injury of rice even in the condition of temperature below ice point (Kawamura, 2003b) and low temperature minimizes deterioration of rice and maintains rice quality for long-term storage (Kawamura, 2004c). The quality of rice stored in the storehouse for 12 months was preserved higher than the quality of the room temperature storage, but lower than or similar to the quality of the super-low temperature storage. These results also indicate that low temperature minimizes deterioration of rice and maintains rice quality.

This storage experiment was started in December 2008 and will be continued until December 2011. In winter 2010, we will make a snow pile three-times larger than that used in 2009 and we will try to achieve 100% replacement of electrically cooled energy with natural cold renewable energy generated from snow by increasing water flow from the snow pile and by using more radiators. A snow pile can be utilized for cooling a rice storehouse as a high-quality rice storage system without electric energy consumption except for energy for water pump and circulating fan.

CONCLUSION The objective of this study was to determine whether renewable energy generated from snow can be used to replace the cooling system and electricity for cooling a rice storehouse.

1. About 27% of the electric energy to cool the storehouse could be replaced by using the snow cooling system.
2. Low storage temperature using renewable energy from snow minimized enzyme activity and thus quality deterioration, and maintained vitality and quality of rice.
3. Renewable energy from snow can be utilized for cooling a rice storehouse as a high-quality rice storage system without electric energy consumption except for energy for water pump and circulating fun.

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