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Development of a Natural Air–drying and Low–temperature Storage Facility for Paddy Rice

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This research aimed at developing natural air–drying and low–temperature storage facility for paddy rice to dry harvested paddy rice by natural ventilation at ambient temperature and then store paddy rice at constant low temperature year–round to prevent influence of changes in external temperature and thereby maintain quality of the paddy rice over extended period of time. Results of the research are presented below.

1. The developed and manufactured prototype (natural air–drying and low–temperature storage facility for paddy rice) monitors temperature of the grain and inside the storage during high–temperature season starting in April and automatically operates cooler unit to maintain temperature of the grain in the storage bin and throughout the whole storage below 15˚C all year round.

2. By measuring germination rate, water content, crack rate, fat acidity, and milling yield of paddy rice stored in the prototype for each storage period, changes were significantly small compared to storage by natural air–drying alone. It was thus concluded that excellent quality of paddy rice upon harvest can be maintained over extended period of time using the developed prototype.

3. Economic analysis of the prototype showed that it maintained quality of the paddy rice higher than the traditional natural air–drying method to enhance their price, leading to annual profit of 1,343 thousand won for storing 10 ton of paddy rice.

Key words: paddy rice, natural air–drying, low temperature storage, grain temperature

INTRODUCTION

With expansion of the free trade agreement (FTA), international trade volume of rice and domestic sales of imported rice are expected to increase. To respond to such a trend, storage facility and after–harvest management technology are direly needed to increase quality of domestic rice and enhance of its competitiveness.

In Korea, large Rice Processing Centers (RPC) have been installed and are in operation for production of high–quality rice, but storage capacity nationwide is only 25% and most paddy rice are stored in facilities of individual farms (RPC Research Society, 2004).

Natural air–drying storage facilities currently used by farms (Yoon *et al*., 2000) experience rapid decrease in quality of rice after the start of the high–temperature season in April. Considering economic aspects, it is required to still use the existing facilities but modify them such that low–temperature storage is possible and thereby minimizing reduction in quality.

Takekura *et al*. (2003a, b) have demonstrated that low–temperature storage below 15˚C is superior to storage at ambient temperature in terms of stability of rice quality, storage capability, and economic aspects by comparing water content, germination rate, fat acidity, and viscosity. Lee *et al*. (2005) also reported that low–temperature storage can maintain paddy rice at high quality for longer period of time compared to traditional ambient–temperature storage, while Agricultural Outlooks (2005) reported that paddy rice stored at ambient temperature and at low–temperature significantly differ in taste starting from 2 months of storage.

Therefore, this study attempted to modify the existing natural air–drying dryer to naturally dry paddy rice harvested in fall and then store them at constant low temperature (15˚C) throughout the year until July of the following year without being exposed to effects of temperature increase. The developed natural air–drying and low–temperature storage facility for paddy rice (hereafter referred to as the dryer and storage for paddy rice) would serve as a dryer during harvest season and low–temperature storage during high–temperature season.

MATERIALS AND METHODS

Manufacture of a natural air–drying and low–temperature storage facility for paddy rice

Structure

As shown in Fig. 1, the natural air–drying and low–temperature storage facility for paddy rice has a natural air–drying dryer inside an insulated storage in which temperature sensor and cooler unit are installed to keep temperature and humidity constant.

Takekura *et al*. (2003) was referred for temperature for low–temperature storage. Considering stability and

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<Natural air-drying dryer> <Insulated storage> <Inside of the low-temperature storage >

Fig. 1. Natural air–drying and low–temperature storage facility for paddy rice.

Table 1. Specifications of the natural air–drying and low–temperature storage facility for paddy rice

Classification		Type and dimensions
Dimensions of low–temperature storage (L×W×H, mm)		5,000 × 4,000 × 7,300
Material and width of insulator (mm)		Sandwich panel, 100
Natural air–drying dryer	Dimensions (L×W×H, mm)	2,600 × 2,600 × 6,350
	Drying capacity (kg)	10,000
	Ventilator capacity (kW)	2.2
	Elevator capacity (kW)	1.5
	Input performance (t/h)	7
	Output performance (t/h)	7
	Circulating performance (n/h)	2
	Power (V)	Single–phase 220
Cooler unit	Cooler capacity (kcal/h)	24,000
	Target temperature (℃)	15
	Power (V)	3–phase 380

economic aspects of paddy rice quality, the target temperature was determined to be 15°C.

Specifications of the natural air–drying and low–temperature storage facility for paddy rice are as in Table 1. The facility was installed in a farm located at Geungok–ri, Baegam–myeon, Yongin–si, Gyeonggi–do, Korea.

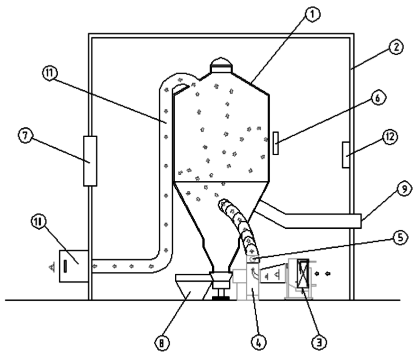
Composition of each unit and operating principles

The natural air–drying and low–temperature storage facility for paddy rice is composed of inlet and outlet for input and output of harvested paddy rice, temperature sensor for detecting temperature increase inside the storage, cooler unit for releasing cooled air upon signal from the temperature sensor, air flow control device that can be closed to send ventilator air inside the storage bin when drying and opened to circulate cooled air from the cooler unit inside the storage, and pressure controller for controlling pressure inside the storage when cooler unit is operated.

Operating principles during drying and low–temperature storing are as follows.

a) Natural air drying

When drying the harvested paddy rice by natural air ventilation, air flow control device is closed as in Fig. 2 to supply ambient–temperature air into the storage bin through the vent installed in the lower part and to dis-



①Storage bin ②Insulated storage ③Cooler unit ④Ventilator
⑤Air flow control device ⑥Temperature sensor ⑦Pressure controller
⑧Paddy rice inlet ⑨Paddy rice outlet ⑩Moisture exhaust
⑪Moisture exhaust hose ⑫Control panel

Fig. 2. Principle of natural air–drying of paddy rice.

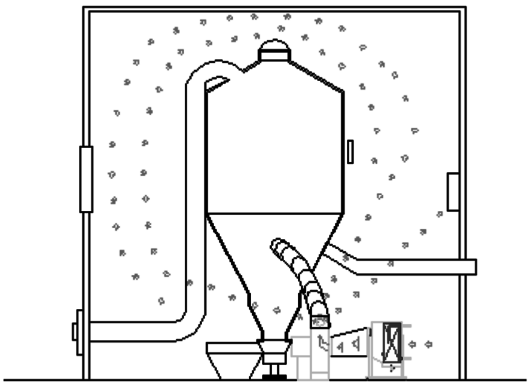


Fig. 3. Principle of low–temperature storage of paddy rice.

charge moisture of the paddy rice inside the storage bin to the outside. At this time, the cooler unit does not operate.

b) Low–temperature storage

When storing the dried paddy rice at low–temperature for an extended period of time during high–temperature season, temperature sensor detects temperature above a pre–set threshold inside the storage and opens the air flow control device as shown in Fig. 3. This activates the cooler unit to send low–temperature air (15˚C) via ventilator to circulate inside the storage to keep the temperature inside constant.

Performance test

Test material

The paddy rice species used in the experiment was Chucheong rice, with average initial water content of 19.1% (w.b.). Storage duration was about 9 months, from November to July the following year.

Test methods

a) Drying performance

In order to evaluate the drying performance of the prototype, water content was measured every day until it reached 16% (w.b) and drying rate was calculated. Ventilator was operated 7 hours every day (10:00~17:00), and paddy rice circulation was performed for 2 hours for each day (13:00~15:00). Specimen for water content measurement was collected at specimen collection sites (Fig. 4(b)) installed at 1,800 mm, 3,600 mm, and 5,400 mm from the ground using specimen collection rod (Fig. 4(c)), at 100 mm, 600 mm, and 1,200 mm from the wall, sampling at total of 8 locations excluding protruded part at the bottom. Water content was measured using a grain moisture tester (PQ–510, Kett, Japan).

b) Measurement of grain temperature and ambient temperature

Temperature sensors were installed inside the prototype and, as a contrast, the storage bin of natural air–drying storage to measure grain and ambient temperature. A RT sensor (error ±0.2˚C) was manufactured for use, and a multi–point temperature recorder (DR–230, Yokogawa, Japan) was used to measure temperature every hour.

c) Paddy rice cooling experiment

When grain temperature inside the storage bin of the prototype increased, cooler unit was activated to send cooled air directly into the storage bin to maintain the grain temperature to be below 15˚C year–round. Relative humidity was also investigated.

d) Temperature control test of low–temperature storage

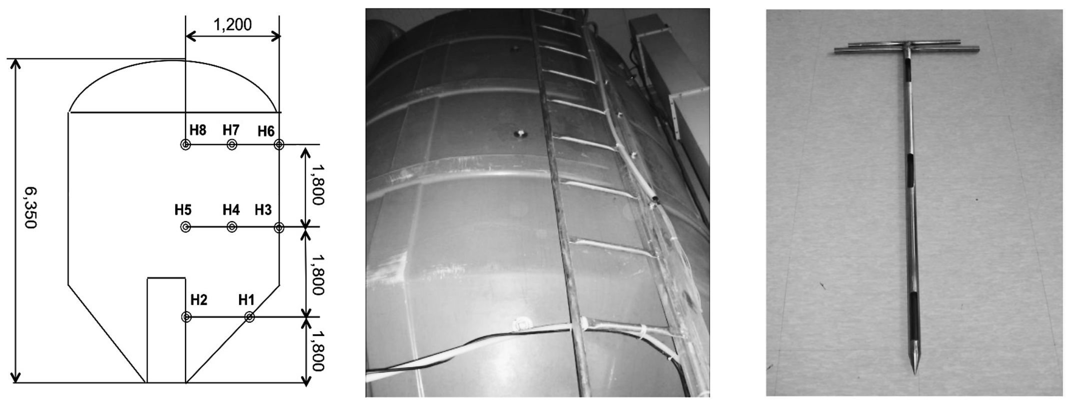
When temperature inside the storage increased, cooler unit was activated to circulate the air inside the storage to keep temperature inside the storage below 15˚C year–round. Relative humidity was also investigated.

e) Experiment comparing quality of stored paddy rice

Using paddy rice stored in the existing natural air–drying storage as a control, the paddy rice stored at low–temperature was evaluated for its quality. Fat acidity, milling yield, crack rate, germination rate, and water content were measured once every month with measurement in triplicate.

① Fat acidity: Measurement of fat acidity in sampled specimen was performed according to AOAC (Method 14.073, 1980).

② Milling yield: The rate was measured using an automatic milling yield checker developed by the National Institute of Agricultural Engineering.



(a) (b) (c)

Fig. 4. Location for specimen (a), Specimen collection site (b) and Specimen sampling collection rod (c).

③ Crack rate: The sampled specimen were husked and crack rate was measured 10 times for 50 grains each using a rice crack checker (RC–50, Kett, Japan), and the measurements were averaged.

④ Germination rate: Of the sampled specimen, 50 grains of paddy rice were randomly selected. The selected grains were washed by water, inserted into growth media inside a Petri dish. 20cc of distilled water was sprayed onto the dish, which was then stored inside a constant temperature and humidity chamber set at 25˚C and relative humidity of 60%. Germination state was measured for 14 days. Germination rate was calculated as the ratio of paddy rice that germinated to total number of rice grains.

⑤ Water content: Water content of the sampled specimen was measured using a moisture tester (PQ–510, Kett, Japan).

RESULTS AND DISCUSSION

Drying performance

In order to verify drying performance of the prototype, water content of paddy rice over drying time was measured and corresponding drying rate was deduced. Fig. 5 shows change in paddy rice water content over drying time. In the beginning, there were some differences among paddy rice in different locations of the storage bin, e.g. the upper/middle/lower part, near the wall, around the center, etc. The difference significantly decreased as drying progressed. About 8 days were required for average initial water content of 19.1% (w.b.) to decrease to 16.0%, which corresponds to drying rate of 0.39% (w.b.)/day. During the drying period, ventilator was operated for 7 hours each day (10:00~17:00) and circulation was performed for 2 hours each day (13:00~15:00).

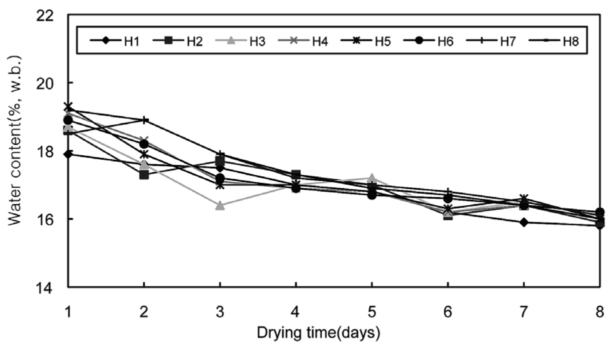


Fig. 5. Change in water content of paddy rice over drying time.

Temperature change of grains in the storage bin

Fig. 6 compares trends of temperature change in grains around the center of the storage bin with ambient temperature change between the newly developed low–temperature storage and traditional ambient–temperature storage. As shown in the figure, temperature of grains in the ambient–temperature storage tended to change in synchrony with changes in ambient temperature and even exceeded the ambient temperature during the high–temperature season, reaching over 30˚C, which may significantly reduce grain quality, on significant number of days.

However, in case of the low–temperature storage, the grains were stored at naturally low temperature during the winter, and the cooler unit was activated when the ambient temperature exceeded 15˚C around mid May when high–temperature season starts. As a result, grain temperature was maintained almost constantly below 15˚C regardless of changes in ambient temperature.

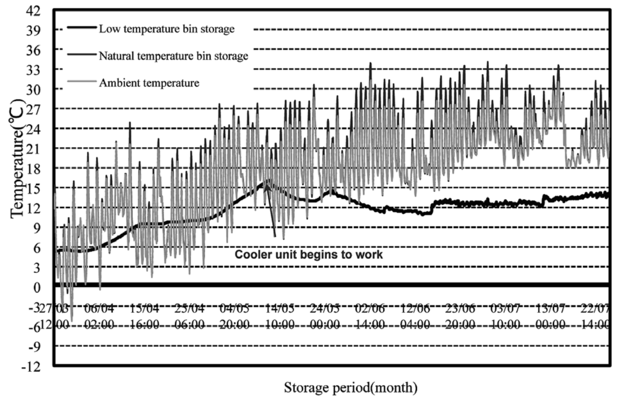


Fig. 6. Comparison of trends of grain temperature change between the low–temperature storage and traditional ambient–temperature storage.

Temperature control capability of the storage bin

We performed paddy rice cooling test to confirm that temperature sensor detects increase in temperature of the grain inside storage bin of the prototype and activates the cooler unit to send cooled air into the bin, thereby maintaining grain temperature below 15˚C throughout the year.

Fig. 7 shows trends of temperature and relative humidity changes of the prototype storage bin from early stages of storage in late December to late June the following year. As shown in Fig. 7, when grain temperature rises above 15˚C in the high–temperature season, the cooler unit is activated to bring the grain temperature below 15˚C and maintains this level. Temperature of ventilated cooled air from the cooling unit was around –2˚C,

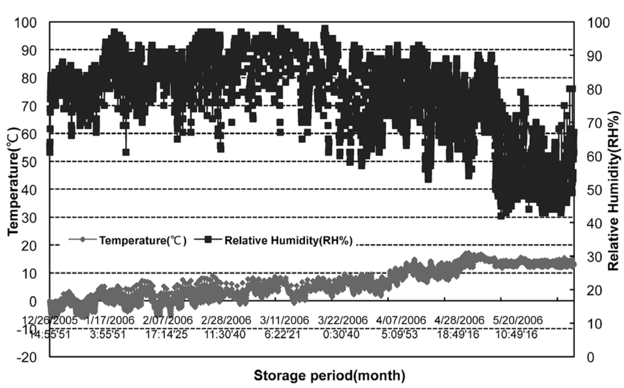


Fig. 7. Trends of temperature and relative humidity changes of the prototype.

Table 2. Changes in water content of paddy rice before and after the cooling for each location

Classification	Water content of paddy rice in the upper part (%, w.b.)	Water content of paddy rice in the middle part (%, w.b.)	Water content of paddy rice in the lower part (%,w.b.)
Before cooling paddy rice	15.7	15.5	15.4
After cooling paddy rice	15.7	15.5	15.3

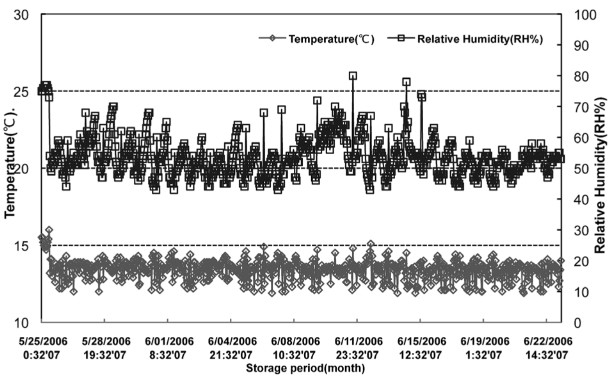


Fig. 8. Trends of temperature and relative humidity changes inside the prototype after activation of the cooler unit.

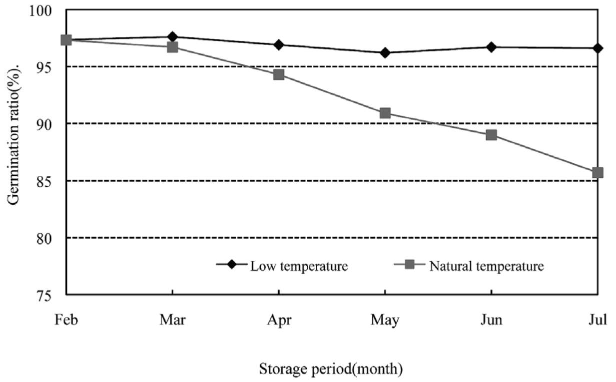


Fig. 9. Changes in germination rate of low–temperature storage and ambient temperature storage.

and temperature of the grain in the storage bin was constantly below 15°C without large deviation. The time required to cool the paddy rice that initially had temperature elevated above 15°C was about 4 days (May 10th to 13th), but once cooled the grain temperature was constantly maintained below 15°C.

Fig. 8 presents a closer view of grain temperature and relative humidity inside the prototype for 1 month from the time grain temperature inside the storage bin exceeds 15°C and the cooler unit is activated. It is clearly shown that inside of the prototype is almost constantly maintained below 15°C at all times. Some changes in grain temperature and relative humidity inside the storage bin were observed with changes in ambient temperature but the changes were slight.

Table 2 shows water content of paddy rice at different locations inside the prototype before and after the cooling. Changes in water content due to cooling were shown to be very small regardless of location.

Quality of stored paddy rice

In order to compare qualities of paddy rice (Chucheong rice) stored in conventional natural air–drying storage and the low–temperature storage prototype, germination rate, water content, crack rate, and fat acidity were measured for paddy rice stored in each storage.

Fig. 9 shows germination rate for each storage condition over time. As shown in the figure, paddy rice stored at low temperature maintained germination rate at the range of 96.2~97.3%, but paddy rice stored at ambient temperature experienced rapid decrease in germination rate starting from start of high–temperature season at April and showed germination rate of 85% in July.

Fig. 10 shows water content of paddy rice for each storage condition over time. Although water content of

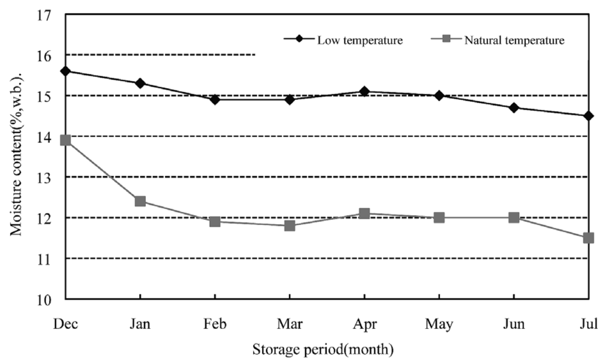


Fig. 10. Changes in water content of low–temperature storage and ambient temperature storage.

paddy rice stored at ambient temperature was lower than that of paddy rice stored at low–temperature, the former experienced water content decrease of 2.4% from 13.9%, w.b. to 11.5%, w.b. over 7 months while water content in the latter only decreased by 1.1% from 15.6%, w.b. to 14.5%, w.b. over the same time period. Therefore, water content of paddy rice stored at low temperature decreased much less compared to paddy rice stored at ambient temperature, with the decrease being less than half of the decrease experienced by the ambient temperature paddy rice.

Fig. 11 shows changes in crack rate between paddy rice stored at low temperature and ambient temperature over time. In case of low–temperature storage, crack rate was maintained below 8%. In case of ambient temperature, however, the rate increased from 6% to 19% as storage time increased.

Fig. 12 shows changes in fat acidity of low–temperature storage and ambient temperature storage over time.

Paddy rice stored at low temperature maintained fat acidity around 15~16 mgKOH/100 g over the storage time without large changes but paddy rice stored at ambient temperature experienced significant increase in fat acidity from 14 mgKOH/100 g to 19 mgKOH/100 g.

Fig. 13 shows changes in milling yield between low–temperature storage and ambient temperature storage. No difference was observed in the beginning, but starting from the beginning of high–temperature season in April the difference became more and more pronounced, with milling yields in low–temperature storage being about 5% higher than that of ambient temperature storage after May.

In summary, low–temperature storage was shown to maintain excellent quality in terms of germination rate, water content, crack rate, fat acidity, and milling yield for extended period of time compared to ambient temperature storage.

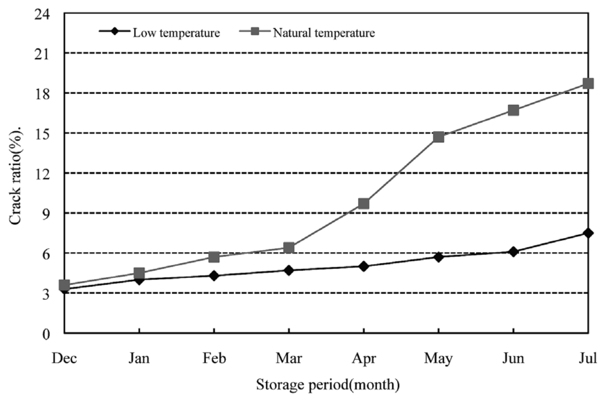


Fig. 11. Changes in crack rate of low–temperature storage and ambient temperature storage.

Economic analysis

Economic analysis of natural air–drying and low–tem-

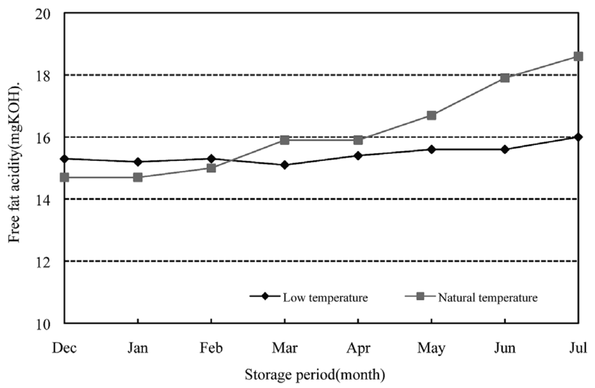


Fig. 12. Changes in fat acidity of low–temperature storage and ambient temperature storage.

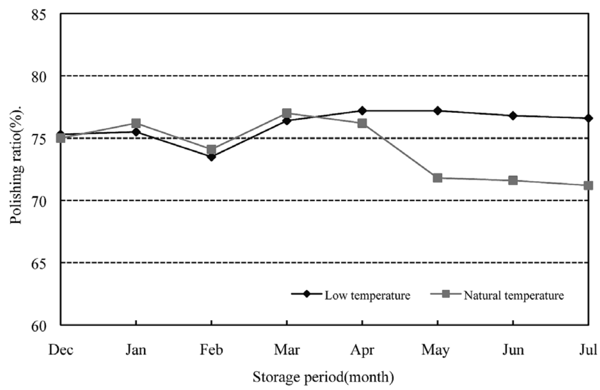


Fig. 13. Changes in milling yield over time for different storage conditions.

Table 3. Economic analysis

(Unit : won/year)

Classification		Cost for additional installation
Cost for additional installation of low–temperature storage (won)		10,000,000
Expected years of usage (year)		10
Storage capacity (ton/year)		10
Fixed costs (won/year)	Depreciation and amortization	1,000,000
	Repair	600,000
	Interests	250,000
	Sub–total	1,850,000
Variable cost (won/year)	Electricity	306,920
Total cost (Won/year)		2,156,920

* Useful life : 10 years, residual ratio: 0%, repair cost factor: 6%, annual interest rate: 5%

(Unit : won/year)

Detrimental factors (B)	Beneficial factors (A)
Increased costs – Increase in machinery usage fees: 2,156,920	Increased revenue – Maintaining high–quality rice: 3,500,000
Estimated net profit (A–B) = 1,343,080	

* Price for paddy rice stored at low temperature: 1,600 won/kg,
price for paddy rice stored at ambient temperature: 1,250 won/kg (for delivery in July)

perature storage facility for paddy rice is shown in Table 3. When the prototype developed in this research is used, increase in price of the paddy rice from maintaining high quality of rice results in annual profit of 1,343 thousand won when storing 10 tons of paddy rice.

SUMMARY AND CONCLUSION

In this study, we developed a natural air–drying and low–temperature storage facility for paddy rice that first dries harvested paddy rice by natural air drying then maintains temperature at low temperature throughout the year, thereby maintaining excellent quality of paddy rice for long duration by protecting the paddy rice from influence of ambient temperature changes. Summary of results is shown below.

1. Cooler with capacity of 25,000 kcal/h and sandwich panel insulator (100 mm) was used to build a natural air–drying and low–temperature storage facility with drying capacity of 10 tons, paddy rice input and output efficiency of 7 ton/h, circulation efficiency of 5 ton/h, and average drying rate of 0.39% (w.b.)/day.

2. As a result of temperature control performance test of cooling and low–temperature storage of the prototype, the cooler unit was successfully activated with increase in grain temperature and temperature inside the storage as external temperature increased in April. The cooler unit circulated cool air inside the storage bin, thereby maintaining temperature of grains and storage bin below 15°C throughout the year.

3. Observing germination rate, water content, crack rate, fat acidity, and milling yield of paddy rice stored in the prototype over time showed that these properties changed less in low–temperature storage compared to ambient temperature storage. From this result, it was concluded that the prototype is capable of maintaining excellent quality of paddy rice at the time of harvest over long periods of time.

4. Economic analysis of the prototype showed that it resulted in higher quality of paddy rice compared to the existing natural air–drying storage, leading to higher price of paddy rice and annual net profit of 1,343 thousand won when storing 10 tons of paddy rice.

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