Original Article
Journal of Biosystems Engineering

J. of Biosystems Eng. 39(4):336-344. (2014. 12)
http://dx.doi.org/10.5307/JBE.2014.39.4.336

eISSN : 2234-1862
pISSN : 1738-1266

Changes in Water Content Affect the Post-Milling Quality of Paddy Rice Stored at Low Temperature

Young-Keun Kim[1], Seong-Gi Hong[1], Sun-Ho Lee[1], Jong-Ryul Park[1], Jung-Seob Choe[2]*

[1]*National Academy of Agricultural Science, Rural Development Administration, Jeonju, Korea*
[2]*Department of Precision Mechanical Engineering, Kyungpook National University, Sangju, Gyeongbuk, Korea*

Received: October 26th, 2014; Revised: November 10th, 2014; Accepted: November 27th, 2014

Abstract

Purpose: In this study, the effect of milling on paddy rice stored at low temperature, the changes in grain temperature of bulk storage bags exposed at room temperature, the post-milling water content of paddy rice, the whiteness of rice, and the rate of pest incidence were investigated and data were analyzed. **Methods:** Changes in temperature inside the bulk storage bags kept at low temperature and grain temperature after exposure to room temperature were measured. Experiments were conducted for identifying the reasons of post-milling quality changes in paddy rice stored at low temperature. **Results:** It was determined that a short-term increase of water content in paddy rice was directly related to surface condensation, and that rice should be milled at least 72 h after removal from low-temperature storage, in order to completely eliminate surface condensation of paddy rice kept in bulk storage bags. It was observed that post-milling quality of rice changed, but water content was maintained at high levels for more than 18 d in rice that was milled when condensation occurred, regardless of paper or vinyl packaging. Rice whiteness rapidly decreased in rice that was milled when condensation occurred, regardless of packaging, while rice that was milled 72 h or more after removal from low temperature storage did not show any significant changes in whiteness. No pest incidence was observed up to 12 d after removal from low temperature storage, regardless of packaging. Starting at 18 d, after removal from low temperature storage, rice that was milled when condensation occurred, was affected by pests, while 24 d after removal from low temperature storage, all portions of rice were affected by pests. **Conclusions:** Our results suggest that changes in post-milling quality of rice could be significantly reduced by exposing paddy rice to room temperature for at least 72 h before milling, in order to allow the increase of grain temperature and prevent surface condensation.

Keywords: Low temperature storage, Milling, Paddy rice, Rice quality

Introduction

Since the enactment of free trade policy for rice, trade volume of imported rice has been steadily increasing. Domestic rice is more competitive compared to imported rice, although the latter is much cheaper, mainly because of its low quality, including taste. Post-harvest processing technology helps to minimize decrease of rice quality and is the best method for promoting competitiveness of domestic rice.

Usually, rice is stored for up to a year until the harvest of the following year rice crop, and this extended storage period inevitably leads to a decrease in quality. Much research has been done on methods that delay or minimize changes in quality, and low temperature storage has been proposed as the most effective one. Currently in Korea, large rice processing centers (RPCs) and agricultural rice storage facilities are switching from room temperature storage to low temperature storage.

Takekura et al. (2003) and Kim et al. (2013) studied the effect of low temperature storage on paddy rice, and they reported that storage at temperatures lower than 15°C is considered optimal, in terms of paddy rice quality and economic perspectives. Paddy rice that is stored at low temperature

***Corresponding author:** Jung-Seob Choe
Tel: +82-54-530-1276; **Fax:** +82-54-530-1278
E-mail: jschoe@knu.ac.kr

has superior water content, germination rate, fat acidity, and viscosity than that stored at room temperature. Lee et al. (2005) also reported that low temperature storage helps paddy rice to maintain high quality over longer periods than that stored at room temperature.

However, milling technology of paddy rice stored at low temperature and management of post-milling quality changes have not yet been well established. As a result, paddy rice stored at low temperature shows much more rapid deterioration of color or frequent post-milling pest incidence. Furthermore, quality decrease is more frequently observed during summer. Such situations highlight the urgent need for technology development to minimize changes in post-milling quality of paddy rice stored at low temperature.

Therefore, this study aimed to identify the reasons of rapid post-milling quality decrease in paddy rice stored at low temperature and to develop a method for reducing changes in post-milling quality. Additionally, the effect of milling and the trend of post-milling quality changes in paddy rice stored at low temperature were investigated. Temperature distribution of paddy rice stored at low temperature, changes in temperature after exposure to room temperature, and surface condensation of paddy rice that was milled at different times after exposure to room temperature were measured. Finally, water content, whiteness, and post-milling pest incidence on different days were also investigated.

Materials and Methods

Effect of milling on paddy rice stored at low temperature

In order to investigate the effect of milling on paddy rice stored at low temperature and changes in post-milling quality, two RPCs that store paddy rice at low temperature were selected for this study. The storage method, storage temperature, milling timing, crop temperature at the time of milling, product temperature at each step of milling, milling duration, the effect of milling machine management and distribution, and the changes in post-distribution quality were investigated.

Temperature inside the bulk storage bags and changes in grain temperature after exposure to room temperature

Experimental materials and low temperature storage

For low temperature storage of paddy rice in RPCs or milling factories, coolers are attached to silos or paddy rice is kept in 500-kg or 1,000-kg bulk storage bags at low temperature and removed from storage when needed (RPC report 2004, Machine operation technique for RPC processes, 2007). However, small RPCs and milling factories mostly use bulk storage bags for low temperature storage. Therefore, in this study, paddy rice kept in bulk storage bags at low temperature was used for measurement of crop temperature distribution and paddy rice temperature inside the bulk storage bags over time after exposure to room temperature. Ilpoom and Shindongjin germplasm lines harvested in October 2013 were used for the measurement of paddy rice temperature changes. Average water content when crop temperature measurement took place was 15.1% wet basis moisture (w.b. moisture) for Ilpoom and 16.2% w.b. moisture for Shindongjin. All bulk storage bags (size: 900 mm 900 mm × 1,200 mm; capacity, 500 kg; material: polypropylene) were placed at a low temperature storage used as fruit storage at the National Research Institute of Agricultural Engineering. Temperature inside the storage during the experimental period was lower than 14°C, and relative humidity ranged between 60% and 80% (Manual of RPC facility and operation technique, 2006).

Changes in temperature inside the bulk storage bags

In order to measure temperature distribution and changes in temperature of grains inside the bulk storage bags over time after exposure to room temperature, 13 real-time temperature sensors (standard error of ± 0.2°C) were installed as shown in Figure 1. Measurements were saved using a multi-point temperature recorder (DR-230, Yokogawa, Japan).

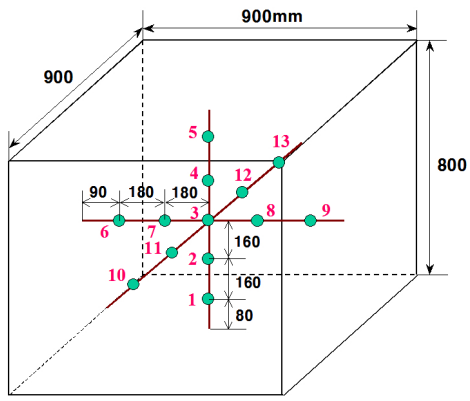

Figure 1. Location of 13 real-time temperature sensors inside the bulk storage bags.

Changes in post-milling quality of paddy rice stored at low temperature

Surface condensation and crack growth rate of paddy rice stored at low temperature and milled at different times after exposure to room temperature

Paddy rice kept at low temperature storage is generally milled during summer and delivered to customers. When paddy rice is removed from storage before milling, grain temperature is lower than the dew point temperature of paddy rice and consequently condensation occurs on the surface. Surface condensation increases the water content and crack growth rate of paddy rice, thereby adversely affecting post-milling quality.

We hypothesized that surface condensation would significantly effect post-milling quality of rice. To test this hypothesis, we collected 20 kg of Ilpoom and Shindongjin from each of 10 trials and kept them in bulk storage bags at low temperature. These 20-kg samples were milled at 5 different times (immediately, 1 h, 3 h, 24 h, and 72 h) after removal from low temperature storage. For each time, grain temperature, ambient temperature, and relative humidity, along with paddy dew point temperature, paddy surface condensation, and crack growth rate were measured. Crack growth rate was estimated as the average value of 50 grains from each of 10 trials using a grain scope (RC-50, Kett, Japan).

Changes in post-milling quality during distribution

Paddy rice is usually stored at low temperature and then milled and packaged before the delivery to customers. In order to identify the reasons of post-milling quality changes in paddy rice stored at low temperature and develop a method for preventing quality decrease, Ilpoom and Shindongjin paddy rice were removed from low temperature storage and milled at different times (immediately, 1 h, 3 h, 24 h, and 72 h) after removal from low temperature storage. Milled rice was packaged in 20-kg paper or vinyl packaging units. Water content, whiteness, and pest incidence were measured over time (Ha et al., 2006). Water content was measured using a grain moisture tester (PQ-510, Kett, Japan), and whiteness was estimated as the average value of 10 whiteness measurements using a whiteness meter (C-100, Kett, Japan). Pest incidence was expressed as the number of pests observed per kg of rice.

Results and Discussion

Effect of milling on paddy rice stored at low temperature

In July we visited two RPCs, and we removed paddy rice stored at low temperature for milling. The effect of milling on paddy rice stored at low temperature was studied and results are shown in Table 1. Both RPCs kept paddy rice in bulk storage bags at a temperature lower than 15°C. Paddy rice was usually milled 24-48 h after

Table 1. Effect of low temperature storage and milling on paddy rice in two rice processing centers (RCPs)

Rice processing centers (RCPs)		RPC(A)	RPC(B)
Germplasm lines		Ilpoom	Ilpoom
Storage method		Bulk bag	Bulk bag
Storage temperature (°C)		13	15
Milling timing		Milled 24–48 h after removal from low temperature storage	Milled 24 h after removal from low temperature storage
Grain temperature and ambient temperature during milling (°C)		17.1 and 26.8	16.5 and 27.3
Product temperature during milling processes (°C)	Brown rice	26.5	28
Product temperature during milling processes (°C)	Wholly milled rice	37	38
Milling duration (min)		30	30
Distribution units and distributors		5, 10, and 20-kg vinyl and paper packaging units Large discount stores and department stores	5, 10, and 20-kg vinyl and paper packaging units Large discount stores and department stores

removal from low temperature storage, in order to allow the increase of grain temperature above the dew point of paddy rice before milling and thereby to prevent surface condensation. Product temperature during milling ranged between 26.5°C and 28°C during brown rice milling step and between 37°C and 38°C during the wholly milled rice milling step. Milling duration was approximately 30 min.

Figure 2. Measurement of grain temperature inside the bulk storage bags.

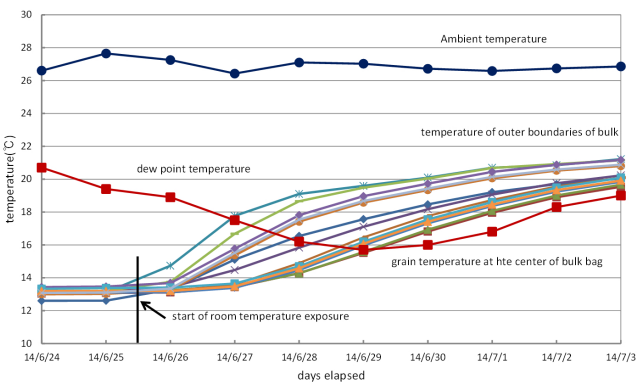

Figure 3. Changes in grain temperature of paddy rice stored inside bulk storage bags at low temperature after exposure to room temperature.

Changes in grain temperature of paddy rice kept in bulk storage bags at low temperature after exposure to room temperature

Grain temperature over time inside the 500-kg bulk storage bags that were exposed to room temperature after storage at low temperature, along with paddy rice dew point temperature, and changes in ambient temperature are shown in Figure 3. Grain temperatures measured at 13 locations inside the bulk storage bags did not differ significantly during low temperature storage, but several hours after exposure to room temperature, grain temperature rapidly increased from outside to inside of the bulk storage bags. The center of the bulk storage bags reached a temperature above the paddy rice dew point 72 h after exposure to room temperature. It was concluded that bulk storage bags should be exposed to room temperature for at least 72 h before milling, in order to completely eliminate surface condensation of paddy rice.

Post-milling quality of paddy rice stored at low temperature immediately after milling

Changes in grain temperature of paddy rice stored at low temperature after exposure to room temperature

Changes in grain temperature of 20-kg Shindongjin paddy rice that stored at low temperature and exposed to room temperature, along with paddy rice dew point temperature, and changes in ambient temperature, and relative humidity are shown in Figure 4. At the time of testing, ambient temperature was 30.6°C, relative humidity ranged between 40% and 50%, initial grain temperature was 13.3°C, and paddy dew point temperature was approximately 18.1°C. Early after exposure to room temperature, grain temperature

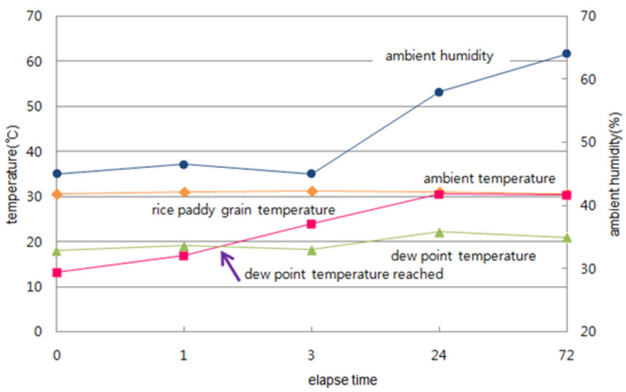

Figure 4. Changes in grain temperature of paddy rice stored at low temperature after exposure to room temperature.

was lower than paddy dew point temperature, but within 2 h after removal from low temperature storage, grain temperature exceeded paddy dew point temperature. Grain temperature was similar to ambient temperature 24 h after removal from low temperature storage. Based on these results, it was concluded that surface condensation of paddy rice stored at low temperature would not occur 2 h after exposure to room temperature.

Surface condensation and crack growth rate of rice milled at different times

Grain temperature, ambient temperature, and relative humidity, along with paddy dew point temperature, paddy surface condensation, and crack growth rate measurements of 20-kg paddy rice from each germplasm line that stored at low temperature and exposed to room temperature are presented in Table 2.

Germplasm line had no effect on surface condensation that was observed within 1h after removal from low temperature storage, when paddy grain temperature was below paddy dew point temperature. Surface condensation was 0.22 g×kg^{-1} for Ilpoom and 0.38 g×kg^{-1} for Shindongjin 1h after exposure to room temperature. Paddy grain temperature exceeded paddy dew point temperature 3h after exposure to room temperature, and no surface condensation was observed. Finally, paddy grain temperature reached the ambient temperature 24 h after removal from low temperature storage. Crack growth rate was 4% for Ilpoom and 5% for Shindongjin 24 h after removal from low temperature storage, but it increased slightly to 5% for Ilpoom and 7% for Shindongjin 72 h after removal from low temperature storage.

Table 2. Surface condensation and crack growth rate of paddy rice stored at low temperature and milled at different times

Time of milling after removal from low temperature storage	Germplasm line	Paddy temperature (°C)	Ambient temperature and relative humidity (°C, %)	Paddy dew point temp. (°C)	Surface condensation (g·kg^{-1})	Crack growth rate (%)
Immediately	Ilpoom	13.2	31.5 and 45	18.1	-	4
Immediately	Shindongjin	13.3	31.5 and 45	18.1	-	5
1h	Ilpoom	17	31.8 and 47	19.2	0.22	4
1h	Shindongjin	17	31.8 and 47	19.2	0.38	5
3h	Ilpoom	23	32 and 45	18.5	0	4
3h	Shindongjin	23	32 and 45	18.5	0	5
24h	Ilpoom	30	32 and 57	22.2	0	4
24h	Shindongjin	31	32 and 57	22.2	0	6
72h	Ilpoom	29.8	29.8 and 65	20.8	0	5
72h	Shindongjin	30.5	29.8 and 65	20.8	0	7

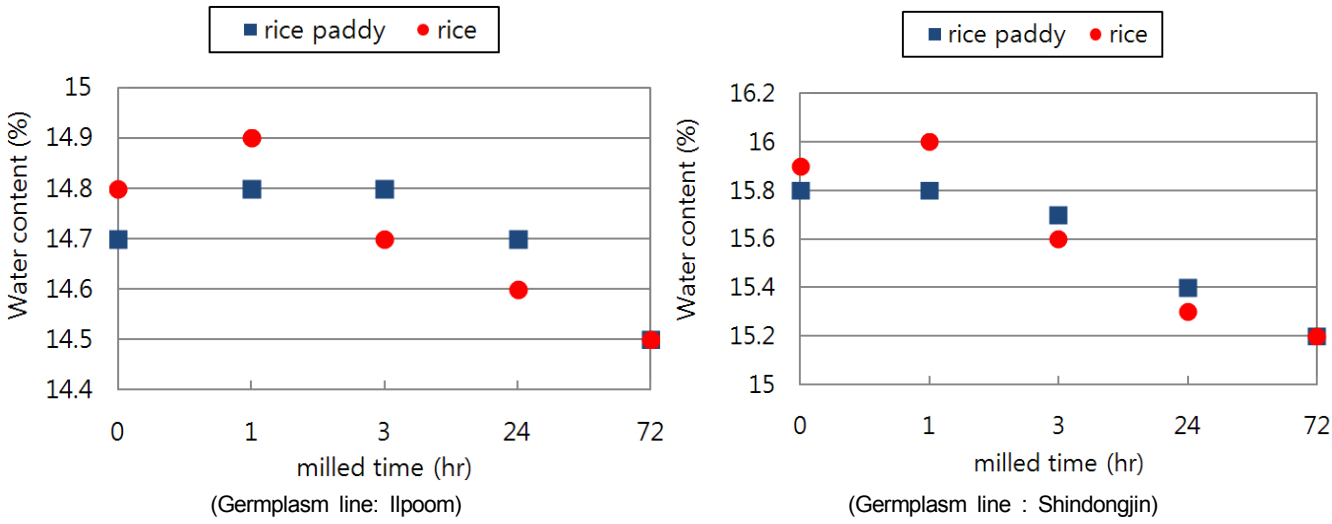

Figure 5. Water content of paddy rice and rice milled at different times.

Water content of paddy rice milled at different times

Changes in water content of paddy rice milled at different times after removal from low temperature storage are shown in Figure 5. Regardless of germplasm line, water content was the highest 1h after removal from low temperature storage and then decreased over time. The highest water content coincides with surface condensation, which occurs 1h after removal from low temperature storage. This shows that water content of paddy rice that was milled at different times is positively associated to surface condensation.

Changes in post-milling quality during distribution

Changes in post-milling quality over time during distribution were investigated. We measured any changes in grain temperature during milling and packaging into 20-kg paper or vinyl packaging units. The properties of packaging units are presented in Table 3.

Changes in water content

Changes in water content over time for Ilpoom germplasm line that was milled at different times and packaged in paper or vinyl units are shown in Figure 6. Packaging type had little effect on water content. Rice showed a high water content that ranged between 14.7% and 14.9% w.b. moisture approximately 1h after removal from low temperature storage, which was maintained at these level for more than 18 d. Water content was also measured 30 d after removal from low temperature storage; paper packaging units showed an average reduction of water content from 14.7% w.b. moisture to 14.2% w.b. moisture, which was significantly higher than that of vinyl packaging units that reduced from 14.7% w.b. moisture to 14.4% w.b. moisture. Paper packaging units showed a more rapid decrease in water content than that of vinyl packaging units, probably due to superior air permeability. Results for Shindongjin had no significant differences that those presented for Ilpoom.

Changes in whiteness

Changes in whiteness of Ilpoom rice milled at different times and packaged in paper or vinyl units are shown in Figure 7. Regardless of packaging, rice that was milled approximately 1h after removal from low temperature storage showed a high decrease in whiteness from 36% to 30% in 30 d, while rice that was milled 72 h after removal from low temperature storage showed the smallest decrease in whiteness from 36% to 35% in the same time period.

As shown in Figure 8, changes in whiteness of Shindongjin did no differ significantly from , the overall trend of change

Table 3. Properties of the packaging samples

Packaging type	Moisture vapor permeability ($g \cdot m^{-2} \cdot 24\ h$)	Oxygen permeability ($cm^3 \cdot m^{-2} \cdot day \cdot atm$)	Longitudinal tensile strength ($N \cdot 15\ mm^{-1}$)	Transverse tensile strength ($N \cdot 15\ mm^{-1}$)	Ash (%)
Paper	-	-	41.9	100	1.9
Vinyl	0.6	3.0	-	-	-

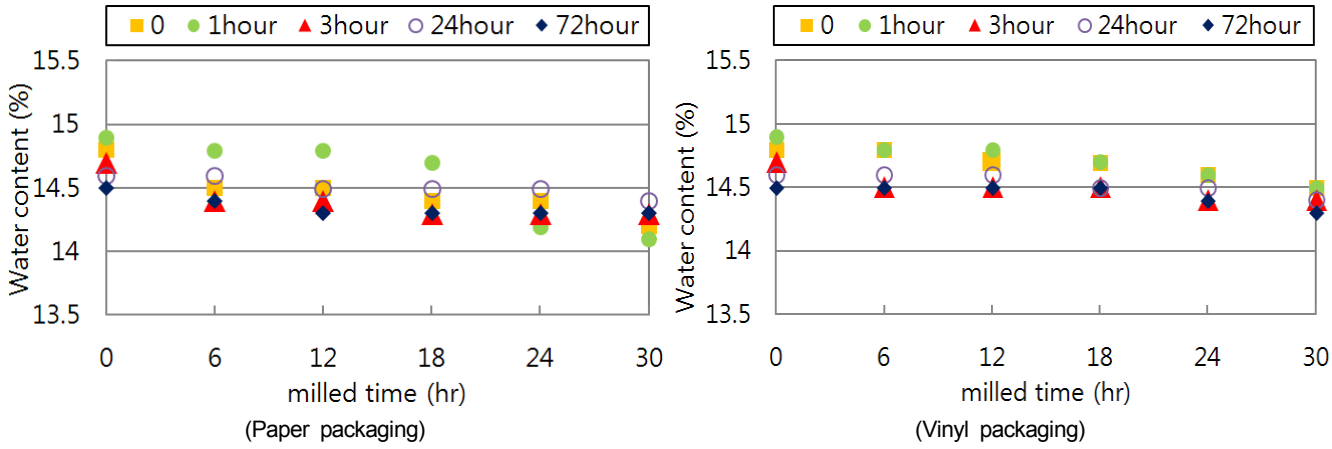

Figure 6. Changes in water content of rice milled at different times (Germplasm line: Ilpoom).

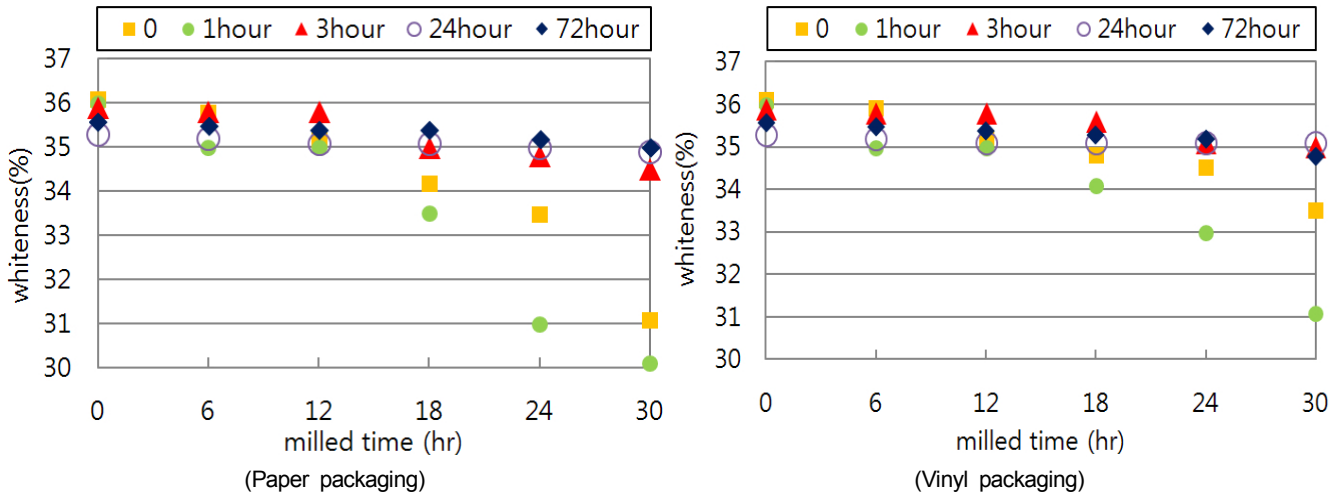

Figure 7. Changes in whiteness for rice milled at different times (Germplasm line: Ilpoom).

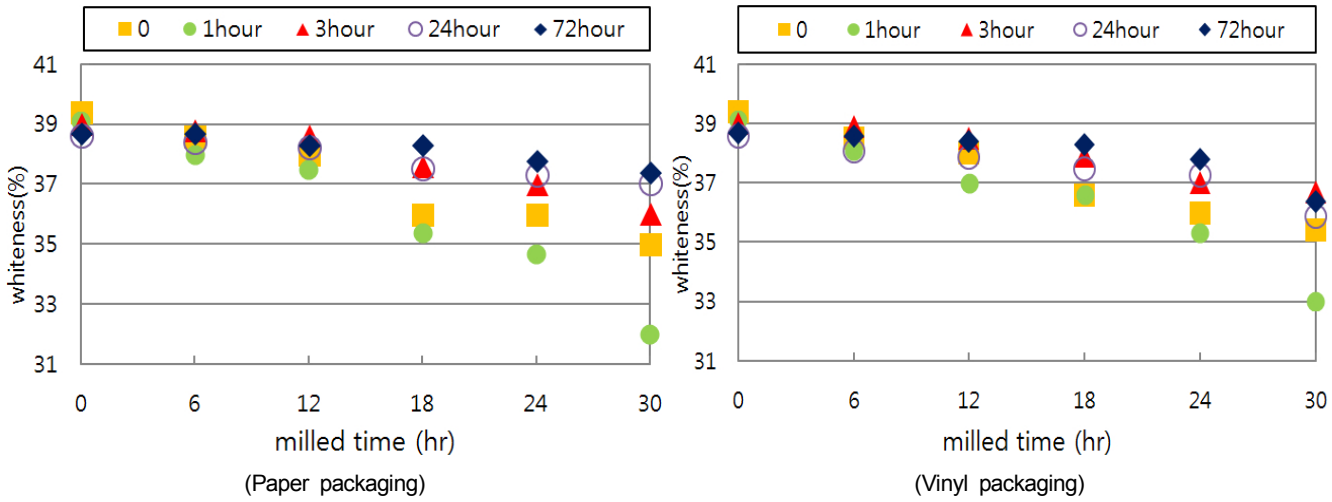

Figure 8. Changes in whiteness for rice milled at different times (Germplasm line: Shindongjin).

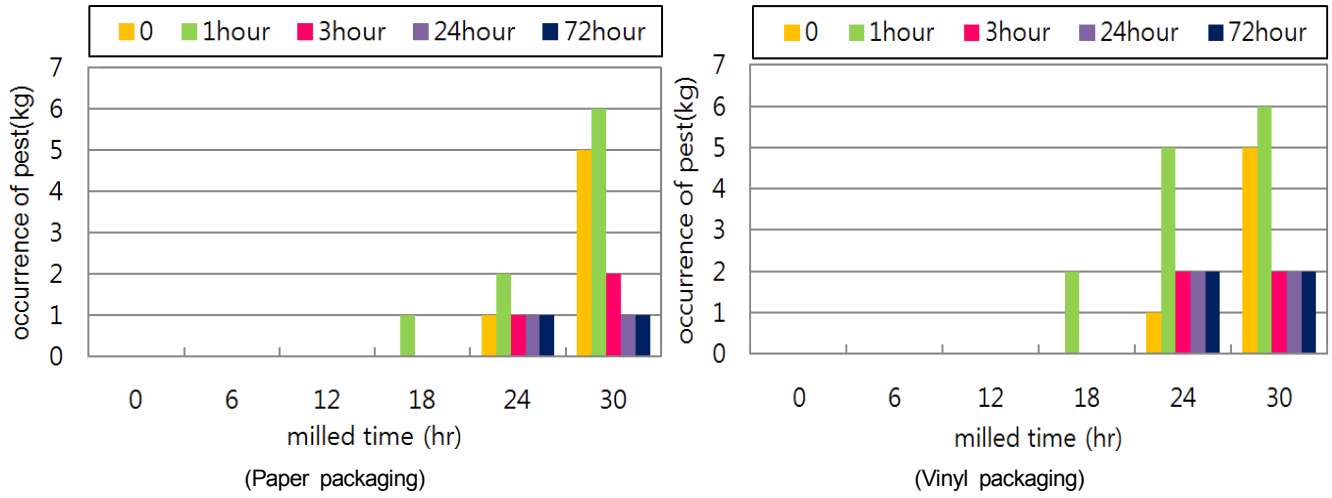

Figure 9. Pest incidence in rice milled at different times (Germplasm line: Ilpoom).

Figure 10. Indian meal moth found in rice during distribution.

in Ilpoom.

Changes in pest incidence

Pest incidence over time in Ilpoom rice that was milled at different times and packaged in paper or vinyl units is shown in Figure 9. Both paper and vinyl-packaged rice did not show any pest incidence for 12 d. After 18 d, rice that was milled 1h after removal from low temperature storage was the first that affected from pests, while all portions of rice were affected by pests after 24 d. Regardless of packaging, rice that was milled 1h after removal from low temperature storage was affected the most from pests, while rice that was milled 72 h after removal from low temperature storage was affected the least.

Pest incidence in Shindongjin differed slightly from that in Ilpoom, but the overall trends were the similar in both germplasm lines. Indian meal moth found in rice during distribution as shown in Figure 10.

Conclusions

In order to build a strong rice industry, we should identify the reasons of rapid post-milling quality decrease in paddy rice stored at low temperature and identify solutions for this problem. In the current study, we investigated the effect of milling on paddy rice stored at low temperature and the changes in post-milling quality. Thereafter, temperature distribution of paddy rice stored at low temperature, changes in grain temperature after exposure to room temperature, and surface condensation of paddy rice that was milled at different times after exposure to room temperature were measured. Finally, water content, whiteness, and pest incidence in milled rice over time were analyzed. Consequently, results can be summarizes as follows:

(1) Most RPCs keep paddy rice in bulk storage bags at a temperature lower than 15°C and milling takes place 24-48 h after removal from low temperature storage. Grain temperature near the center of 500-kg bulk storage bags was found to exceed paddy rice dew point temperature 72 h after exposure to room temperature. Based on these results, it was concluded that the duration of exposure to room temperature should be extended up to 24-48 h, in order to completely eliminate surface condensation before milling In other words, paddy rice should be left at room temperature for 72 h after removal from low temperature storage before milling.

(2) Surface condensation and water content were measured in 20-kg paddy rice samples stored at low temperature, exposed to room temperature, and milled at different times. Grain temperature was lower than paddy rice dew point temperature and surface condensation was observed within 1h after removal from low temperature storage. Regardless of germplasm line, water content in rice was the highest in rice that was milled immediately after removal from low temperature storage, and decreased with exposure to room temperature before milling. The highest water content coincides with surface condensation, which occurs 1h after removal from low temperature storage. This shows that water content of paddy rice and milled rice is positively associated to surface condensation.

(3) Changes in quality during distribution were investigated in 20-kg paper or vinyl packaging units by measuring water content, whiteness, and pest incidence for 30 d. Regardless of packaging type, water content was the highest in rice that was milled 1h after removal from low temperature storage and maintained between 14.7% and 14.9% w.b. moisture for up to

18 d. Rice in paper packaging units showed higher decrease in water content than that in vinyl packaging, probably due to superior air permeability.

Regardless of packaging, rice that was milled approximately 1h after removal from low temperature storage showed a high decrease in whiteness from 36% to 30% in 30 d, while in the same time period, rice that was milled 72 h after removal from low temperature storage showed the smallest decrease in whiteness from 36% to 35%.

Both paper and vinyl-packaged rice did not show any pest incidence for 12 d. After 18 d, rice that was milled 1h after removal from low temperature storage was the first that affected from pests, while all portions of rice were affected by pests after 24 d. Regardless of packaging, rice that was milled 1h after removal from low temperature storage was affected the most from pests, while rice that was milled 72 h after removal from low temperature storage was affected the least.

Our results recommended that changes in post-milling quality of rice could be significantly reduced by exposing paddy rice to room temperature for at least 72 h before milling, in order to allow the increase of grain temperature and prevent surface condensation.

Conflict of Interest

The authors have no financial or other conflicts of interest.

Acknowledgement

This study was supported by the "Research Program for Agricultural Science & Technology Development (Project No. PJ0102182014)", National Academy of Agricultural Science, Rural Development Administration, Republic of Korea.

References

Ha, K.Y., H.K. Park, J.K. Ko, C.K. Kim, Y.H. Choi, K.Y. Kim and Y.D. Kim. 2006. Effect of storage period and temperature on the characteristics related with rice quality. Korean J. Crop Sci., 51(S):25-29 (In Korean).

Kim, Y.K., J.S. Choe, H.S. Yoon and E. Inoue. 2013. Development of a natural air-drying and low-temperature storage facility for paddy rice. Journal of the Faculty of Agriculture. Kyudhu University 58(1):61-67 (In English).

KREI. 2008. Agriculture Prospect 2008 (In Korean).

Lee, J.S., C.S. Han, T.M. Ham and K.S. Yon. 2005. Low temperature storage of rough rice using cold-air in winter(1) – Storage characteristics after rough rice cooling. J. of Biosystems Eng., 30(3):155-160 (In Korean).

MAFRA and KFRI. 2006. Manual of RPC Facility and Operation Technique (In Korean).

NAMRI. 2007. Machine Operation Technique for RPC Processes (In Korean).

RPC Research Society. 2004. RPC Report 2004 (In Korean).

Takekura, K., S. Kawamura and K. Itoh. 2003a. Development of techniques for storing rough rice in cold regions (Part 1). Journal of the Japanese society of agricultural Machinery 65(4):57-64 (In Japanese).

Takekura, K., S. Kawamura and K. Itoh. 2003a. Development of techniques for storing rough rice in cold regions (Part 2). Journal of the Japanese society of agricultural Machinery 65(4):65-70 (In Japanese).

Takekura, K., S. Kawamura and K. Itoh. 2003b. Development of techniques for storing rough rice in cold regions (Part 3). Journal of the Japanese society of agricultural Machinery 65(5):40-47 (In Japanese).

Takekura, K., S. Kawamura and K. Itoh. 2003b. Development of techniques for storing rough rice in cold regions (Part 4). Journal of the Japanese society of agricultural Machinery 65(5):48-54 (In Japanese).