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Effects of Moisture Content, Storage Temperature, and Storage Time on Grain Yellowing and Head Rice Recovery of Paddy

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Abstract

Rice grain yellowing is one of the challenges in the production of good-quality milled rice. The study was conducted to determine the effects of moisture content, storage temperature, and length of storage time on grain yellowing and head rice recovery in paddy. Samples of freshly harvested PSBRc18 were dried to three moisture content levels, kept in three storage temperatures, and subjected to varying lengths of storage time. The resulting milled rice showed that grain yellowing was significantly affected by the interaction of moisture content, storage temperature, and storage time. The amount of yellow grains increased proportionally with length of storage time regardless of moisture content and storage temperature. The rate of grain yellowing abruptly increased after 8 weeks of storage. The interaction of moisture content and storage temperature affected head rice recovery. Head rice recovery of paddy stored at lower temperatures generally increased with storage time while that of paddy stored at ambient temperature decreased over time.

Keywords: *Grain yellowing; Head rice recovery; Storage temperature; Storage time*

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Introduction

Rice is the staple food in East, Southeast, and South Asia. The region accounts for more than 90% of global rice production and more than 88% of total consumption (Champagne, 2004). The introduction of high-yielding varieties has resulted in a significant increase in rice production, thereby contributing to a stable rice supply. However, consumer preferences are changing and demand for better quality rice in developing countries in Asia is increasing. Production of good-quality rice thus becomes imperative. Postharvest grain yellowing is one of the challenges in the production of good-quality rice. Handling of wet paddy is a major problem during the wet season (Mendoza., *et al.* 1981) as grain quality rapidly deteriorates at this time. Rice quality deterioration is visibly manifested by grain yellowing and other discolorations, low milling recovery, high percentage of broken, and poor cooking and eating quality, among others. Most often, farmers cannot thresh and dry their harvest on time. Cut crops are piled in the field longer than necessary and wet grains are left waiting for the right drying opportunity. Inadequate labor, delayed threshing, and lack of drying facilities during peak harvest are critical constraints. These conditions favor grain yellowing and other undesirable grain discoloration. Paddy at safe moisture content (MC) stored in bags or bins develop hot spots, which yields yellow grains upon milling.

The identification of causes or factors involved in rice grain yellowing during storage will be useful in formulating effective approaches in product handling and postharvest management to prevent or minimize such an occurrence.

Various studies have been done to determine the cause of rice grain yellowing and other discolorations. The effects of on-farm threshing and drying delays have been investigated. Several microorganisms associated with rice grain yellowing and discolorations have likewise been identified, but their exact role in rice grain yellowing and other discoloration has not been verified. Results were inconclusive. One other aspect that needs to be examined is what causes rice grain yellowing during storage.

This study aimed to determine the individual and interaction effects of moisture content, storage temperature, and storage time on rice grain yellowing and head rice recovery. It was limited to individual and interaction effects of moisture content, storage temperature, and storage time on rice grain yellowing and head rice recovery. Other aspects of grain yellowing and discoloration such as enzymatic browning and others were not included. The study was conducted at the Grain Quality, Nutrition, and Postharvest Center of the International Rice Research Institute, University of the Philippines Los Baños complex.

Review of Literature

Rice millers and retailers in the Philippines claim that physical appearance and color of milled rice are critical attributes that influence consumers' marketing decisions. This claim is supported by the results of an assessment of milled rice quality (Billate., *et al*. 1999) in selected markets in the Philippines. In general, the physical appearance of milled rice is a significant determinant of its market value. The presence of yellow 'fermented and other discolored grains' in milled rice result in a much reduced market value.

Rice grain yellowing can occur during the production phase, particularly in the grain-filling and ripening stages. Insects such as stink bugs and rice bugs attack the grain during the soft to hard dough stage, causing deformed and spotted grains. Bacterial infection transmitted during feeding results in spotty grains (Vidhyasekaran., *et al.* 1984). Pathogens that cause grain discoloration and the relationship between discoloration and weather factors were studied (Duraiswamy., *et al*. 1983). Dehusked and discolored grains were classified into green, purple, or brown. Associated fungi were isolated from each classification by the blotter technique. No fungi were found in the white grains (control). Eight percent of the green grains yielded *Helminthosporium oryzae;* 54% of the purple grains yielded *H. oryzae*, 12% yielded Trichoconis padwickii, and 5% yielded *Curvularia lunata*. The brown grains yielded 65.0, 8.0, and 3.0%, respectively, of these fungi. Crops harvested from October to December had more discolored grains. During this period, there was high relative humidity, low temperature, high rainfall, and more rainy days. All three species of fungi caused grain discoloration in the plants inoculated during the flowering, milk, and dough stages. More grain discoloration was observed at the flowering stage. *Helminthosporium oryzae* caused the greatest grain discoloration.

In a study of Phillips., *et al*. (1988) in Indonesia, fungi of the genera *Aspergillus, Penicillium*, and *Rhizopus* were detected in rice. *Rhizopus* sp. A*spergillus flavus, A. Candidus*, and species of *Penicillium, including P. purpurogenum* and *P. miezynskii* were associated with active mold growth. Observations on their growth in relation to grain discoloration could not pinpoint the cause of yellowing. The exact role of fungi in rice yellowing is yet to be determined.

Improper timing or delayed harvesting can trigger rice grain yellowing. Ripe grains subjected to the cyclical desorption and absorption of moisture and fluctuating high day and low night temperatures can result in fissured grains that easily break during milling, resulting in more broken grains, low head rice, and reduced milling recovery. These translate into poor milled rice quality. The various postproduction processes undergone by paddy, from cutting to piling, threshing, drying, storage, and milling, also affect the final grain quality features. If these operations are done properly on time, the internal and external qualities of the grain at harvest can be preserved. Timeliness in performing postproduction operations and type of postharvest machinery influence milling recovery and milled rice quality.

Threshing delays can cause grain yellowing due to 'stack burning, mold growth in heated piles, and mycotoxin. A 1-day threshing delay of cut crop in a conical pile (mandala) and small rectangular piles resulted in 17% and 5% yellow grains, respectively, whereas a 5-day delay resulted in 68% and 40% yellowing of grains in the mandala and small rectangular piles, respectively (NAPHIRE, 1988). Delayed drying of wet grains results in stack burning due to non-enzymatic browning, microbial growth, and mycotoxin production in parboiled rice (NRI, 1991). In another study, 100% yellowing of the grain was noted in wet paddy with more than 20% MC. Mold growth and heating of the grains were noted (Phillips., *et al.* 1989). Heating of the heap occurred within 1 day, mold growth was visible after 2 days, and yellowing of the grains happened within 5 days. Paddy threshed and dried to 14% MC immediately after harvest yielded < 1% yellow grains.

It has been shown that rice yellowing or stack burning is caused by the heating of relatively moist grains and that microbial growth assists in raising grain temperature (Yap., *et al.* 1988). Yellow milled rice is harder than white milled rice, has lesser lysine, and shows lower net protein utilization in growing rats. The effects of MC, incubation period, and variety on the yellowing of surface-sterilized rough, brown, and milled rice were studied at 60°C to better understand this yellowing phenomenon. After 4 days at 6°C, the *L*a*b** yellow b values of brown rice and milled rice increased progressively with MC (12, 14, 16, 18, and 20%) of the stored rough rice but leveled off at 16% moisture for stored brown and milled rice. The values were higher in samples stored as brown and rough rice than in those stored as milled rice. The extent and rate of yellowing were similar among rice with varying amylose content, gelatinization temperature, and gel consistency; these were not significantly correlated to initial levels of free amino acids and reducing sugars in brown rice. Significant increases in b values were observed after 24 hours in IR64 brown rice at 12% MC and after 6 hours in four brown rice samples with 14.4% MC.

The effects of drying temperature and relative humidity on rice grain yellowing were also studied (Soponronnarit., *et al.* 1998). An empirical equation was developed to predict the rate of rice grain yellowing. The yellowing rate followed zero-order kinetics. The value of the yellowing constant increased exponentially with temperature and increased linearly with water activity. An analysis of variance showed that the interaction of temperature and water activity significantly influenced the rate of rice grain yellowing.

The effects of temperature, exposure time, and MC on the yellowing of rice grain were investigated (Dillahunty., *et al*. 2001). They concluded that the combined effects of temperature and exposure time were the most important determinants of rice grain yellowing. Minimizing exposure time to a certain temperature reduced yellowing of the grain. Temperature and exposure time also affected viscosity. Longer exposure to a certain temperature decreased peak viscosity in all treatments. The decrease in viscosity indicates physicochemical changes in the rice grain occurring during the yellowing process. This supports the findings of Desikachar (1956) on the browning of rice. His study showed that browning of rice was not due to the Maillard reaction. Browning of all shades developed in white polished rice with about 25% MC that was incubated at 25-30°C range within 48-72 hours. Temperatures not within the 25-30°C range failed to induce browning within 48 hours.

Studies have shown that rice quality deterioration, including discoloration, varies directly with storage time. The effects of MC and temperature on respiration rate of rice were also studied (Dillahunty., *et al*. 2000). Results showed that respiration rates increased as MC increased from about 15 to 25%. Maximum respiration was at 50°C when MC was 20–25%. At 15% MC, respiration increased from 20 to 70%. At 12% MC, respiration rate was very low but it appeared to increase up to 80°C.

Staining was described by a research team as another profit theft (Siebenmorgen, 1998). Stained rice is a serious problem with heavy costs to growers. If a bulk of rice has more than five lightly stained rice grains per 500 grams, it will probably be subjected to sample grade discounts. Siebenmorgen blamed staining to respiration. The wetter the grain, the more it respires. But what is not known is how long the rice grain has to respire before staining occurs (Roods, 1999).

In another study, a technique was developed to induce postharvest rice grain yellowing on a laboratory scale (Miller., *et al.* 2005). Milled rice kernels were rinsed with water and incubated in transparent microfuge tubes at a temperature range of 65–80°C, allowing direct observation of the color change and measurement using a colorimeter. Rice cultivars (including long- and medium-grain japonica and indica varieties) showed some level of grain yellowing, which increased with temperature. Maximum color change was attained at 79°C. Most color changes occurred within 1 day. By using sterilization and culture techniques, they found no indications of direct fungal involvement in postharvest rice grain yellowing.

Materials and Methods

The factorial experiment was conducted using a randomized complete block design with three replicates. The independent variables were three levels of MC, three levels of storage temperature, and four levels of storage time. Amount of yellow grains and head rice recovery were the dependent variables. Figure 1 shows the flow diagram of the experiment.

Freshly harvested PSBRc18 variety was cleared of chaff, dockages, unfilled grains, partially filled grains, immature grains, and insect-damaged grains. Paddy was dried to 14% MC in a mechanical dryer. The MC of the grains was constantly monitored using an oven-calibrated Kett moisture meter. In preparing the samples, the ISO standard quadrant sampling technique was used. Three 600-gram samples of paddy (14% MC) were prepared each for the three storage temperature levels. Each 600-gram sample was divided into four 150-gram batches (150g) for the four treatments of storage or exposure time.

Paddy samples were dried to 18 and 20% MC and the MC monitored accordingly. Similarly, three 600-gram samples each for the 18% MC and the 20% MC level were each divided into four 150-gram samples for the four storage time levels. Subsamples were placed in labeled paper bags and the lids folded to prevent entry of unwanted materials. The prepared and labeled samples were then placed in their respective storage environments. Data loggers were installed in each storage environment to record actual relative humidity and temperature.

After the scheduled storage times (2, 4, 8, and 12 weeks), one sample each of the 14, 18, and 20% MC were drawn from each of the three storage temperature levels (refrigerator, air-conditioned room, ambient temperature room). The 18% and 20% MC samples were first dried to 14% MC before milling after which data on yellow grains were gathered. A Satake laboratory rubber roll huller and rice mill were used to dehull and mill the samples following the same procedure-i.e., one pass hulling followed by 1-minute polishing. Data on the *L*a*b** values, amount of yellow grains (% w/w), and head rice recovery were recorded. The *L*a*b** values were determined using a Minolta colorimeter based on the Hunter color system. The amount of yellow grains was determined by separating the yellow grains from three 25-gram milled rice from each sample. The percentage of yellow grain was computed on weight basis. Head rice (3/4 long or whole rice kernels) were separated from the milled rice lot using a length grader. Percentage head rice was computed on weight basis.

The raw data on the response variables were reduced and analyzed using a statistical analysis software. The data were analyzed for simple and interaction effects of the independent variables.

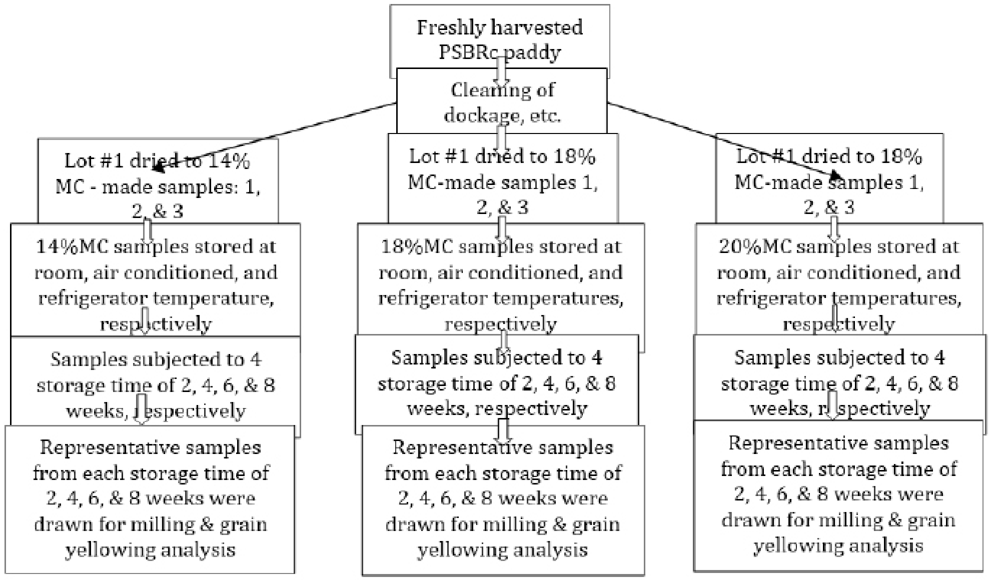

Figure 1: *Flow diagram of processes undergone by paddy samples during the experiment.*

Results and Discussion

Grain yellowing

The actual average temperatures of the various storage environments were -5, 18.0, and 28.0°C in the refrigerator, air-conditioned room, and ambient temperature condition, respectively. The actual average relative humidity values were 32.0, 65.0, and 77.0%, respectively. Storage temperature and relative humidity were fluctuating in all storage conditions (Figure 2). Table 1 shows the average yellow grains (% w/w) under various experimental conditions. The average yellow b values are given in Table 3.

Storage temperature (°C)	Exposure time (wk)	14% MC	18% MC	20% MC
-5	0	0.10	0.00	0.10
	2	0.10	0.00	0.31
	4	1.13	1.75	1.52
	8	1.26	2.26	1.67
	12	4.37	4.01	4.20
18	0	0.00	0.24	0.22
	2	0.00	0.24	0.22
	4	0.12	0.56	0.75
	8	1.67	2.13	2.03
	12	4.15	4.25	5.35
28	0	0.10	0.00	0.02
	2	0.10	0.00	0.02
	4	0.58	0.25	0.67
	8	1.14	1.02	1.36
	12	4.03	2.26	4.79

Table 1: *Average yellow grains (% w/w) of milled rice from paddy with different MC, stored in different temperatures, and exposure times.*

The results of the study showed increasing amounts of yellow grains over time regardless of MC and storage temperature. This is consistent with the findings in a previous study (Phillips., *et al.* 1988). After 8 weeks of storage, milled rice from paddy with 18% MC stored in the refrigerator at -5°C average temperature incurred the highest amount of yellow grains (2.26 %w/w), whereas the paddy with 20% MC stored in ambient condition at 28°C average temperature developed the least amount of yellow grains (1.02 %w/w). An abrupt increase in the rate of grain yellowing was observed after the 8th week of storage (Figures 2 to 4).

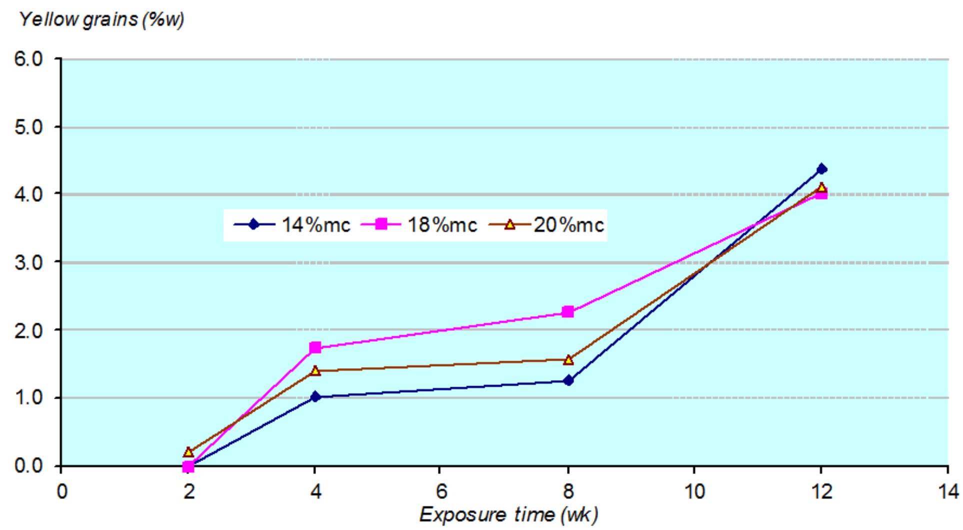

Figure 2: *Effect of MC and exposure time on yellowing of grains of paddy stored in the refrigerator (-5°C)*

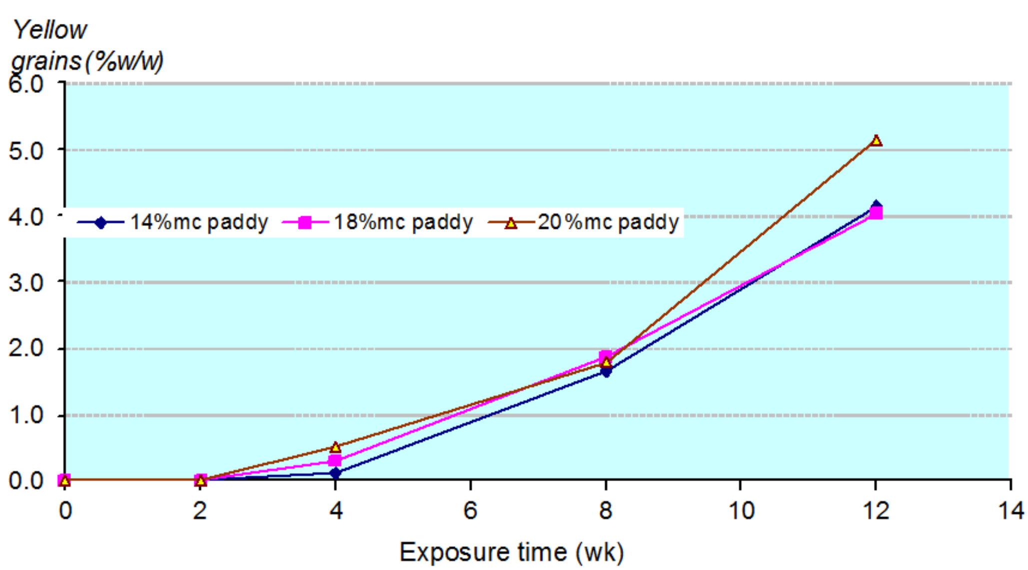

Figure 3: *Effect of MC and exposure time on grain yellowing in paddy store in air conditioned room (18°C).*

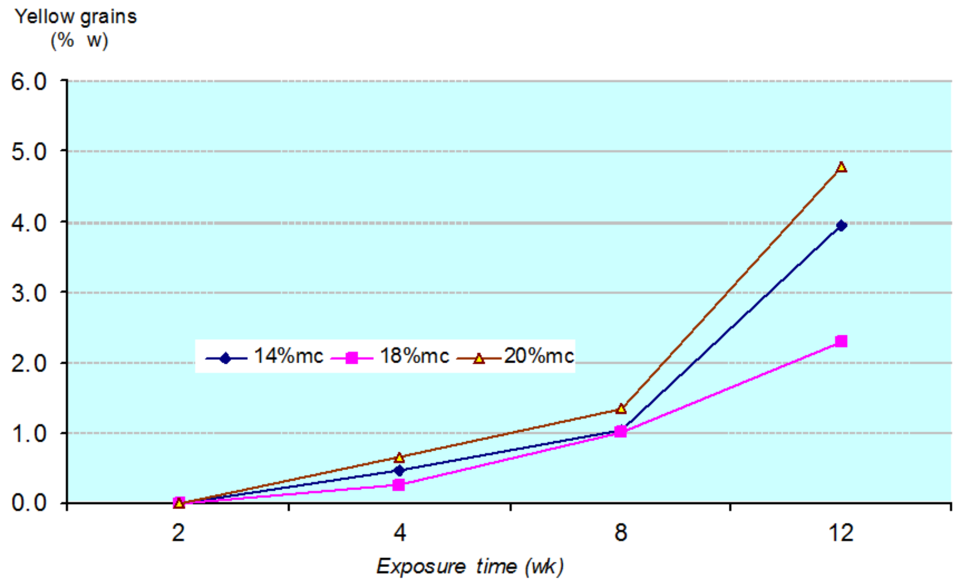

Figure 4: *Effect of MC and exposure time on the yellowing of grains in paddy stored at ambient temperature (28°C)*

After 3 months of storage, milled rice from paddy with 20% MC stored in the air-conditioned room (18°C) had the highest amount of yellow grains (5.35 %w/w), followed by paddy with 20% MC stored in ambient condition with 28°C average temperature (4.79 %w/w). Paddy with 18% MC stored at ambient condition, developed the least amount of yellow grains (2.26 %w/w). Generally, less than 2 %w/w yellow grains developed after 8 weeks of storage time, except for the 18% MC paddy samples stored in -5 and 18°C and the 20% MC paddy samples stored in 28°C ambient temperature.

Statistical analysis of on yellow grain data (%w/w) proved that grain yellowing in paddy was significantly affected by the interaction of the three parameters. The interaction effect of MC and storage temperature was significant at the 1% level of significance, while that of MC, storage temperature, and exposure time was significant at 5% level of significance by the least significant difference (Table 2). Mean comparison showed that the amount of yellow grains (%w/w) from the 20% MC and 18% MC samples were significantly higher than the 14% MC sample (Table 3). There was no significant difference in the amount of yellow grains between the 20% MC and 18% MC samples. On the other hand, the yellow b values (Table 4) were significantly affected by MC and storage temperature. Samples subjected to a longer exposure time got higher yellow b values.

Moisture content (%)	14	0.07833a
	18	0.01972ab
	20	0.01694b
Storage temperature (°C)	-5	0.08222a
	18	0.01806b
	28	0.01472b
Storage time (weeks)	2	0.01741b
	4	0.04926ab
	8	0.01185b
	12	0.07481a

Table 2: *Effects of moisture content, storage temperature, and storage time on yellowing of grain in paddy.*

Moisture content (%)	Average temperature (°C)	Storage time (weeks)			
		2	4	8	12
14	-5	10.19	9.89	9.51	11.19
	18	9.81	9.56	10.13	10.78
	28	10.22	10.28	10.21	10.65
18	-5	10.23	11.29	10.10	11.46
	18	11.40	11.33	10.59	11.04
	28	10.70	11.41	10.74	11.43
20	-5	10.69	11.29	10.24	11.41
	18	11.14	10.63	11.17	11.57
	28	11.17	10.68	11.05	12.53

Table 3: *Yellow b values of milled rice from paddy samples with different MC, storage temperature, and storage time.*

Moisture content (%)	14	10.6375b
	18	11.3008a
	20	11.3167a
Storage temperature (°C)	-5	10.2892c
	18	10.7178b
	28	12.2481a
Storage time (weeks)	2	11.1200ab
	4	10.8904b
	8	11.1570ab
	12	11.1726a

Table 4: *Effects of MC, storage temperature, and storage time on grain yellowing of grain in paddy.*

Head rice recovery

Results of statistical analysis revealed that the interaction of MC and storage temperature significantly affected head rice recovery. Generally, head rice recovery of paddy stored at -5 and 18°C storage temperatures showed increasing head rice recovery over time, regardless of MC (Table 5). Paddy stored at ambient condition (28°C) showed decreasing head rice recovery over time. The 18% MC paddy at -5°C had the highest head rice recovery (71.93%) upon milling and the 20% MC paddy stored at ambient temperature got the lowest (25.16%) after a 12-week exposure. Paddy stored at ambient condition (28.0°C) showed decreasing head rice recovery over time at all MC levels.

From these observations, it could be inferred that the trend in head rice recovery would mean a corresponding trend in milling recovery. A reduction in head rice recovery would result in increased amounts of broken grains whose edges will be polished into dust during milling and therefore would eventually mean reduced milling recovery.

Storage temperature (°C)	Storage time (weeks)	14% MC	18%MC	20% MC
-5	0	63.79	51.87	56.01
	2	64.03	65.25	57.16
	4	60.53	62.28	57.11
	8	65.53	69.36	59.56
	12	65.17	71.93	63.05
18	0	63.79	51.87	56.01
	2	63.56	65.53	58.96
	4	57.61	58.63	53.61
	8	63.11	63.77	58.87
	12	68.05	66.91	62.71
28	0	63.79	51.87	56.01
	2	57.83	49.72	29.97
	4	42.51	47.97	31.43
	8	42.19	50.41	37.49
	12	35.31	36.79	25.16

Table 5: *Average head rice recovery at various MC, storage temperature, and storage time.*

Conclusions and Recommendations

This study showed that interaction between MC, storage temperature, and storage time significantly affect rice grain yellowing in stored paddy. The amount of yellow grains increased with storage time regardless of MC and storage temperature levels. The rate of grain yellowing rapidly increased after 8 weeks of storage at all storage temperature levels regardless of MC. Paddy stored at -5, 18, and 28°C storage temperatures with 14, 18, and 20% MC, respectively, developed less than 2% yellow grains. Hence, the rate of yellow grain formation is directly proportional to storage time regardless of MC and temperature.

Head rice recovery of paddy was significantly affected by the interaction of MC, storage temperature, and storage time. Paddy samples exposed to -5 and 18.0°C have increasing milling recovery over time at all MC levels, while head rice recovery of paddy stored at ambient temperature decreased over time regardless of MC. In general, cooler storage temperature was more favorable in terms of head rice recovery.

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