Influence of Drying and Post-drying Conditions on the Head Rice Yield of Aromatic Rice

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ABSTRACT

The effects of various drying temperatures, low final moisture, and post-drying duration, on fissure formation and head rice yield (HRY) reduction in aromatic short-grain rice, were investigated. The results of post-drying duration showed that most fissured kernels were produced within 12-h after drying process ceased and then became to stable within 24 h for all treatments. The whole kernel percentage of Kaori aromatic rice was reduced significantly ($P<0.01$) when rice was dried at 50°C and 60°C for both standard and low final moisture content (FMC). For a given post-drying duration and conditions, low FMC treatments exhibited more HRY reduction than did standard FMC. It is well known that moisture gradient has much influence in producing fissure in kernels. In addition, increased difference between immediate storage temperature and drying air temperature augmented the increase in the percentage of fissured kernels (P<0.01).

Keywords: Drying, fissure, head rice, low moisture, post drying, Iran

1. INTRODUCTION

It is a common practice for freshly harvested rice to be dried to safe moisture content (MC), typically 12 to 13% (MC is wet basis unless otherwise specified), and then stored for some months prior to milling. Fissuring can occur in the field prior to harvest, or during harvesting, processing, and storage after drying. Drying creates moisture and temperature gradients within a kernel, which induces development of tensile stress at the surface and compressive stress at the interior of the kernel (Sharma and Kunze, 1982). Various studies (Sarker and Kunze, 1996; Jia *et al*., 2002; Yang *et al*., 2002; Zhang *et al*., 2003) explained several hypotheses regarding fissuring of rice kernels during drying at high temperature and low relative humidity. Moisture adsorption gradients cause differential stresses inside the kernel, which, if sufficiently large, causes the kernel to fissure (Kunze, 1979). Improper drying processes and post-drying conditions can be a major cause of fissuring (Ban, 1971; Kunze and Choudhury, 1972; Sharma and Kunze, 1982; Wiset *et al*., 2001). The magnitude of fissure percentage depends on the thickness of kernel, FMC, and the conditions at which samples were dried. Understanding the effects of FMC and drying conditions on the rice kernel fissuring in particular short grain aromatic rice during the immediate post-drying duration is important to optimize drying and post-drying conditions for maximizing milling quality.

Several researchers (Ban, 1971; Kunze, 1979; Sharma and Kunze, 1982; Nguyen and Kunze, 1984) observed that fissures do not occur until drying has ceased. Sharma and Kunze (1982) stated that few whole rough rice kernels fissure during the drying process itself. As most kernels are not fissured immediately after drying, a small number of studies have considered post-drying fissure development in rough rice. Sharma and Kunze (1982) reported that most fissures appear within 48 h of the cessation of drying. Nguyen and Kunze (1984) studied the influence of post-drying environments on fissure formation and noted that drying air temperature have a significant effect on fissuring of rough rice. Li *et al*. (1999) showed that most fissures appeared shortly after drying; the fissured kernel percentage increased rapidly in the first 4 h of post-drying, and there was no further increase in fissures beyond 48 h. They also reported that discontinuing the drying process with tempering could decrease the hydro stresses in the rice kernel, resulting in a reduction in fissure formation.

A number of studies have shown the significance of MC of rice in determining kernel fissure and milling quality (Kunze and Prasad, 1978; Banaszek and Siebenmorgen, 1990). Kunze and Prasad (1978) reported that kernel fissures create during drying are associated with reabsorption of moisture by low moisture grains. Regarding to the rice drying conditions in Iran, the rough rice is dried by batch type dryers at relatively high temperature, where the final moisture reaches to less than 9% (Hashemi *et al*., 2005). This FMC is very low which increases during the storage period up to the equilibrium MC level. Therefore, further studies are needed to identify the conditions that cause creation of fissures and reduced HRY in post-drying duration for samples dried at different drying temperature up to low FMC. This research might be helpful to develop processes and procedures to minimize losses and maintain rice quality. The objective of this research was to study the effects of various drying protocols and post-drying durations up to 48 h on fissure formation and milling behavior of the rice kernel, reflected by head rice yield reduction in *Kaori* aromatic rice.

2. MATERIALS AND METHODS

2.1 Materials

Freshly harvested *Kaori* rice of the aromatic, short and bold grain variety, containing approximately 26% MC, was collected from the Agriculture Research Farm of the University of Tsukuba in Japan. After harvest, about 9 kg of rough rice was immediately cleaned and placed in sealed polythene bags and kept at 5°C till the experimentation.

2.2 Experimental Design

Experimental design for the drying process consisted of different drying conditions resulting from a combination of drying air temperatures, namely 30^{o}C, 40^{o}C, 50^{o}C, and 60^{o}C and different drying times to obtain a standard (about 12%) and a low (about 9%) FMC. After drying process ceased, samples were tempered at room conditions (22^{o}C temperature and 50% relative humidity) for 1 hour and then were kept in plastic bags in ambient environment storage. After 1 h, 120 grams of the sample was randomly taken for fissure enumeration and HRY determinations. The same procedure was followed after 12, 24, and 48 h durations at room temperature. These durations were selected in accordance with the findings reported by Li *et al*. (1999) that there is little increase in the number of grains with fissures beyond 48 h.

For comparison with experimental data, a reference sample (about 500 g rough rice) was dried in a temperature- and humidity-controlled chamber (Humidity Cabinet, LHL-113, TABAI Espec Corp. Japan), which was set at 25^{o}C, 60% RH, corresponding to a rice equilibrium MC (EMC) of approximately 12.5% (Perdon *et al*., 2000).

The drying time is a function of the FMC of paddy. Drying was conducted using a laboratory scale batch-type dryer (Hashemi *et al*., 2006). As shown in Table 1, the experiment was considered completed when the FMC reached to approximately 12% [a standard FMC for milling and safe storage (ASAE, 1982)] and 9%, representing the low FMC widely used in Iran (Hashemi *et al*., 2006).
The number of Fissured kernels was counted in 100 rice kernels which were randomly taken from control and drying treatments and each sample was manually dehulled and then kernel was inspected using a grain scope (TX-200, Kett Electric Laboratory, Tokyo, Japan) based on light reflection on the grain. The rigidity test was conducted on each of 20 kernels without fissure using a texture analyzer (Texture Analyzer TA-XT2i, Stable Micro System, Surrey, U.K.) based on force to reach the max strain and crush. The MC of samples before and after drying was measured using an oven drying method (ASAE, 1982; Chiachung, 2003), in which 5 to 10 g of rough rice were dried in a convection oven for 48 h at 105°C. It was replicated twice.

2.3 Milling Process

A total 72 samples (9 drying conditions including control, 4 post-drying duration, 2 replicates) were made for this study. In each run, 100 g of dried paddy was weighed and hulled in rubber roll husker (L-THU-35A, Satake engineering Co., LTD., Higashihiroshima, Japan) and subsequently weighed and milled with a vertical friction-type milling machine (VP-31T, Yamamoto Co., Tendu, Japan) and then separated into head rice and broken rice by an indent cylinder type rice grader (TRG type, Satake Co., Higashihiroshima, Japan). The HRY was measured based on the percentage of head rice mass remaining from the original 100-g rough rice sample after complete milling (Cnossen *et al*., 2000). The HRY reduction (HRYR) for each dried rice sample was calculated by subtracting from the HRY of reference sample.

2.4 Statistical Analysis

The statistical analysis was performed as a two-factor experiment in completely randomized design (2F-CRD). The two factors are expressed as drying temperature and FMC, with four and two levels, respectively. The experimental variables included drying rate (dR), Rigidity (R), fissure formation (F1, F12, F24,and F48), and head rice (HR1, HR12, HR24,and HR48) at 1, 12, 24, and 48 h post-drying duration, respectively.

3. RESULTS AND DISCUSSION

Analysis of variance among variables and their interactions was performed at a significance level of 0.01 unless otherwise indicated (Table 2). A Pearson's correlation test was performed among the variables and is shown in Table 3.

Table 1. Experimental data of Kaori aromatic rice when subjected to different drying temperature to attain a standard or low FMC

Moisture variables	Standard FMC (~ 12%)				Low FMC (~9%)			
Drying temperature (^oC)	30	40	50	60	30	40	50	60
Initial MC (%)	27.01	26.70	26.81	26.41	26.87	25.9	26.7	26.9
Final MC (%)	12.38	12.45	12.32	11.84	9.95	9.76	9.64	9.75
Drying time (min)	698	366	255.00	197.50	1290.0	727.5	420.0	270.0
Drying rate (%/hr)	1.26	2.34	3.42	4.45	0.79	1.3	2.4	3.8

Table 2. Analysis of variance at different post-drying duration of *Kaori* aromatic rice

Variables	*df*	dR	F_1	F_{12}	F_{24}	F_{48}	HR_1	HR_{12}	HR_{24}	HR_{48}
Drying temp.	3	212^{**}	28^{**}	111^{**}	390^{**}	319^{**}	74^{**}	726^{**}	1236^{**}	952^{**}
Final MC	1	70.7^{**}	1.3^{ns}	14.4^{**}	53.4^{**}	52.0^{**}	32.1^{**}	4.7^{ns}	25.8^{**}	21.5^{**}
Temp. & FMC	3	1.9^{ns}	1.6^{ns}	2.4^{ns}	8.9^{*}	6.4^{*}	5.4^{*}	4.9^{*}	5.5^{*}	10.8^{**}

^{ns} Not significant, * Significant at level of 5%, **Significant at level of 1%,

F: fissured kernel and HR: head rice at indicated post-drying duration

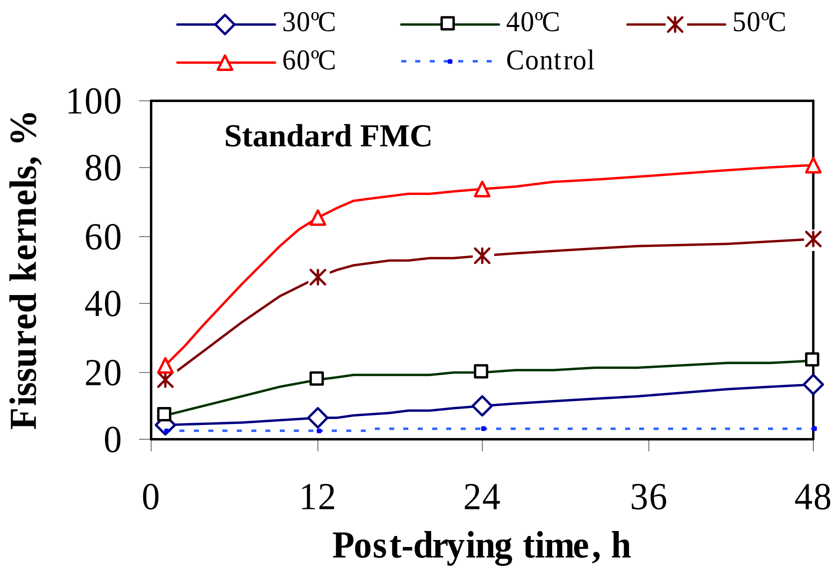
Table 3. Pearson's correlation coefficient for the relationship between physical and milling variables at indicated post-drying duration

Variables	HR_1	HR_{12}	HR_{24}	HR_{48}	dR
Drying rate (dR)	-0.91**	-0.90**	-0.90**	-0.90**	--
Fissure after 1 h (F_1)	-0.85**	-0.95**	-0.96**	-0.96**	0.89**
Fissure after 12 h (F_{12})		-0.97**	-0.98**	-0.98**	0.86**
Fissure after 24 h (F_{24})			-0.98**	-0.98**	0.86**
Fissure after 48 h (F_{48})				-0.98**	0.87**

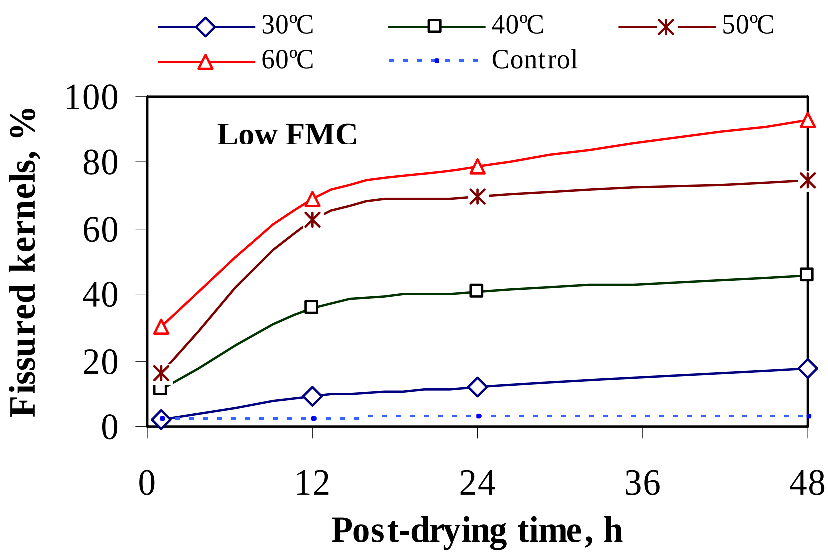
** Significant at P<0.01

3.1 Fissure Formation

Figure 1 shows the percentage of fissured kernels at each indicated post-drying duration in the samples dried at different drying temperatures at a FMC of about 12% (Fig. 1a) and 9% (Fig. 1b). With increasing post drying duration, the percentage of fissured kernels significantly (P<0.01) increased in both standard and low FMC treatments. After one hour of drying process ceased, with the increase in drying temperature, the percentage of fissured kernels increased from 4% to 22% for grains with a standard FMC, and from 2% to 30% for grains with a low FMC.



(a)



(b)

Figure 1. Percentage of fissured kernels which developed during 48 h of post-drying for samples dried at indicated drying temperature to (a) a standard FMC of about 12% and (b) a low FMC of about 9%. The control sample was dried at 25^{o}C temp. and 60% RH.

After 48 hour, samples dried at 50^{o}C and 60^{o}C, the maximum percentage of fissured kernels was about 60% and 80%, respectively, for grains at a standard FMC and 75% and 96%, respectively, for grains at a low FMC. If the moisture gradient is sufficiently high, it causes the kernel to fissure (Kunze, 1979). This might be the reason for increased percentage of fissured kernel with increased drying temperature and very low FMC. The effect of post-drying duration (1 to 48 h after drying has been finished) on the percentage of fissured kernels could be explained by drying temperature, moisture, thickness, and storage conditions in the following section.

3.1.1 Drying Temperature

As shows in Fig. 1, the final curves aligned themselves in the order of increasing fissures with increasing drying temperature and decreasing FMC. The maximum number of fissures occurred at drying air temperature of 60^{o}C followed by 50^{o}C, 40^{o}C, and then 30^{o}C in grains of both FMCs after 48-h. The final fissuring response following drying at 60^{o}C was nearly 5 times as large as that following drying at 30^{o}C, in grains of the same FMC. Statistical analyses show that drying temperature had a significant ($p<0.01$) effect on the drying rate and fissure formation at different post drying durations (Table 2 & 3). It shows that with increase in drying temperature, drying rate increased and also moisture gradient increased, which subsequently increased the amount of fissured kernel increased significantly ($p<0.01$), regardless of FMC. This finding was confirmed by Siebenmorgen *et al*. (2005) in samples dried under severe drying condition.

3.1.2 Final Moisture

The percentage of fissured kernels with low FMC (Fig. 1b) was about 15% higher than that of kernels with standard FMC (Fig. 1a), at different post-drying durations, in particular at temperatures higher than 50^{o}C.

3.1.3 Thickness

As mentioned earlier, the maximum percentage of fissured kernels was about 80% and 93% for grains of standard and low FMC, respectively. The deviation in the extent of fissured kernels found in this research and the findings reported by other researchers (Kunze, 1991; Siebenmorgen *et al*., 2005), might be due to the variety with different size and shape of kernels. In comparison to other research results, Siebenmorgen *et al*. (2005) observed the maximum percentage of fissured kernels as about 35% for long grain varieties after 48-hour post-drying duration for samples dried at 60^{o}C, whereas Sharma and Kunze (1982) reported a maximum of about 46% for long grain rice and about 90% for medium grain rice.

Thickness of kernels has an important role on the magnitude of moisture gradient in kernels. The average thickness of the *Kaori* variety was 2.12 mm which is about 35% higher than that of the variety used by Siebenmorgen *et al*. (2005) and almost same as that of the medium grain used by

Sharma and Kunze (1982). This thickness made the grain more vulnerable to produce the fissure especially at severe drying condition.

The moisture gradient creates tension at the surface and compression in the central portions of the grain during drying, and the kernel pulls apart or fissures (Kunze, 1979). Moisture gradients also occur during the adsorption process in storage; these gradients have the potential to produce fissures in kernels during the post-drying period (Kunze and Prasad, 1978). After drying, when the moisture gradient subsides, the grain surface gains moisture (expand) while the grain center looses moisture and contracts. The expanding surface is in compression while the contracting center is in tension, which produces fissures.

3.1.4 Storage Conditions and Duration

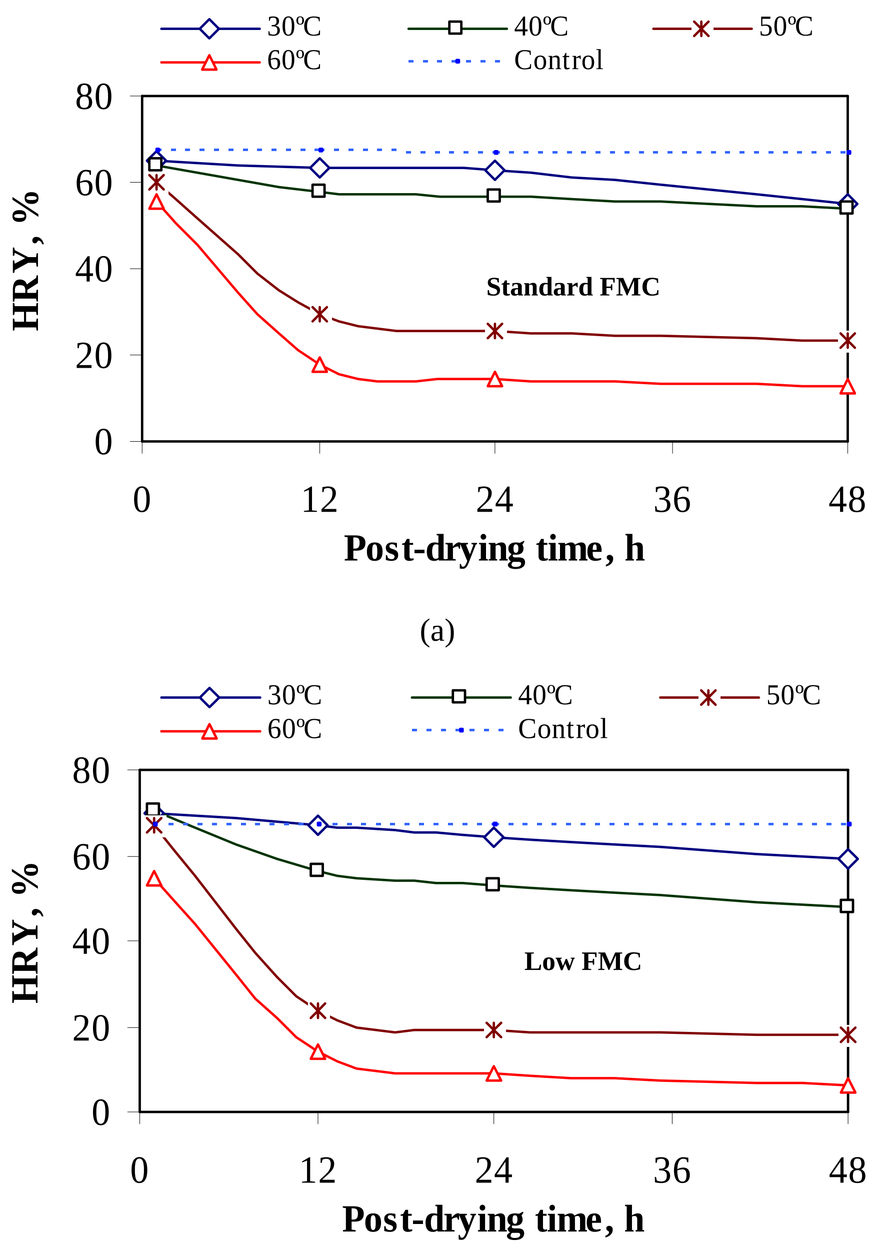
It is evident from Fig.1 that the percentage of fissured kernels varied from 18% to 80% for standard FMC and 18% to 90% for low FMC as the difference between drying temperature and storage temperature increased from 8^{o}C to 38 ^{o}C, respectively in both cases. After one hour of drying, the highest occurrence of fissured kernels belonged to a low FMC dried at high temperature (Figs.1). The percentage of fissured kernels increased at given post-drying duration and visual appearance of fissures occurred almost entirely within 12 h of cessation of drying, then reaching a steady state; the appearance of fissures was completed by 48 h. A similar fissure-producing trend was reported by Siebenmorgen *et al*. (2005), stating that all fissures occur within 24 h after drying, regardless of the drying temperature and variety, are completely formed by 48 h. The occurrence of fissuring was less for treatments dried at 30 and 40^{o}C which produced a low moisture gradient at end of drying and also was closer to immediate storage temperature. The increased moisture gradient in the low FMC caused the increase in the percentage of fissured grains (Sharma and Kunz, 1982; Li *et al*., 1999; Siebenmorgen *et al*., 2005) which was augmented by the increased difference of temperature between drying air and the immediate ambient after drying ($P<0.01$). Sudden changes in kernel temperature cause expansion or contraction of kernels which might have attributed to fissure augmentation. This subsequently leaded to increased HRY reduction.

3.2 Head Rice Yield Behavior at Different Post-drying Duration

Fig. 2 shows the change in HRY for sample dried at different drying temperature to standard and low FMC level at identical post-drying duration. At the end of drying, the low FMC rice had the bigger moisture gradient reclines, the surface gains moisture and the center looses moisture. As a result, surface expands and center contracts leading to grain fissuring. Process occurs during period after drying. Many researchers (Jindal and Siebenmorgen, 1994; Siebenmorgen *et al*., 2005; Wiset *et al*., 2001) reported that the variation in HRY depend on the drying air temperature, fissuring, rigidity, post-drying duration and temperature, grain thickness.

3.2.1 Drying Temperature

As indicated by the Fig. 2, the differences of HRY caused by drying temperature (30^{o}C and 60^{o}C) varied as 9, 45, 48, and 43% for standard FMC and 15, 52, 55, and 53% for low FMC after 1, 12, 24, and 48 h after the drying process ceased, respectively. The maximum difference value belongs to low FMC treatments. This indicates that the HRY was significantly depended upon drying air temperature at low FMC. Siebenmorgen *et al*. (2005) reported that the HRY is dramatically decreased when the drying air temperature reached to 60^{o}C especially at low FMC.



(b)

Figure 2. Reduction of head rice yield during 48 h of post-drying for samples dried at indicated drying temperature to (a) a standard FMC of about 12% and (b) a low FMC of about 9%. The control sample was dried at 25^{o}C temp. and 60% RH.

Statistical analysis shows that the drying temperature had a significant effect (*P<0.01*) on the HRY for different post-drying duration. There was no significant difference in HRY reduction for the 30^{o}C and 40^{o}C drying air temperature. The maximum reduction of HRY was occurred at 50 and 60^{o}C for identical post-drying duration. Higher drying temperatures produced significant

HRY reduction at different post-drying duration. Low FMC was most severely affected by the drying conditions, followed by standard FMC (at about 12%). This might be attributed to combination of moisture sorption at low FMC treatments (Shimizu *et al.* 2008).

3.2.2 Final Moisture Effect

The FMC also had significant effect ($P<0.01$) on the HRY (Table 2 and Fig. 2). The percentages of head rice yield obtained from paddy dried for standard FMC were slightly higher than that achieved from low FMC (about 5 to 10%) at same post-drying duration until 48 h. This is because of adsorption condition which could occur in low FMC samples reflected by HRY reduction. Shimizu *et al*. (2008) addressed the evidence of fissuring of rice kernels in a moisture-adsorbing environment.

Banaszek and Siebenmorgen (1990) also found that RH and initial MC are significantly related to the HRY reduction caused by moisture adsorption. Jindal and Siebenmorgen (1987) quantified the effect of moisture adsorption directly on HRY reduction for long-grain rough rice. Based on the findings reported by Siebenmorgen *et al*. (2005), the greater HRY reduction can be attributed to the greater thickness of kernels and closely correlated to development of fissure. Fan *et al*. (2000) showed that the HRY reduction of Bengal, a medium and bold kernel variety, was greater under the same drying condition as cypress, a long-grain and more slender. Thicker kernels are more susceptible to fissuring than thin kernel particularly at severe drying conditions due to higher moisture gradient which was explained earlier. Siebenmorgen *et al*. (2005) found strong linear correlations between HRY and the percentage of fissured kernels, confirming the present results.

4. CONCLUSIONS

The effects of various drying conditions and immediate post-drying duration, on fissure formation in aromatic short-grain rice, were investigated. The occurrence of fissuring was less for treatments dried at 30 and 40^{o}C in all post-drying durations. With elapse of post-drying duration, the magnitude of fissured kernels for low FMC was higher than those treatments in the standard FMC. The maximum fissuring response for treatment dried at 60^{o}C was nearly 5 times higher than that of 30^{o}C drying temperature for the same FMC. Regardless of drying temperature, most fissured grain was produced within the first 12 h after drying ceased. For a given post-drying duration and condition, low FMC treatments exhibited more HRY reduction than that of standard FMC. The increased moisture gradient in the low FMC caused the increase in the percentage of fissured grains which was augmented by the increased difference of temperature between drying air and the immediate ambient after drying ($P<0.01$). Sudden changes in kernel temperature cause expansion or contraction of kernels which might have attributed to fissure augmentation.

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