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INFLUENCE OF DIFFERENT TEMPERING PERIOD AND VACUUM CONDITIONS ON THE RICE GRAIN BREAKAGE IN A THIN LAYER DRYER

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ABSTRACT. Drying and milling of the paddy are known as the most important process influencing the rice grain breakage. Therefore in this study, influence of tempering period and the reduced atmospheric pressure (vacuum) on the crack formation of two rice varieties (Nemat and Pajouhesh) during the tempering stage is presented. Four different level of drying temperature (40, 50, 60 and 70°C) were used in this study. After drying, paddies have been transferred to a vacuum chamber ranging from 0.4 at to 1 atm (ambient pressure). Based on the results obtained in this study, crack formation in rice grains increases with increasing drying time and drying temperature. In contrast, a reduced pressure during the relaxation stage significantly reduced the rice grain breakage. During the relaxation period in the vacuum chamber, heat transfer within the rice grain occurs slowly, yields minimizing the thermal and moisture stresses. The optimized combination of temperature, time, and pressure for the Nemat and Pajouhesh rice varieties obtained 60°C, 5 hr, and 0.8 atm, respectively.

Key words: Rice; Tempering; Vacuum; Reduced pressure; Drying.

INTRODUCTION

Rough rice should be dried to a moisture content of 12–13% wet basis (w.b.) for safe storage after harvesting. Improper drying and tempering processes can be a major cause of fissuring. During drying, moisture and temperature gradients created inside the kernel induce stresses that can cause the kernel fissuring (Dong *et al.,* 2010). Drying stage is a critical step in process of paddy-to-white rice, since most of the losses in post-harvest processing of rice occurred in drying and milling stage (Dong *et al.,* 2010). Rice kernel fissuring depends not only on the variety and crop management, but also on the post-harvest operations, especially on drying conditions. Temperature and drying time are two

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drying parameters that play a significant role in reduction of rice moisture content (MC). Fissured kernels usually break during the milling, lead to a reduction in head rice yield (HRY).

Recently a new method developing in the process of agricultural and food products is vacuum drying and vacuum preservation. Cheenkachorn (2007) used a microwave-vacuum dryer to drying of paddy. Zemin *et al.* (2010) used Neural Network Model for prediction the influence of vacuum drying parameters on the rice taste value. Application of vacuum in drying process results in a lower boiling point. This allows water to vaporize at a lower temperature. Lower drying temperature leads to minimizing the heat damage and nutritional losses. Artnaseaw *et al.* (2010) used a kind of vacuum heat pump for drying chili.

Fan *et al.* (2000) outlined several factors involving in occurrence of fissure and crack formation. Some of them occur when the temperature difference between the drying air and the rice kernel exceeds 43 ^{o}C (Fan *et al.,* 2000).

Kunze and Prasad (1978) reported that formation of kernel fissures during the drying process are primarily associated with reabsorption of moisture by kernel. Moisture reabsorption by dry rice grains, as well as other cereal grains, is hygroscopic. Dried grains reabsorb moisture from any exposed sources. Moisture absorbed through the grain surface causes the starch cells to expand and produce compressive stresses. Since the grain is a "free body", compressive stresses are countered by equal but opposite tensile stresses at the grain center. When the compressive stresses at the surface exceed the tensile strength of the grain at its center, a fissure develops. Fissured grains usually break during the milling operations (Kunze and Prasad, 1978).

The objective of this research is to investigate the influence of different drying temperature and also the low ambient pressure (vacuum) during the tempering period (rest time) after various drying conditions. Influence of different vacuum levels on the rice breakage in the tempering stage is examined and the obtained results is compared with the atmospheric tempering condition. Tempering is necessary to avoid a significant moisture content gradient within the rice kernels that may induce undesirable fissuring of rice kernels.

MATERIALS AND METHODS

Two rice varieties have been studied in this research (Nemat and Pajouhesh) which was harvested from GABIT[1] farm in summer 2010 in Iran (*Fig. 1*). Both of them are high yield rice varieties. Initial, moisture content of the selected varieties at the start of the research was 21 to 23%. Their average dimensions are given in *Table 1*.

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Each sample dried in a Lab-Oven equipped with PID-Controller (Atbin, Korea) in the form of a thin layer model at four temperature levels (40, 50, 60 and 70^{o}C) with three drying time levels (1, 3 and 5 hours). Then moisture content of the samples (MC) were measured by a Resistant Type Digital moisture-meter (GMK-303 G-Won, Korea). Each drying measurement was performed in three replications for increasing the measurement accuracy.

Table 1- Average dimensions of two rice varieties studied in this research

Measured quantity	Nemat	Pajouhesh
Average paddy length (L) in mm	11.73	10.34
Average paddy diameter (d) in mm	2.03	1.94
Average paddy length-to-diameter ratio (L/d)	5.77	5.33

Nemat **Pajouhesh**

Figure 1 - Photograph of two rice varieties studied in this research

In this research, samples were transferred to a vacuum chamber during the relaxation period (tempering). The objective of tempering is to equalize the moisture content by slowly moisture migration inside the rice kernel during the post-harvest process of paddies (Cnossen and Siebenmorgen, 2000).

The vacuum chamber was made from a hard polyethylene material (HPE). A vacuum pump (Platinum JB- DV-42N-250, USA) coupled to this chamber (*Fig. 2*). Time duration for this stage was 1.5 hours (90 min). During this time, samples were rested to reach thermal and moisture equilibrium with surrounding. Four different constant vacuum levels were examined in this experiment: ambient pressure (1 atm), 0.8 atm, 0.6 atm and 0.4 atm. The vacuum environment continually controlled and fixed by control valves, digital vacuum gauge (Autonics PSA-01, Korea), and turning on/off the vacuum pump.

After tempering, moisture content (wet basis) of the samples were measured by means of the mentioned Digital moisture-meter (GMK-303 G-Won, Korea) and a digital balance (Jadever-Sky 600, Japan). Then 100 grains randomly selected from each vacuum tempered samples. The randomly chosen grains were husked by a laboratory rice husker (TZ4.5, China - *Fig. 2*). Then the number of broken and intact kernel was counted and the percentage of cracked grains

(% C) was determined by using the following equation:

$$\% C = \frac{\text{Number of broken kernel}}{\text{Total number of the counted kernels}} \times 100$$

Figure 2 – Vacuum chamber and pump used in this study

The experimental study was treated as a split-split plot design. Data were analyzed using the SAS software to illustrate the influence of all experimental variables on the rice breakage. Duncan's Multiple Range Test were used to compute differences between means at $P < 0.005$ and to compare two whole plot means averaged (vacuum level) over all sub and sub-sub-plot treatments (temperature and time, respectively) used by Mstat-C software.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) for the crack of rice grains at different vacuum conditions in tempering stage and different drying conditions are presented in *Table 2*.

Based on the results presented in *Table 2*, it is evident that the crack occurrence is significant at the 1% probability for drying conditions (Time and Temp), and also vacuum condition (Vac).

Comparing between the results presented in *Fig. 3* indicates that crack formation in rice grains increases with increasing drying temperature after 60°C. The crack percentage significantly is large at drying temperature of 70°C. In contrast, crack occurrence decreased with increasing the vacuum level (decreasing the environmental pressure within the vacuum chamber) during the tempering period. The same qualitatively results have been observed for both varieties, e.g., for Nemat and Pajouhesh varieties.

Tg concept to explain rice kernel fissure formation during the drying process was first proposed by Cnossen and Siebenmorgen (2000). They found that placement As shown in *Table 2* and illustrated in *Fig. 3*, interaction between temperature, time and vacuum level (Vac×Temp×Time) was significant at the 1% probability for crack occurrence. Results presented in *Fig. 3* indicate that the crack occurrence is practically low at the combination of "50°C drying Temp × 3 hr drying time× 0.8 atm tempering pressure" or "60°C drying Temp × 3-5 hr drying time× 0.8 atm tempering pressure". Each of the two mentioned optimum conditions (3 or 5 hr drying time) can be used in practice depending on the final moisture content requirements. Higher vacuum conditions (0.6 atm and 0.4 atm) is difficult in practice; therefore they are suggested in industrial equipment.

Table 2 - Means of Square of Crack (C%) for two variety of rice: Nemat and Pajouhesh

Source of variation	df	Mean Square	
		Nemat	Pajouhesh
Vac.	3	289.01**	2625.94**
Temp.	3	600.05**	3099.74**
Vac×Temp	9	183.03**	483.93**
Time	2	80.01**	174.88**
Vac×Time	6	55.78**	78.45**
Time×Temp	6	73.50**	131.65**
Vac×Temp×Time	18	60.53**	71.54**
Error	64	428.58	25.32
CV (%)		27.47	31.04

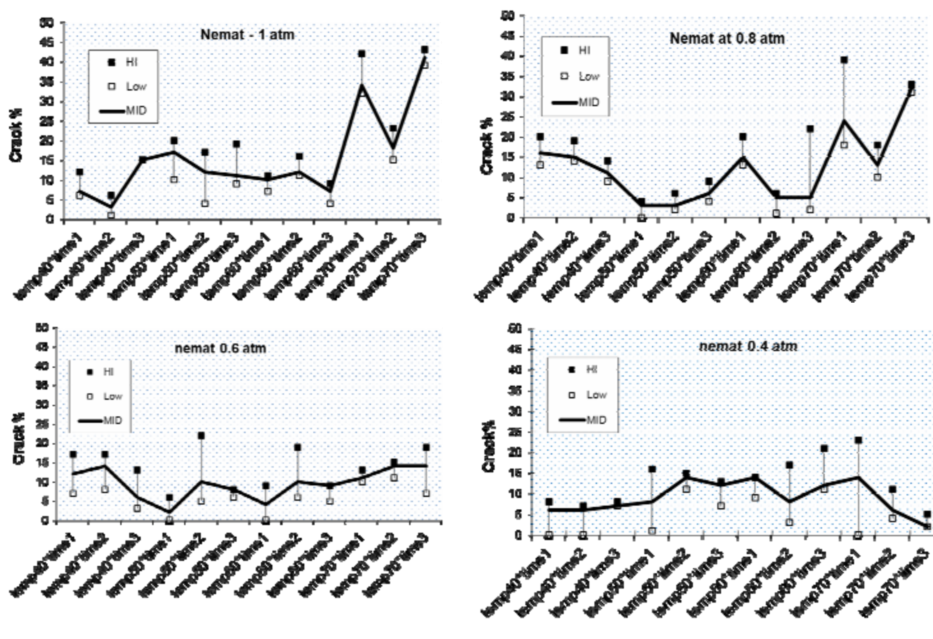

Figure 3 - Crack formation in rice grains as a function of drying temperature × tempering time at different vacuum levels, time 1: 1 hr drying, time 2: 3 hr drying, and time 3: 5 hr drying.

High moisture content gradients within the kernel produce stresses that can cause the fissure development. The resulted stresses may exceed the tensile strength of the rice kernel yielding crack formation in the grain (Kunze and Prasad, 1978). Furthermore, Cnossen and Siebenmorgen (2000) showed that fissures are produced when a rapid transition from the rubbery to glassy region is occurred. Inter-kernel moisture content gradients can be reduced by tempering, in which internal kernel moisture is allowed to migrate towards the surface of the kernel (Siebenmorgen *et al.,* 2004). In this study by keeping and preservation of dried rice in vacuum chamber, moisture content gradient was slowly decreased without interruption of the Tg line; therefore the thermal and moisture equilibrium was occurred in the region above and/or below the Tg line. The application of the of rice kernel above or below Tg significantly affects drying rate and fissure initiation in the rice kernel (Cnossen and Siebenmorgen, 2000; Perdon *et al.,* 2000).

Comparison between drying constant rate (K) and step of moisture measurements for two varieties of rice in three levels: 1 (after drying), 2 (after 1 hr tempering) and 3 (after 2 hr tempering) is presented in *Fig. 4*. According to the results presented in this figure, drying rate increases with increasing the drying temperate, but the amount of K decreases with increasing the tempering period, i.e., the rest time after drying. These changes is due to the grain surface moisture absorption that increases with increasing the rest time, until reaching the equilibrium moisture content (EMC). Then the amount of absorption and release of surface moisture balances and the amount of K in 2 and 3 hr tempering period will be close to each other.

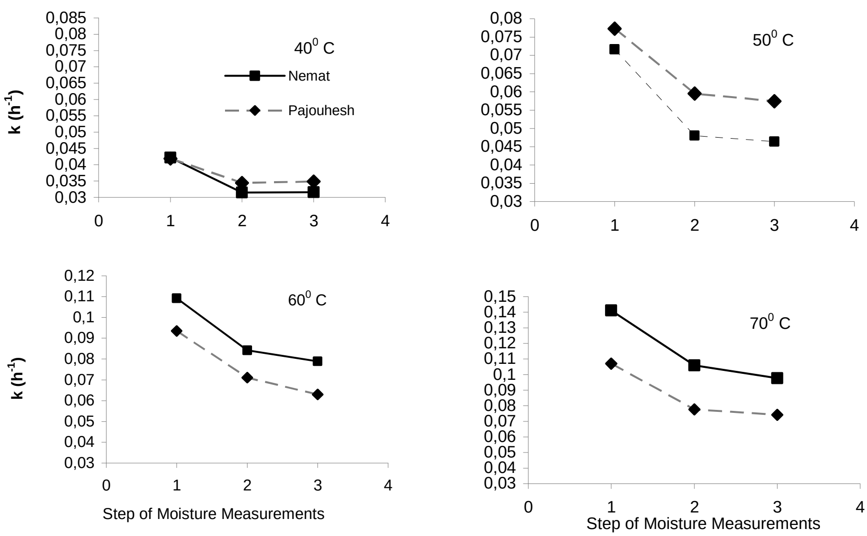

Figure 4 - Comparison between drying constant rate (K) and step of moisture measurements for two varieties of rice in three levels: 1 (after drying), 2 (after 1 hr tempering) and 3 (after 2 hr tempering).

According to the results shown in *Table 2* - Means of Square of Crack (C%) for two variety of rice: Nemat and Pajouhesh, it can be seen that the slope of drying rate constant at the beginning of the rest stage (after heating) is too much more than the next resting stages (between 1 to 2 hr tempering). It can be observed in *Fig. 3* that in drying temperatures above 50°C, it needs more resting time to reach the EMC condition, i.e., needs increasing the tempering period from 1hr to 2 hr. The results of experiments indicated that the rate of moisture absorption and release in the rest time influences directly the rice grain breakage or crack.

According to the results of experiments presented in *Fig. 3*, the tempering time of 1 hour obtained the best condition for drying temperatures less than 50°C. For drying temperatures more than 50°C, the tempering period of 2 hours is more appropriate, because the grain moisture and thermal variations arrive to equilibrium (constant slope of K). This result is consistent with the previous investigations that suggested the tempering time between 1-2 hours for two-phase drying method.

CONCLUSION

Results of this study indicate that the most suitable condition for drying the both varieties (Nemat and Pajouhesh) is combination of "50-60°C drying temperature, 3-5 hours drying time, and 0.8 atm vacuum pressures" in a thin layer drying condition depending on the final moisture content requirements. For drying at 50°C and 60°C, tempering time of 1 hr and 2 hr are suggested, respectively. According to the results obtained in this study, optimal management of the tempering conditions, especially tempering pressure, have significant influence on the reduction of the crack formation in paddies.

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