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Head rice yield response to low and high drying and tempering conditions

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A b s t r a c t. The influence of drying and tempering conditions on head rice yield of long- and medium-grain rough rice varieties was investigated. The head rice yield values for the medium-grain variety at high drying conditions and 1.5 and 3% points moisture content removal were even significantly higher than the corresponding values for the long-grain variety at low drying conditions. 1.5% points moisture content removal yielded the least damage to the rough rice. Under low drying conditions, tempering had no meaningful effect on head rice yield for all drying durations. For both varieties, using high drying conditions with 6% points moisture content removal at first drying stage associated with 120 min tempering duration could be suggested as a rapid and energy-saving operation to achieve high head rice yield values.

K e y w o r d s: glass transition, grain drying, milling, moisture gradient, rice, tempering

INTRODUCTION

Rice (*Oriza sativa* L.) is one of the most important foods for the majority of the people in the world (Amiri-Chayjan and Esna-Ashari, 2010). It is an important source of energy, vitamins, mineral elements and rare amino acids (Ashtiani Araghi *et al*., 2010). Head rice yield (*HRY*), the mass percentage of rice kernels that remain as sound rice after milling, is the most important quality characteristic in the rice industry. *HRY* is especially sensitive to drying conditions and is commonly taken as a standard index to assess the effect of drying system on rice quality (Yang *et al*., 2003a; 2003b). Fissured kernels are more susceptible to breakage during subsequent hulling and milling operations and hence, decrease *HRY* (Jiménez *et al*., 2000). Therefore, it has been a long-term objective of researchers to develop a rice drying process that can maximise the final product quality.

During drying, temperature and moisture content (MC) gradients are developed within the kernel (Cnossen *et al*., 2003). In order to analyse moisture content gradients and simulate intermittent drying of rough rice, some mathematical models have been developed (Cihan and Cem Ece, 2001; Cihan *et al*., 2007; Igathinathane *et al*., 2008; Nishiyama *et al*., 2006; Putranto *et al*., 2011). Through investigating moisture distribution in a rice kernel during tempering drying, Dong *et al*. (2009) showed that MC gradients were produced during drying periods, which remarkably decreased at the early stage of tempering processes and then decreased gradually.

Researchers recommend multi-pass drying procedure (drying-tempering) to remove moisture from freshly harvested rough rice (Cnossen and Sibenmorgrn, 2000; Dong *et al*., 2010; Igathinathane and Chattopadhyay, 2002; Madamba and Yabes, 2005; Thakur and Gupta, 2006). Time and temperature are the main parameters in tempering operation. By determining the minimum tempering time required to sufficiently reduce kernels MC gradients, the drying process can be optimised (Cnossen and Siebenmorgen, 2000). The effect of the number of drying passes associated with different tempering treatments on kernel fissuring and *HRY* for a medium-grain rough rice variety was studied (Aquerreta *et al*., 2007). Tempering at high temperature of 60°C reduced the percentage of the fissured kernels and enhanced *HRY*, independently of the number of drying passes. Hashemi *et al*. (2008) investigated the fissure formation and *HRY* reduction for an aromatic short-grain rough rice variety affected by different drying temperatures, low final moisture contents and post-drying durations. In terms of post-drying duration, they showed that the most fissured kernels were produced within 12 h after drying process ceased, and then became stable within 24 h. Fan *et al*. (2000) showed that the variety, drying conditions and drying duration affected the *HRY* of rough rice subjected to heated air drying. They also reported that under more severe drying conditions, *HRY* significantly decreased after a certain drying duration.

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The objective of the present study was to investigate the effect of drying conditions and tempering operation on milling quality of two common rough rice varieties namely, Shafagh (long-grain) and Sazandegi (medium-grain) in a two-stage drying method.

MATERIALS AND METHODS

Shafagh (long-grain) and Sazandegi (medium-grain) varieties of rough rice were obtained in 2009 from the Rice Research Institute (Amol, Mazandaran province, Iran), and the Agricultural and Natural Resources Research Centre (Isfahan, Iran), respectively. The samples were cleaned manually to remove stones, straw and dirt, and then sieved to remove broken and damaged kernels. The initial moisture contents (MCs) of Sazandegi and Shafagh were around 20 and 20.5% (w.b.), respectively. The rough rice samples were sealed in polyethylene bags to avoid moisture change due to evaporation and stored at approximately 4°C until the experiments were conducted.

Prior to each drying experiment, the bags of rough rice samples were placed in the laboratory for 4 h to equilibrate at room temperature. Then, the samples were dried at two drying air conditions:

– high drying conditions (air temperature of 60°C and 17% relative humidity (RH)),
– low drying conditions (air temperature of 40°C and 12% RH), resulting in similar equilibrium MCs of 5.5 and 5.8%, respectively.

A drying chamber with temperature and RH controller systems (with accuracy of ±0.5°C and ±1%, respectively) was used to dry the samples in a thin layer drying mode (layer thickness of 3 to 5 mm). All drying experiments were carried out at constant drying air velocity of 1 m s^{-1}. The air velocity was measured using a hot wire anemometer (Lutron AM4204) with velocity range of 0.2-20 m s^{-1} and accuracy of 0.1 m s^{-1}.

For each level of drying conditions, the samples were dried at four different durations (1.5, 3, 4.5 and 6 percentage points moisture removal, PPMR). Weight loss of the rice in the drying process was measured using a digital balance with accuracy of 0.001 g (Sartorius GMBH) in order to terminate the drying operation as soon as the desired MC reduction was achieved.

In order to assess the influence of different tempering duration on *HRY*, each drying batch was split into seven sub-samples and tempered for 0, 40, 80, 120, 160, 200 and 240 min. For tempering, each sealed sub-sample was put in an oven set at a temperature equals to the drying temperature. To perform the second stage of drying, immediately after tempering the samples were taken out of the sealed bags and placed as thin layer batches in the drying chamber under drying air conditions of 21°C and 55% RH to gently dry to 12.5% MC. This MC is recommended for proper hulling and milling of rough rice industrially dried. Finally, the samples were held in sealed bags in storage set at 4°C until the milling process was conducted.

To determine *HRY*, each sample was hulled using a husker with rubber rollers (SATAKE TRU 358) and subsequently weighed and milled for 60 s in a laboratory abrasive rice milling machine (SATAKE TM). Then the samples were manually separated into sound and broken rice. Two 20 g sub-samples were randomly taken out of each milled sample to calculate the percentage of the *HRY* using Eq. (1):

$$HRY = \frac{m_h \; m_w}{20 m_r} 100, \tag{1}$$

where: m_h, m_w, and m_r are the mass of head kernels in sub-sample, the mass of total white rice, and the mass of total rough rice (g), respectively. The average of *HRY* for two sub-samples was considered as each sample *HRY*.

The effect of variety, drying conditions, drying time and tempering duration on *HRY* were studied using a factorial experiment in a completely randomised design (CRD). Two hundred and twenty four samples (2 varieties, 2 drying conditions, 4 PPMRs and 7 tempering duration with 3 replicates; Fig. 1) were used in this study. All data were analysed by analysis of variance (ANOVA) procedures using the SAS statistical software package. When the F-test indicated statistical significance at the p = 0.05 probability level, treatment means were separated by the least significant difference ($LSD_{0.05}$) test.

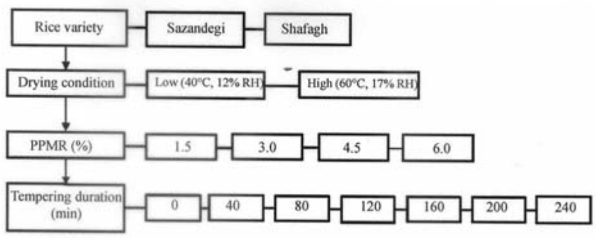

Fig. 1. Experimental design for drying and tempering operations.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) showed that *HRY* was significantly influenced by variety and drying conditions. Figure 2 shows the effect of variety, drying conditions and percentage point moisture content removal (PPMR) on *HRY*. For both levels of drying conditions, the medium-grain (Sazandegi) variety had higher values of *HRY* at all PPMR levels. The obtained values of *HRY* for this variety at high drying conditions were even significantly higher than the corresponding values for the long-grain (Shafagh) variety at low drying conditions when removing 1.5 and 3 percentage points moisture content. This could be due to the inherent different characteristics of tested varieties, such as state diagrams as well as physical properties; the

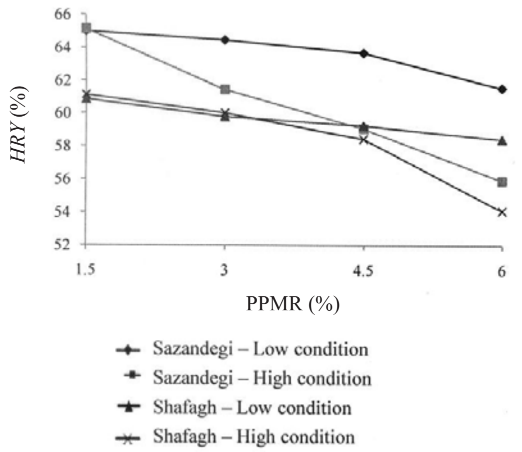

Fig. 2. Effects of variety, drying condition, and point percentage moisture content removal on head rice yield (LSD = 0.5716).

Sazandegi is a medium-grain whereas Shafagh is a long-grain variety according to their aspect ratios. The latter fact could influence the rough rice behaviour during the hulling and milling operations.

In terms of drying conditions, higher values of *HRY* were obtained under low drying conditions when removing more than 1.5 and 3% points moisture content, respectively, for Sazandegi and Shafagh varieties (Fig. 2). This could be attributed to the lower MC gradients at this level of drying conditions, which in turn cause less fissuring in the kernels. Moreover, at low drying conditions the kernels were probably kept below the glass transition line and, therefore, were not forced to tolerate a state transition during the second drying stage. But at high drying conditions, greater differential stresses could be developed within the kernels. Cnossen and Sibenmorgen (2000) stated that some of differential stresses will remain even after tempering and cause breaking of the kernels during the milling process. Also, under high drying conditions, the kernels state might be changed from rubbery to glassy during the second stage of drying.

For both varieties and levels of drying conditions, increasing PPMR resulted in *HRY* reduction due to increase in MC gradients with drying time (Fig. 2). Sazandegi variety dried under both low and high drying conditions showed no reduction in *HRY* at 1.5 PPMR. This shows that at initial drying times, regardless of the drying conditions, MC gradients inside the medium-grain kernels were not sufficient to cause damage to the rice. For Shafagh variety, the difference was not significant for 1.5 and 3 PPMRs. Hence, for this variety the longer drying times created MC gradients enough to produce fissure inside the kernels as compared to Sazandegi. The rate of *HRY* reduction with PPMR (drying time) was higher for Sazandegi than for Shafagh variety at both levels of drying conditions.

Figures 3a, b depict the variation in *HRY* with tempering duration and drying time (PPMR) for Sazandegi and Shafagh dried at temperature of 40°C and 12% RH, respectively. Removing 1.5 PPMR yielded the least damage to the rough rice. However, for both varieties dried under low conditions, tempering had no significant effect on *HRY* for all drying times (PPMR levels). Therefore, it can be concluded that when using low drying conditions, for any PPMR level or drying duration, tempering is not necessary as the MC gradients are small and not sufficient to fissure or break the kernels. This is why, for the tested verities, the highest values of *HRY* were obtained for low drying conditions. However, drying operation under those conditions is slow and hence, energy intensive.

The variation in *HRY* with tempering duration and drying time (PPMR) for the medium-grain (Sazandegi) variety dried under high drying conditions (60°C and 17% RH) is illustrated in Fig. 3c. When removing 1.5% points MC, *HRY* was not significantly influenced by the tempering duration. This is due to lower MC gradient within rough rice kernels after removing a small amount of moisture compared to that of the longer drying durations. Therefore, the least damage to rice kernels was induced and, consequently, the highest *HRY* values were obtained. However, reducing the tempering duration for samples treated by higher moisture removal at the first stage of drying resulted in *HRY* reduction. So that, the *HRY* related to 6 PPMR treatment without any tempering operation reduced drastically. Therefore, a long drying duration could cause enough MC gradients to create fissures inside kernels during the second drying stage. However, when it was tempered for at least 40 min, a pronounced increase in *HRY* was observed (Fig. 3c). For 6 PPMR, tempering duration longer than 80 min had no major effect in increasing *HRY*. Also it can be observed that, when applying tempering durations of 120 min or greater for treatments of 3 and 4.5 PPMR, no significant differences were observed among *HRY* values. Therefore, for the medium-grain variety, 6 PPMR at first stage of drying associated with 120 min tempering could be suggested to achieve high *HRY* values as well as a rapid and, consequently, energy-saving operation.

Considering the total experiments, for the medium-grain variety dried under high drying conditions, when removing 3, 4.5 and 6% points moisture content, *HRY* percentage enhanced around 14, 44 and 92%, respectively at tempering duration of 160, 160 and 120 min, as compared to that of the control (no tempering operation).

Figure 3d shows the change in *HRY* values with tempering duration and drying time (PPMR) for the long-grain (Shafagh) variety dried under high drying air conditions. As stated before, for this variety, longer drying times was induced enough MC gradients to cause fissure within the kernels. So, for the long-grain variety, when reducing MC up to 3% points, tempering duration had no significant effect on *HRY*. But for higher PPMRs, by increasing tempering duration from 0 to 120 min, the *HRY* was significantly increased. However, by increasing tempering duration beyond 120 min, no significant increase in *HRY* was observed.

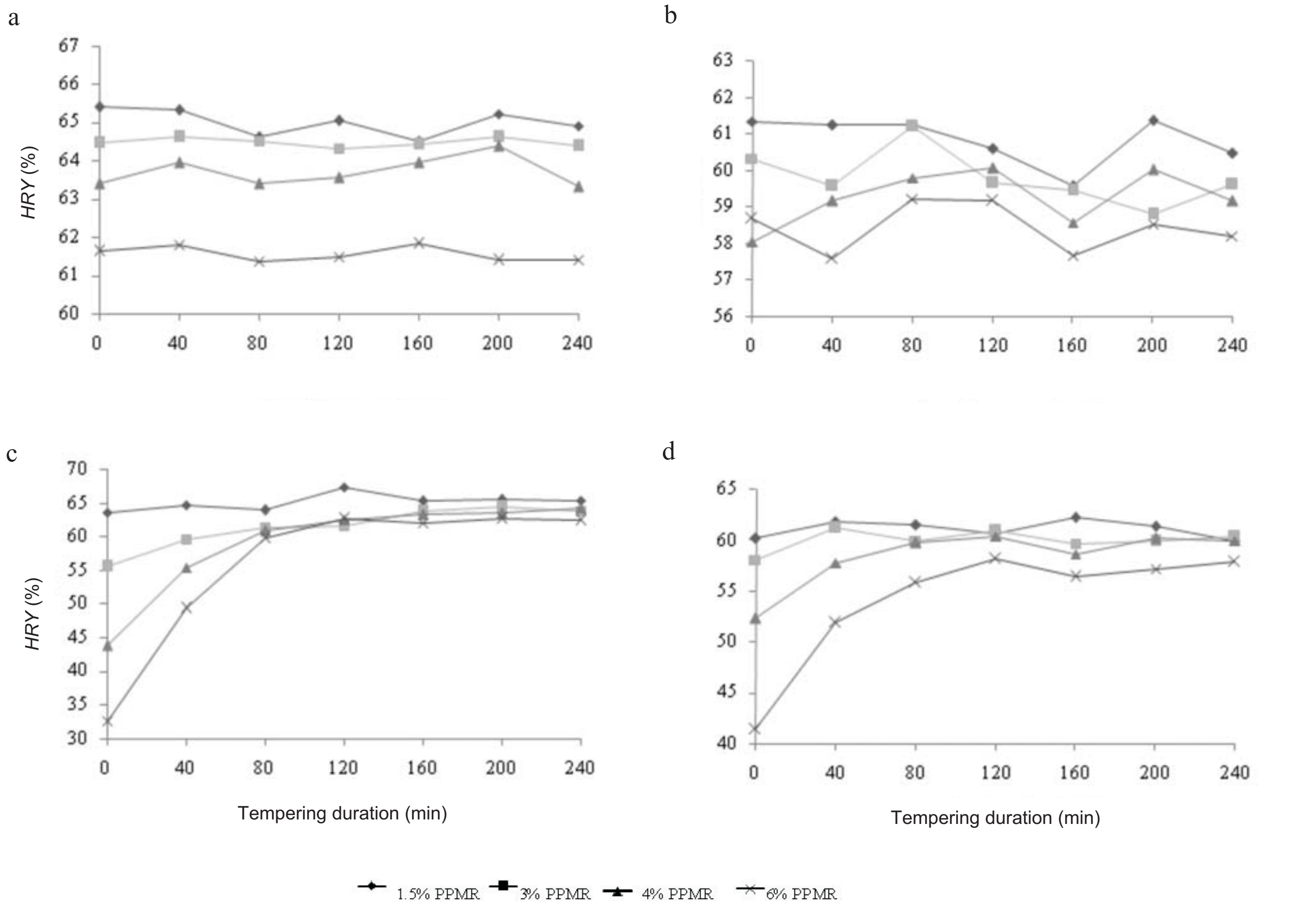

Fig. 3. Variation in *HRY* with PPMR and tempering duration for varieties: a – Sazandegi, b – Shafagh under low drying condition, c – Sazandegi, d – Shafagh under high drying condition (LSD = 1.516).

Therefore, similar to the medium-grain variety, for Shafagh variety, 6 PPMR at first stage of drying along with 120 min tempering could be suggested as a cost-saving operation.

Overall, for the long-grain variety dried under high drying conditions, when removing 4.5 and 6% points moisture content, *HRY* percentage enhanced around 14, and 40%, respectively, for samples tempered in 80 and 120 min in comparison with that of the control. In order to achieve acceptable *HRY*s, Cnossen *et al*. (2003) proposed 80 and 160 min of tempering after drying of two rough rice varieties, namely, long-grain (Cypress) and medium-grain (Bengal) dried under drying conditions of 60°C and 50% RH, respectively. Also, Aquerreta *et al*. (2007) dried a rough rice variety, namely, medium-grain (Lido) at air temperature of 60°C and 4% RH in order to reduce 6% points moisture content from initial moisture content in one, two and three steps. Each drying step was followed by tempering operation to enhance *HRY*. They reported tempering duration of 24 min per each drying stage at tempering temperature of 60°C *ie* the tempering time for one step drying procedure was 72 min.

CONCLUSIONS

1. The obtained values of head rice yield for the medium-grain variety (Sazandegi) at high drying condition were significantly higher than the corresponding values for the long-grain variety (Shafagh) at low drying conditions when removing up to 4.5% points moisture content.

2. For both varieties, the higher values of head rice yield were obtained under low drying condition when removing more than 1.5 and 3% points moisture content, respectively. In comparison with Sazandegi, for Shafagh the longer drying times created moisture content gradients enough to produce fissure inside the kernels.

3. Under low drying conditions, tempering had no significant effect on head rice yield for all drying times (percentage points moisture removal levels). However, tempering rough rice immediately after drying under high drying condition prevented head rice yield reduction, as this drying condition created sufficient moisture content gradients within the kernels.

4. For both varieties, it was possible to use high drying conditions and 6 percentage points moisture removal in the first drying stage without any significant reduction in head rice yield as long as 120 min tempering duration was allowed.

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