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# Milling characteristics of rice grains as affected by paddy mixture ratio and moisture content

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**Key words:** Rice, milling, whitener, head rice yield, whiteness index.

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**Abstract**

The paper presents results of study on the effects of moisture content and paddy mixture ratio (defined as the mass percentage of paddy accompanied with brown rice when arriving into rice whitener machine on milling characteristics of rice grains. The experiments were conducted at four levels of moisture contents (MC), namely 8, 10, 12 and 14% (w.b.) and five levels of paddy mixture ratio (PMR), including 2, 3, 4, 5 and 6%. The milling characteristics were determined in terms of fissured kernels (FK), Head Rice Yield (HRY), whiteness percentage (WP) and whiteness index (WI). The results revealed that as PMR increased from 2 to 6%, the values of FK and WP decreased, whilst HRY decreased by increasing PMR from 2 to 6%. At all of the evaluated PMRs, the values of HRY, WP and WI decreased by decreasing MC from 14 to 8% (w.b.). It was observed that with decreasing MC from 14 to 10% (w.b.), the number percentage of FK decreased and then the further decrease in MC from 10 to 8% (w.b.) caused the FK to increase. It was concluded that in the whitening process, if rice grains arrived into the whitener with higher levels of PMRs, higher values of HRY could be obtained for the product. This is also accompanied with lower WPs.

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**Introduction**

Among the cereals, rice (*Oryza Sativa* L.) is considered as a staple food for nearly one-half of the world's population. World rice production increased from 518.8 million tonnes in 1990 to 683 million tonnes in 2008 (FAO, 2009). Rice provides fully 60 percent of the food intake in Southeast Asia and about 35 percent in East Asia and South Asia. About 95 percent of the crop is grown and consumed in Asia. Although rice has a relatively low protein content (about 8 percent in brown rice and 7 percent in milled rice versus 10 percent in wheat), brown rice ranks higher than wheat in available carbohydrates, digestible energy (kilojoules per 100 grams), and net protein utilization (Juliano, 1985).

Cereal grains are frequently damaged by the operation of working elements of agricultural machinery. The most frequent reason for the damage inflicted on cereal grains results from the shock and mechanical impact of harvesting, cleaning, transport and processing (Fraczek and Slipek, 1998). During rice milling processes, in which paddy hull and bran layer are removed from brown rice, the occurrence of mechanical damage due to the involved intensive forces and stresses cannot be neglected. The extent of these stresses could be induced by changes in materials properties such as moisture and texture. If the stresses exceed the rupture strength of the material, it will lead to fissure or breakage (Siebenmorgen, 1994). A commercial rice milling system is a multi-stages process where paddy is first subjected to de-husking and then to the removal of outer bran layer, known as whitening. Finally, polishing is carried out to remove the bran particles and provide surface gloss to the edible white portion. The most important parameters during milling are head rice yield (HRY) and kernel whiteness. These two parameters are used to define the quality of milled rice in their sale price. The transaction price of rice has been strongly correlated to the size and shape, whiteness and cleanliness of the rice (Conway *et al.*, 1991). Rice kernel with 3/4 or more of their original length after complete milling operation is termed as head rice (USDA, 1983). The price of head rice is almost double or triple as compared to that of the broken kernels. Hence, maximizing the proportion of head rice with desired degree of kernel whiteness is the priority for rice milling industry (Yadav and Jindal, 2008). It has also been stated that the mechanical damage to grain could decrease its biological value (Dreszer and Gieroba, 1999). Thus, proper design and adjustment of the processing equipments for harvested rice is essential to reduce further probable losses in the crop production and hence a retention in grain quality.

Recently, qualitative characteristics of rice grain have been reported in the literature. Most of these studies have focused on the pre-milling optimum conditioning of rice for maximizing the HRY. The recommended optimum harvest moisture content of the paddy for seven US varieties is between 16.0% and 21.5% (d.b.) to achieve maximum HRY (Jodari and Linscombe, 1996). Rice kernel whiteness increases significantly with increased removal of bran layer during milling (Champagne *et al.*, 1996; Park *et al.*, 2001; Yadav and Jindal, 1998). It was observed that the changes in HRY and whiteness during milling varied among various varieties. It might be possible that the changes in HRY and whiteness during milling among various rice varieties are related to their physicochemical properties (Yadav and Jindal, 2008). Some studies have been published on measuring the degree of milling and its effect on the nutritional and sensory attributes of cooked milled rice (Roberts 1979; Piggott *et al.*, 1991). Other studies have been focused on improving rice milling quality and optimization of the product harvesting, handling and drying conditions (Sharma and Kunze, 1982; Gravois, 1998; Abud-Archila *et al.*, 2000; Dong *et al.*, 2003; Iguaz *et al.*, 2006; A-Bond and Bollich, 2007).

So far, there is no quantitative information in the published literatures on changes in milling characteristics of rice grains during milling process of the product as affected by the properties such as the ratio of paddy/brown rice when arriving into the whiteners. In most rice milling factories of Iran, there are no paddy separators before whitening stage.

Consequently, a certain amount of un-husked paddies always accompany brown rice grains when arriving into the whiteners. This may affect the milling properties of rice. Hence, the objective of the present study was to determine the effects of MC and PMR on the milling characteristics of rice grains in an abrasive type whitener. The information presented in this study could be useful to optimise the design and adjustment of the machines used in rice milling operations.

## Materials and methods

*Samples preparation*

The paddy grains used in this study were obtained from the Rice Research Institute of Iran (RRII), Rasht, Iran. The paddy variety evaluated, Hashemi, is one of the common varieties of paddy in north of Iran which is characterised by slender kernels having long awns (Bagheri *et al*., 2011). The samples were initially cleaned to remove foreign materials such as dust, dirt, grit and hollow grains. The initial moisture content of the samples was determined by means of a digital moisture meter (GMK model 303RS, Korea) and expressed in percent wet basis. The initial moisture content of the grains was 15.2% (w.b.).

*Experimental Procedure*

The experiments were conducted at the milling laboratory of Agricultural Mechanization Engineering Department, University of Guilan, Rasht, Iran. The effect of moisture content on the milling characteristics of paddy grains were studied by making four levels of moisture contents below the initial moisture, namely, 8, 10, 12 and 14% (w.b.). For this purpose, the samples were dried in an oven at a constant temperature of 43 °C until the desired moisture content of the samples were obtained (Zareiforoush *et al*., 2010). Sixty 50 g sub-samples from paddy grains were taken and kept separately in polyethylene bags. The samples were kept in a refrigerator before milling experiments. Prior to each milling test, the moisture content of each sample was measured using the digital moisture meter (GMK model 303RS, Korea). All paddy samples were shelled using two passes with a laboratory scale rubber roll type test husker (IRE Model HT-3, Taiwan). The clearance between two rubber rolls was set to 0.50 mm. This setting allowed obtaining brown rice with minimum breakage and remaining paddy. The remaining paddy kernels were manually removed from the husked samples. The percentage of broken brown rice was determined after the de-husking of the paddy to record the initial breakage before whitening. For this purpose, the brown rice samples were poured into a laboratory rice grader (Model JFQS, China) and sieved for 60 s to separate the broken grains from whole kernels. In order to study the effect of remaining paddy after de-husking on the milling characteristics of rice grains the mass percentage of paddy in brown rice when arriving to whitener was used. Five levels of PMR, namely 2, 3, 4, 5 and 6% were selected in this study. At each test run, 20 g of brown rice grains considering the defined PMRs were poured into a laboratory abrasive type whitener (Model STAR, China) and milled for 20 s to whiten the kernels.

*Milling characteristics calculation*

Milled rice samples obtained after whitening was cleaned to remove bran particles and tiny rice kernels. The milling characteristics of rice grains were studied in terms of number percentage of fissured kernel (FK), Head Rice Yield (HRY), whiteness percentage (WP) and whiteness index (WI). In order to obtain the extent of grains breakage after milling process, the whole and broken kernels were separated using the laboratory rice grader. The size of grader cylinder groove was 3 mm and the separated grains were collected in the grader container at a set angle of 30° from vertical. The mass percentage of broken kernels after whitening ($B_k$) was calculated through the following equation:

$$B_k = \frac{M_{bk}}{M_t} \times 100 \quad (1)$$

Where, $M_{bk}$ is the mass of separated broken kernels (g) and $M_t$ is the total mass of the milled samples (g). $B_K$ and FK are two important parameters in determining the qualitative losses of rice during its production (Szot *et al*., 1998). The value of FK was determined by means of a fissure detector (MAHSA, Iran). For this purpose, 50 white rice grains were randomly selected from the milled samples and put onto a latticed plate and the light was passed from bottom to the plate, illuminating the fissures in the kernels. Then, the number percentage of fissured kernels after whitening (FK) was calculated by the following equation:

$$FK = \frac{N_{fk}}{N_t} \times 100 \quad (2)$$

Where, $N_{fk}$ is the number of fissured kernels and $N_t$ is the total number of the grains which were put onto the fissure detecting device.

HRY was defined as mass percentage of milled head rice kernels as compared with the weight of paddy kernels (Yadav and Jindal, 2008). This value is directly influenced by the amount of kernels breakage during milling process.

The whiteness of milled rice samples was obtained and expressed in terms of kernels whiteness index (WI). This value was calculated by the following equation (Khan and Mohanty, 1991):

$$WI = (1-y)\left(\frac{W_p}{W_p + B_k + I_p}\right) \quad (3)$$

Where $y$ is the mass percentage of paddy existed in white rice samples after whitening (decimal), $B_k$ is the mass percentage of broken kernels after whitening (%) and is obtained from Eq. (1), $I_p$ is the impurity percentage of rice grains after whitening (%), and WP is whiteness percentage of rice grains that is obtained through the following equation (Khan and Mohanty, 1991):

$$WP = \frac{(M_{br} - M_{wr})}{M_{br}} \times 100 \quad (4)$$

In the Eq. (4), $M_{br}$ is the mass of brown rice before whitening (g) and $M_{wr}$ is the mass of white rice after whitening (g).

Since all of the samples had been initially cleaned from the foreign impurities, the value of $I_p$ at all of the experiments was equal to zero.

*Experimental design and statistical analysis*

The experiments were carried out based on a factorial statistical design. Twenty treatments were evaluated on the basis of randomised complete blocks design (RCBD). The experiments were replicated three times for each treatment and the average values were reported. The mean, standard deviation and correlation coefficient of the qualitative specifications of rice grains were determined using Microsoft Excel 2010 software program. The effects of MC and PMR on the milling characteristics were studied using analysis of variance (ANOVA), and mean significant differences were compared using the Duncan's multiple range test at 5% significant level using SPSS 16 software.

## Results

*Fissured Kernels*

The results of ANOVA indicated that the effects of MC and PMR on the number percentage of FK were significant at the 1% probability level (Table 1). The variations of FK versus the PMR at different MCs are illustrated in Fig. 1. It can be seen that at all of the moisture contents, by increasing the ratio of PMR, FK decreased. The mean values of FK at different levels of PMR and MC are given in Table 2. It was observed that with decreasing MC from 14 to 10% (w.b.), the number percentage of FK decreased and then the further decrease in MC from 10 to 8% (w.b.) caused the FK to increase. The most value of FK (15.33%) was attributed to the PMR of 2% and MC of 8% (w.b.); whilst the lowest FK was observed at the PMR of 6% and MCs of 10% and 12% (w.b.).

*Head rice yield*

HRY could present an effective view of the kernels breakage during milling process. Based on the results obtained through ANOVA, the effects of MC and PMR on HRY were significant at the 1% probability level. The variations of HRY versus PMR at different MCs are presented in Fig. 2. At all of the studied MCs the value of HRY increased by increasing the PMR. The mean values of HRY at different MCs and PMRs are tabulated in Table 3. The highest values of HRY (58.23%) were obtained at the MC of 12% (w.b.) and PMR of 6%; whilst the lowest HRY (39.28%) was observed at the MC of 8% (w.b.) and PMR of 2%. The values of HRY at the MC of 8% (w.b.) were remarkably lower than those of other MCs evaluated.

**Table 1.** Analysis of variance indicating the effects of MC and PMR on milling characteristics of rice grains.

| | | Mean Square | | | |
|---|---|---|---|---|---|
| Source | DOF | FK | HRY | WP | WI |
| MC | 3 | 119.22$^{**}$ | 629.59$^{**}$ | 22.96$^{**}$ | 0.054$^{**}$ |
| PMR | 4 | 79.18$^{**}$ | 47.71$^{**}$ | 10.24$^{**}$ | 0.001$^{ns}$ |
| MC × PMR | 12 | 3.83$^{ns}$ | 1.12$^{ns}$ | 0.59$^{ns}$ | 0.001$^{ns}$ |
| Error | 38 | 6.78 | 4.24 | 2.12 | 0.001 |
| C.V. | | 23.53% | 13.97% | 18.82% | 15.96% |

$^{**}$Significant on the 1% probability level; ns, not statistically significant; FK: number percentage of fissured kernels, HRY: head rice yield, WP: whiteness percentage, WI: whiteness index, MC: moisture content, PMR: paddy mixture ratio.

**Table 2.** Mean comparison of FKs at different levels of PMR and MC.

| | MC (w.b.)* | | | |
|---|---|---|---|---|
| PMR | 14% | 12% | 10% | 8% |
| 2% | 12.00±2.00 cab | 8.00±1.00 cdfe | 7.67±1.03 cdfe | 15.33±1.11 a |
| 3% | 10.67±1.55 cdb | 6.67±1.01 dfe | 6.67±1.15 dfe | 14.67±1.15 ab |
| 4% | 8.67±2.16 cde | 4.67±1.31 fe | 6.67±0.58 dfe | 12.00±1.46 cab |
| 5% | 7.67±1.31 cdfe | 4.33±0.58 fe | 4.67±1.31 fe | 8.67±1.45 cde |
| 6% | 4.00±1.46 fe | 3.33±1.15 f | 3.33±1.16 f | 6.67±1.13 dfe |

* Mean values are given with standard deviation. The values with common index are not significantly different ($P$>0.05) according to Duncan's multiple range test.

*Whiteness percentage*

Results of statistical analysis indicated that the effects of MC and PMR on WP were significant ($P$<0.01). In Fig. 3 the variation of WP versus PMR at different MCs is illustrated. The results revealed that at all of the studied MCs, WP decreased by increasing the ratio of PMR. The results also showed that with decrease in MC from 14 to 8% (w.b.), WP decreased. The mean values of WP at different levels of MCs and PMRs are given in Table 4. The highest value of WP (11.97%) was observed at the MC of 14% (w.b.) and PMR of 2%; while the lowest WP (6.14%) was attributed to the MC of 8% (w.b.) and PMR of 6%.

**Table 3.** Mean comparison of HRY at different levels of PMR and MC.

| | MC (w.b.)* | | | |
|---|---|---|---|---|
| PMR | 14% | 12% | 10% | 8% |
| 2% | 51.07±0.84 e | 52.36±2.31 ed | 51.92±1.91 ed | 39.28±1.29 g |
| 3% | 52.21±2.04 ed | 55.08±2.54 cadb | 55.59±2.17 cadb | 41.52±0.92 fg |
| 4% | 52.61±1.18 ced | 56.83±1.78 ab | 56.28±2.83 cab | 42.88±1.46 f |
| 5% | 54.03±0.82 cedb | 58.12±1.71 a | 56.41±0.78 cab | 43.15±1.54 f |
| 6% | 55.13±0.89 cadb | 58.23±1.72 a | 57.67±0.81 ab | 44.33±1.34 f |

* Mean values are given with standard deviation. The values with common index are not significantly different ($P$>0.05) according to Duncan's multiple range test.

*Whitening index*

Based on the results obtained through ANOVA, the effect of MC on the WI was significant ($P$<0.01), while the effect of PMR and interaction effect of MC and PMR on the WI were not significant ($P$>0.05). Fig. 4 shows the variations of WI versus PMR at different evaluated MCs. As it can be seen, at the MCs of 14 and 8% (w.b.), increasing PMR from 2 to 6% caused the WI to decrease; whilst at the MCs of 12 and 10% (w.b.), WI increased by increasing the PMR.

**Table 4.** Mean comparison of WP at different levels of PMR and MC.

| | MC (w.b.)* | | | |
|---|---|---|---|---|
| PMR | 14% | 12% | 10% | 8% |
| 2% | 11.97±0.56 a | 10.41±0.54 ab | 9.02±0.62 cab | 8.12±0.52 cb |
| 3% | 10.45±0.44 ab | 9.17±0.75 cab | 8.16±0.54 cb | 7.66±0.63 dc |
| 4% | 10.42±0.37 ab | 8.39±0.39 cb | 7.53±0.62 dc | 7.48±0.47 dc |
| 5% | 8.69±0.43 cb | 8.47±0.87 cb | 7.46±0.49 dc | 6.45±0.26 d |
| 6% | 8.57±0.65 cb | 8.16±0.63 cb | 7.46±0.61 dc | 6.14±0.36 d |

* Mean values are given with standard deviation. The values with common index are not significantly different ($P$>0.05) according to Duncan's multiple range test.

**Table 5.** Mean comparison of WI at different levels of PMR and MC.

| | MC (w.b.)* | | | |
|---|---|---|---|---|
| PMR | 14% | 12% | 10% | 8% |
| 2% | 0.2845±0.0099 a | 0.2639±0.0055 a | 0.2333±0.0076 a | 0.1467±0.0052 b |
| 3% | 0.2653±0.0039 a | 0.2633±0.0047 a | 0.2457±0.0068 a | 0.1447±0.0047 b |
| 4% | 0.2692±0.0074 a | 0.2639±0.0062 a | 0.2469±0.0075 a | 0.1508±0.0039 b |
| 5% | 0.2475±0.0062 a | 0.2812±0.0084 a | 0.2351±0.0041 a | 0.1333±0.0047 b |
| 6% | 0.2545±0.0091 a | 0.2786±0.0052 a | 0.2495±0.0082 a | 0.1312±0.0059 b |

* Mean values are given with standard deviation. The values with common index are not significantly different ($P$>0.05) according to Duncan's multiple range test.

The mean values of WI at different levels of MC and PMR are presented in Table 5. The highest value of WI (0.2845) were attributed to the MC of 14% (w.b.) and PMR of 2%; whilst the lowest WI (0.1312) was obtained at the MC of 8% (w.b.) and PMR of 6%.

## Discussion

This research was performed to study the milling characteristics of rice grains during whitening process. The following conclusions are derived from the investigation of the effects of MC and PMR on the values of FK, HRY, WP and WI. It was found that at all of the MCs, the value of FK decreased by increasing PMR. This is may be due to a decrease in the whitener performance intensity as a result of more paddy presence in the whitener at higher levels of PMR. The most values of FK were attributed to the MC of 8% (w.b.). This is probably due to the fact that in the drying process, before arriving into the milling system, the grains with MC of 8% (w.b.) had been exposed to the drying air for longer time than the grains with the other MCs. The longer drying times could intensify the development of intra-kernel hygroscopic stresses resulting from moisture transfer in the kernels which could in turn, increase the possibility of fissure formation in rice kernels (Zareiforoush *et al.*, 2010). Under these conditions, higher values for FK are predictable. Fissured kernels are characterized by reduced mechanical strength and a tendency to crumble during postharvest processing easier than grain with no such damage (Wozniak, 2000). Kunze and Hall (1965) stated that a rice kernel with two or three cross-sectional fissures has lost its commercial value. Fissured kernels usually break during milling and lead to a reduction in head rice yield (HRY), then cause very poor cooking quality and lower the market value (Sarker *et al.*, 1996; Zhang *et al.*, 2005). Milled rice kernels have been reported to rapidly fissure and eventually break when exposed to certain air conditions (Kunze and Hall, 1967; Siebenmorgen *et al.*, 1998). Milled kernels rapidly gain or lose moisture from the environment depending on the air temperature and relative humidity (RH) of the surrounding air, as well as the MC of the kernels (Kunze and Choudhary, 1972; Lu *et al.*, 1993). The moisture migration in the kernel causes tensile and/or compressive stresses in the starchy endosperm of the milled kernel (Stermer, 1968). Depending on the moisture gradient between the kernel and the equilibrium MC of the surrounding air, these stresses can cause kernels to fissure during post-milling operations.

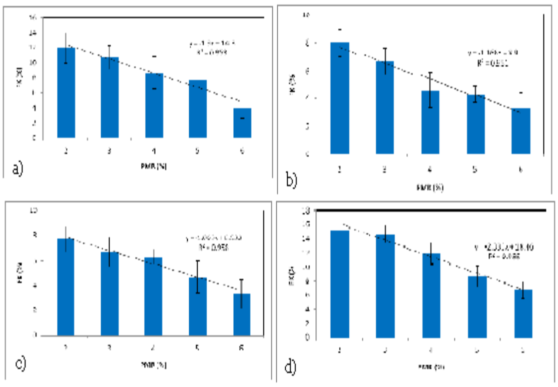

**Fig. 1.** Variation of FK versus PMR at MCs of: a) 14%, b) 12%, c) 10%, and d) 8% (w.b.).

At all of the studied MCs the value of HRY increased by increasing the PMR. As stated in the previous section, this is maybe due to a decrease in the whitener performance intensity as a result of more paddy presence accompanied with brown rice in the whitener at higher levels of PMR. The lowest HRY corresponded to the lowest evaluated MC (8%), because in this condition the grains are more brittle as a result of prolonged exposure to the drying air at drying process and consequently the rice grains of 8% MC are more susceptible to breakage. If the temperature gradient in the rice kernel is sufficiently high, it may cause to kernel cracking. Moreover, the performance intensity of the whitener abrasive stone on the milling rice causes forces and stresses in the kernel which may result in the kernel breakage. The higher the kernel breakage, the lower the HRY. Matthews *et al.*, (1970) reported that rice breakage was mostly due to mechanical stresses rather than thermal stresses. Clement and Seguy (1994) found that long and tiny rice kernels were more susceptible to breakage during the milling process. Dilday (1987) reported that rice breakage during the milling process decreased with the increasing paddy moisture content in the range of 12 to 16%. Afzalinia *et al.*, (2002) indicated that the range of 12 to 14% was the optimum moisture content for paddy milling, because the lowest rice breakage occurred at this range. Sajawan *et al.*, (1990) reported that the delay in harvest lead to reduced HRY due to low kernel moisture contents. They also indicated that HRY was related to the pre- and post-harvest fissures development in the kernels, and the postharvest drying and handling of the paddy.

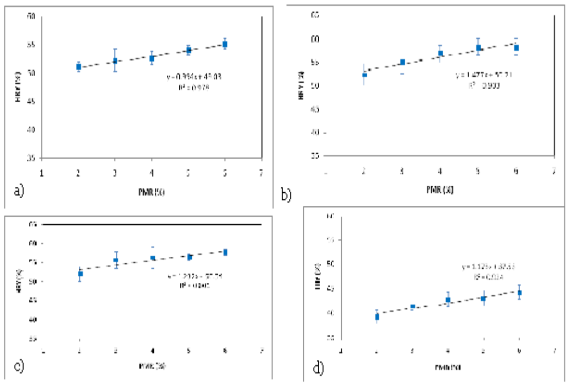

**Fig. 2.** Variation of HRY versus PMR at MCs of: a) 14%, b) 12%, c) 10%, and d) 8% (w.b.).

At all of the studied MCs, WP decreased by increasing the PMR. At higher levels of PMRs, more amounts of paddy are accompanied with brown rice in the whitener. Existence of higher amounts of paddy with brown rice may decrease the effective contact surface between the abrasive rotor of the whitener and brown rice grains. Consequently, WP decreases. With a decrease in MC from 14 to 8% (w.b.), WP decreased. This is may be due to the fact that at higher levels of MC, more water presence in the grains makes the grains surface softer. Therefore, at higher levels of MCs, the bran layer surrounding brown rice kernel could be pulverized easily.

Considering the results presented in Table 3 and Table 4, a practical conclusion could be derived. In the whitening process, if rice grains arrived into the whitener with higher levels of PMRs, higher values of HRY could be obtained. This result is also accompanied with lower WPs. The lower the WP, the higher the bran layer surrounding rice kernel, and therefore, the higher the nutrition values of the final product. Brown rice kernel has an undulating surface profile, rendering uniform removal of bran a difficult operation. Even after 75% of bran removal, streaks of bran are still left on the furrows (Juliano, 1985). Amount of bran in rice kernels varies with variety, environmental conditions and agronomic practices (Van Ruiten, 1985). Most of these factors cannot be controlled. Hence different rice varieties require different milling levels. Different markets require different degrees of bran removal. The colour of rice is an important sensory parameter. Generally, the whiter the milled rice, the more value it has in the market place (Wadsworth, 1994). The sale price of rice strongly depends on the size and shape, whiteness and cleanliness of the rice (Conway *et al.*, 1991). The proteins, fats, vitamins, and minerals are concentrated in the germ and outer layer of the starchy endosperm (Itani *et al.*, 2002; Juliano, 1985) and these are removed in milling operation, thus reducing the nutritive value of the rice. Thus, at higher levels of PMRs, the final product of the milling process is obtained with more whole rice kernels having more nutrition values.

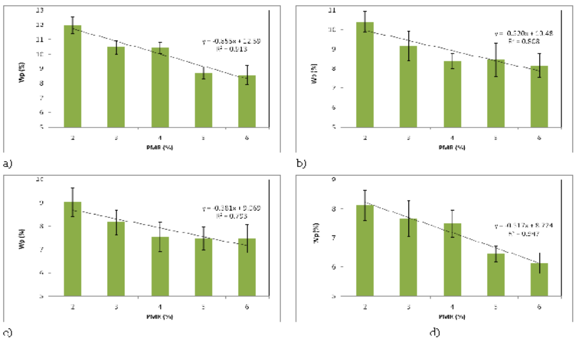

**Fig. 3.** Variation of WP versus PMR at MCs of: a) 14%, b) 12%, c) 10%, and d) 8% (w.b.).

At all of the MCs evaluated, the variation of WI versus PMR was unpredictable. Especially, at the MC of 10% (w.b.), the variation trend of WI versus PMR was observed to have a low coefficient of determination ($R^2$=0.2204). Considering Eq. (3), WI is a function of $B_k$ (mass percentage of broken kernels after whitening) and WP (whiteness percentage of rice grains). Therefore, the variation trend of WI depends on the combinatorial variations of $B_k$ and WP versus PMR and MC. Yadav and Jindal (2008) indicated that HRY and whiteness could be successfully modeled during milling operation in relation to the physicochemical properties of rice. The important contributing physicochemical properties were alkali spreading value and protein content. They reported that milled rice whiteness could be satisfactorily modeled by a two parameters non-linear model with $R^2$ ranging from 0.972 to 0.997 and RMSE values of below 1.0 whiteness index (WI) for all varieties evaluated. The results of this study can be useful to optimise the design and adjustment of the equipment used in rice processing operations.

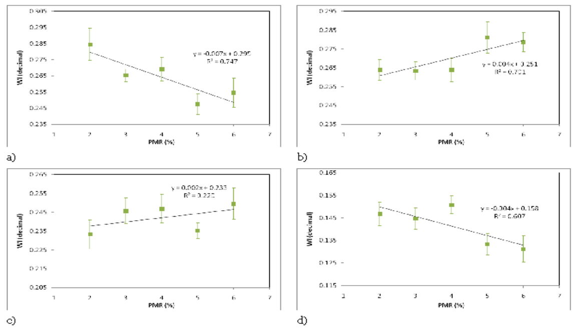

**Fig. 4.** Variation of WI versus PMR at MCs of: a) 14%, b) 12%, c) 10%, and d) 8% (w.b.).

## Conclusion

This research was performed to study the milling characteristics of rice grains as affected by MC and PMR. The following conclusions are derived from the research. At all of the MCs, by increasing the ratio of PMR, the values of FK and HRY decreased and increased, respectively. This could maybe due to a decrease in the whitener performance intensity as a result of more paddy presence accompanied with brown rice in the whitener at higher levels of PMR. In the abrasive whitening machines, if rice grains arrived into the whitener with higher levels of PMRs, higher values of HRY could be obtained. This result is accompanied with lower WPs. The lower the WP, the higher the bran layer surrounding rice kernel, and therefore, the higher the nutrition values of the final product. The results revealed that at all of the studied MCs, WP decreased by increasing the PMR. Existence of higher amounts of paddy with brown rice may decrease the effective contact surface between brown rice grains and abrasive rotor of the whitener. This could cause the WP to decrease. The results also showed that with decrease in the MC from 14 to 8% (w.b.), WP decreased. This is may be due to the fact that at higher levels of MC, more water presence in the grains makes the grains surface softer and consequently, separation of the bran layer surrounding the brown rice kernel at higher levels of MCs is higher as compared with lower MCs. Results also showed that at the MCs of 14 and 8% (w.b.), increasing PMR from 2 to 6% caused the WI to decrease; whilst at the MCs of 12 and 10% (w.b.), WI increased by increasing the PMR.

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**List of abbreviations**

| | |
|---|---|
| $B_k$ | Broken kernels (mass percentage) |
| FK | Fissured kernels (mass percentage) |
| HRY | Head Rice Yield |
| $I_p$ | Impurity percentage of rice grains after whitening (%) |
| $M_{bk}$ | Mass of separated broken kernels (g) |
| $M_{br}$ | Mass of brown rice before whitening (g) |
| MC | Moisture content (%w.b.) |
| $M_t$ | Total mass of the milled samples (g) |
| $M_{wr}$ | Mass of white rice after whitening (g) |
| $N_{fk}$ | Number of fissured kernels |
| $N_t$ | Total number of the grains which were put onto the fissure detecting device |
| PMR | Paddy mixture ratio (mass percentage) |
| WI | Whiteness index |
| WP | Whiteness percentage |
| $y$ | Mass percentage of paddy existed in white rice samples after whitening (decimal) |