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SOME MILLING CHARACTERISTICS OF RICE GRAINS

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ABSTRACT

This research presents results of studies on the effects of moisture content and paddy/brown rice ratio 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/brown rice ratios (PB), 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). The results revealed that as PB increased from 2 to 6%, the values of FK and WP decreased, whilst HRY decreased by increasing PB from 2 to 6%. At all of the evaluated PBs, the values of HRY, WP 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 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 PBs, higher values of HRY could be obtained for the product. This is also accompanied with lower WP.

Keywords: *Rice, milling, head rice yield, whiteness percentage, fissured kernels.*

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 tons in 1990 to 683 million tons in 2008 [9]. Rice provides 60 percent of the food intake in Southeast Asia and about 35 percent in East 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 [15].

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 [10]. 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 [28]. 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 associated with the size and shape, whiteness and cleanliness of the rice [6]. Rice kernel with 3/4 or more of their original length after complete milling operation is termed as head rice [32]. 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 [37]. It has also been stated that the mechanical damage to grain could decrease its biological value [8]. Thus, proper design and adjustment of the processing equipment 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% and 21.5% (d.b.) to achieve maximum HRY [14]. Rice kernel whiteness increases significantly with increased removal of bran layer during milling [4, 22 and 36]. 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 [37]. Some studies have been published on measuring the degree of milling and its effect on the nutritional and sensory attributes of cooked milled rice [23 and 24]. Other studies have been focused on improving rice milling quality and optimization of the product harvesting, handling and drying conditions [1, 2, 11, 12, 27 and 38].

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 paddy/brown rice ratio on the milling characteristics of rice grains in an abrasive type whitener. The information presented in this study could be useful to optimize 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 northern Iran which is characterised by slender kernels having long awns. 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 [39]. 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 (defined as PB ratio) was used. Five ratios of PB, 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 PB ratios were poured into a laboratory abrasive type whitener (Model STAR, China) and milled for 20 seconds to whiten the kernels.

Milling characteristics theoretical

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). 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 30º from vertical. The mass percentage of broken kernels after whitening (Bk) was calculated through the following equation:

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

Where, M_{bk} is the mass of separated broken kernels (g) and M_t is the total mass of the milled samples (g).

BK and FK are two important parameters in determining the qualitative losses of rice during its production [31]. 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:

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

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 [37]. This value is directly influenced by the amount of kernels breakage during milling process. WP is whiteness percentage of rice grains that is obtained through the following equation [16]:

$$WP = \frac{(M_{br} - M_{wr})}{M_{br}} \times 100 \qquad (3)$$

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

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 PB on the milling characteristics were studied using analysis of variance (ANOVA), and mean significant differences were compared using the Duncan's multiple range tests at 5% significant level using SPSS 16 software.

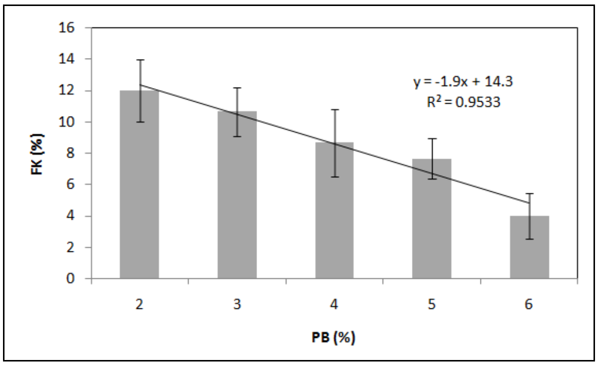
RESULTS AND DISCUSSIONS

Fissured Kernels

The results of ANOVA indicated that the effects of MC and PB on the number percentage of FK were significant at the 1% probability level (Table 1). The variations of FK versus the PB at different MCs are illustrated in Fig. 1. It can be seen that at all moisture contents, the value of FK decreases by increasing PB. This is maybe due to a decrease in the whitener performance intensity as a result of more paddy presence in the whitener at higher levels of PB. 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 highest 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 [39]. 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 [35]. Kunze and Hall [18] 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 [26 and 40]. Milled rice kernels have been reported to rapidly fissure and eventually break when exposed to certain air conditions [19 and 29]. 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 [17 and 20]. The moisture migration in the kernel causes tensile and/or compressive stresses in the starchy endosperm of the milled kernel [30]. 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.

Table 1: Analysis of variance indicating the effects of MC and PB on milling characteristics of rice grains

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



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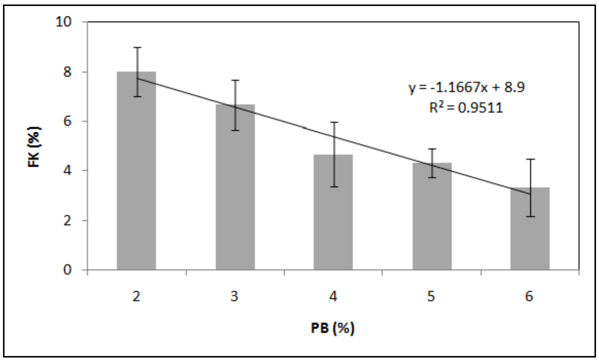

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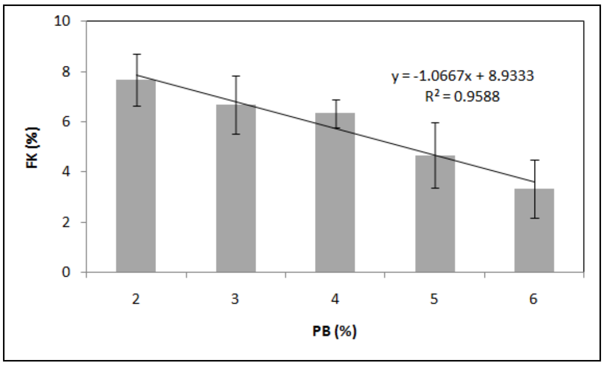

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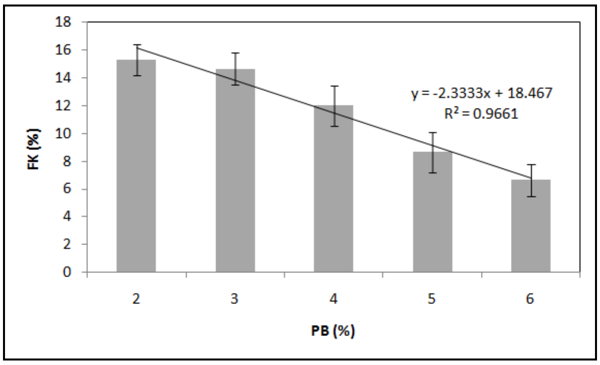

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Fig. 1: Variation of FK versus PB at MCs of: (a) 14%, (b) 12%, (c) 10%, and (d) 8% (w.b.).

Head rice yield

The results of ANOVA showed that the effects of MC and PB on HRY were significant at the 1% probability level. The variations of HRY versus PB at different MCs are presented in Fig. 2. At all of the studied MCs the value of HRY increased by increasing the PB. 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 PB. The results from mean values of HRY at different MCs and PBs showed that the highest values of HRY (58.23%) were obtained at the MC of 12% (w.b.) and PB of 6%; whilst the lowest HRY (39.28%) was observed at the MC of 8% (w.b.) and PB of 2%. 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 the kernel to crack. 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 will be the HRY. Matthews et al. [21] reported that rice breakage was mostly due to mechanical stresses rather than thermal stresses. Clement and Seguy [5] found that long and tiny rice kernels were more susceptible to breakage during the milling process. Dilday [7] 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. [3] 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. [25] 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.

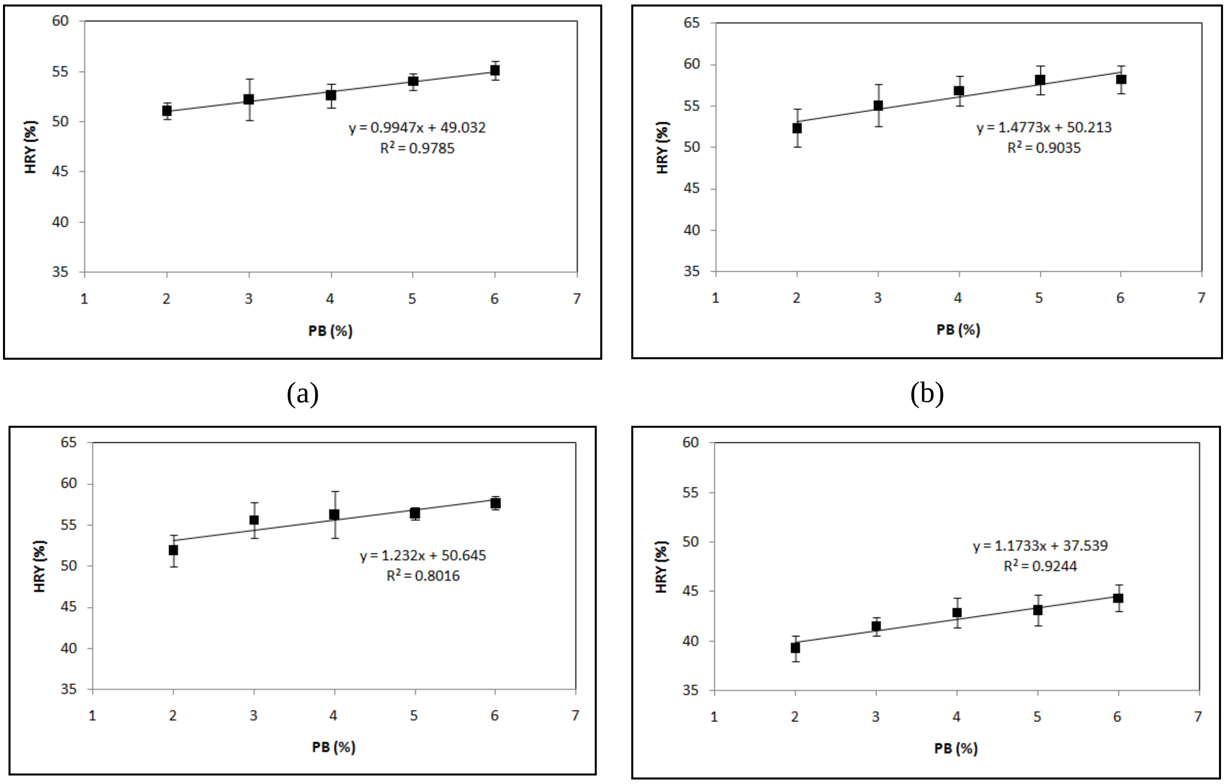
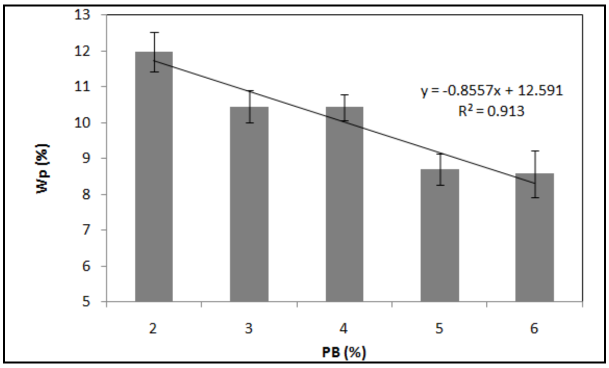


Fig. 2: Variation of HRY versus PB at MCs of: (a) 14%, (b) 12%, (c) 10%, and (d) 8% (w.b.).

Whiteness percentage

Results of statistical analysis indicated that the effects of MC and PB on WP were significant ($P<0.01$). In Fig. 3 the variation of WP versus PB at different MCs is illustrated. The results revealed that at all of the studied MCs, WP decreased by increasing the PB. At higher levels of PBs, 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. The results also showed that with 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. The results from mean values of WP at different levels of MCs and PBs showed that the highest value of WP (11.97%) was observed at the MC of 14% (w.b.) and PB of 2%; while the lowest WP (6.14%) was attributed to the MC of 8% (w.b.) and PB of 6%. Considering the results above, a practical conclusion could be derived. In the whitening process, if rice grains arrived into the whitener with higher levels of PBs, 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 [15]. Amount of bran in rice kernels varies with variety, environmental conditions and agronomic practices [33]. 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 [34]. The sale price of rice strongly depends on the size and shape, whiteness and cleanliness of the rice [6]. The proteins, fats, vitamins, and minerals are concentrated in the germ and outer layer of the starchy endosperm [13 and 15] and these are removed in milling operation, thus reducing the nutritive value of the rice. Thus, at higher levels of PBs, the final product of the milling process is obtained with more whole rice kernels having more nutrition values.



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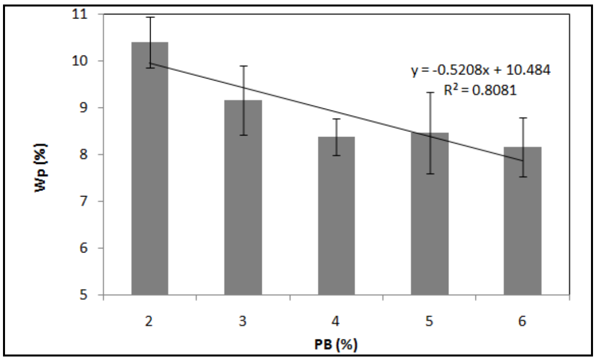

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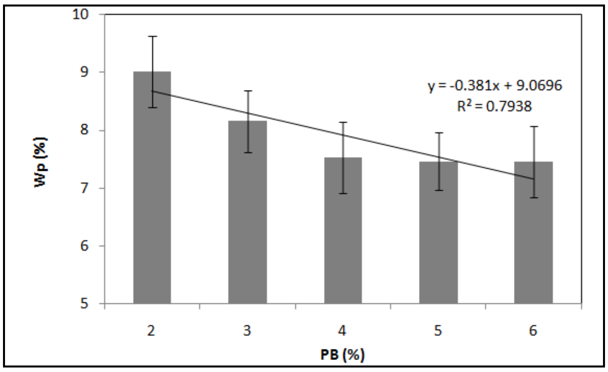

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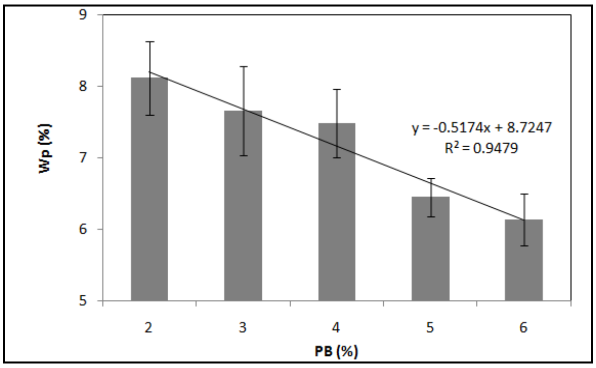

(d)

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

CONCLUSIONS

This research concludes with information on the milling characteristics of rice grains which can be useful for optimising the design and adjustment of the equipment used in rice processing operations. The following conclusions are derived from the investigation of the effect of MC and PB on the values of FK, HRY and WP.

1. At all of the MCs, by increasing the ratio of PB, 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 PB.
2. In the abrasive whitening machines, if rice grains arrived into the whitener with higher levels of PBs, 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.
3. At all of the studied MCs, WP decreased by increasing the PB. 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.
4. 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.

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