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Analysis of Head Rice Recovery using Different Types of Rice Mills for Two Rice Varieties Grown in Two Extreme Rice Growing Altitudes

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ABSTRACT

There have been issues of increased broken rice when farmers finally sell their rice crop, especially in the higher altitudes, and this has always been attributed to the quality of milling machines used. In this study, the head rice recovery of two rice varieties grown in high and low altitudes in Bhutan was assessed in both pre-and post-milling through manually peeling and milling in four different types of rice milling machines, respectively. The head rice recoveries on manual peeling of high and low altitude rice varieties were 54.00±0.41% and 83.68± 0.45%, respectively, and were significantly different at P<0.05. Grain crack percentages were 29.44±0.45% and 5.37±0.45%, respectively, indicating that the climatic conditions had some influence on crack development and head recovery of rice. For machine milling, the rice head recoveries were statistically significant both between varieties and among the milling machines used. The head yield was higher in low attitude variety compared to that of the high altitude one. The friction type machine with 3.32 m/s peripheral velocity gave lower head yield compared to friction type of 1.2 m/s and rubber roller type I and II milling machines. This study recommends improving the drying method presently practised in high altitudes by not laying the paddy on the ground after harvest to avoid exposure of harvested paddy to extreme day and night temperature fluctuation. The use of lower peripheral speed rice milling machines and rubber rollers is recommended to increase head yield.

Keywords: *Head rice recovery; Milling degree; Milling recovery; Rice milling machine; Rubber rollers*

1. Introduction

Bhutan is located in the eastern Himalayas between China in the north and India to its east south and west. It has altitudes ranging from 200 masl in the south to more than 7500 masl in the north. Rice (*Oryza sativa* L.) is the main staple crop of the Bhutanese with a per capita available for consumption computed at 130.51 kg/year as of 2019 (Bajgai, Lakey, Phuntsho, Om et al., 2021). It is grown in altitudes from 200 to 2500 masl, thus having two extreme rice cultivation altitudes in the country. The rice self-sufficiency in the country for the year 2019 is estimated at 34.71% (Bajgai et al., 2021). Rice in Bhutan is cultivated under both irrigated and

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rain-fed systems (Chhogyel, Ghimiray, Wangdue, & Bajgai, 2015). Rice production in Bhutan was recorded at 83,332 t and 86,385 t in the year 2016 and 2017 respectively (RSD, 2018). To achieve 60% rice self-sufficiency in the 12th Five Year Plan (FYP), the Department of Agriculture is assertively promoting rice cultivation in high altitude areas and during spring seasons across the country (Karchung, 2017). Most rice varieties are composed of roughly 20% rice hull, 11% bran layers and 69% starchy endosperm, also referred to as the total milled rice (Das, Saha, & Alam, 2016).

The use of machines both during paddy cultivation and processing of harvested rice is important. The mechanization in rice cultivation has progressed more than for any other crops with the maximum coverage in milling. There are comparatively very high benefits of the machine mills over the traditional method using mortar and pestle, in terms of the capacity, drudgery, total milling and in reducing the operation cost. As a result, milling rice using machines have almost completely replaced the traditional method. More than 3000 rice mill sets of the Engelberg screw type and a few de-husker cum polisher have been supplied to different parts of Bhutan. Engelberg brand machine imported from India is dominant in the country due to their low cost and the same model has prevailed for the last four decades. However, the rice-growing countries that used the Engleberg hullers previously, have now shifted to more sophisticated milling systems due to the high breakage of paddy grain, resulting in very poor rice recovery. However, even today these single-pass mills are found widely in operation in countries like Bangladesh and other African nations (Alam, 2005).

The milling losses were not considered by farmers as actual losses since the by-products constituting the husk, bran and the broken rice exiting the milling machine together, can be ultimately used as animal feed. Therefore, the necessity to introduce a milling machine with a higher head rice recovery was not considered. It is estimated that the 9 % of the total post-harvest losses in rice crops which range from 15 to 16 % is primarily due to the use of old and outdated methods of drying and milling, improper and unscientific methods of storage, transport and handling (Mejía, 2004). Of late, higher head rice recovery capacity of milling machines is given added importance due to the local rice fetching a premium price. The higher head rice recovery has become important, especially for the export market. Increasing efficiency in processing as an important aspect of post-production technology in field crops has been emphasised in the Renewal Nature Research policy of Bhutan (CoRRB, 2012). Many rice growers have also concluded machines as the primary cause behind the higher rates of broken rice without clear studies ever being conducted.

The Agriculture Machinery Centre (AMC) has been putting in concerted effort to assess the milling efficiencies of different rice milling machines from different countries to identify and recommend suitable ones for the farmers. One of the efficiency parameters being looked into is the head rice recoveries during milling. Using the same machines, the head rice recoveries vary considerably from region to region as well as among the rice varieties. The causes of more broken rice in the colder region compared to that in the warmer parts need to be explored using the same machine types. Although no studies have been conducted until recently to determine the causes for the low percentage of head rice and overall low head yield recoveries, these have been prejudicially attributed to the qualities of the machines.

The atmospheric temperature during the harvesting season of paddy varies a lot between the two altitudes. In colder areas, especially in Paro, the temperature fluctuations between warm days and chill nights are quite high. The average maximum temperatures in Paro for October and November are 18.7^{o}C and 13.9^{o}C, respectively and the mean minimum temperatures for the same months are 7.4^{o}C and 1.4^{o}C, respectively. Observations reveal that traditionally after harvesting, paddy is left out in the field for a few days for natural drying. The dried paddy is then stacked in the field and threshing is done a few months later. It is also noticed that rice kernels are exposed to the temperatures stress of fluctuating hot days and chill nights which leads to the development of cracks in the rice kernels during natural drying in the field, and these kernels with cracks get easily broken during milling. On the other hand, there is no report on such cases of broken rice from southern Bhutan. Therefore, this study was taken up to investigate the various causes of broken rice.

2. Materials and Method

2.1 Paddy sample and pre-milling recovery

Two rice varieties from two extreme rice growing altitudes in Bhutan were collected for the experiment. One variety (Yusi Ray Kaap) from high altitude area of Paro Dzongkhag at an elevation of 2250 masl and another variety (Kalo Bhog) from the low elevation area of Sarpang dzongkhag located at 350 masl were used in this study. The dried samples collected from farmers were further sun-dried and brought to a milling moisture content of 12.0%. To check the physical conditions of the grains before milling, the samples comprising 900 grains each were selected randomly, and their husks manually peeled off. The brown rice was then examined for cracks, broken and yellowish colour formation with the help of a grain inspector**.** As a standard practice**,** the broken brown grains of lengths two-thirds and above are considered whole brown rice (BSB, 2018). Three replications were taken for each variety.

2.2 Milling machines and milling recovery

In the present study, four different rice milling machines were evaluated to estimate rice head yield. They were two imported friction type rice mills named Friction Type I and Friction Type II and rice mill with 2 and 3 rubber rollers and polishers together named Roller Type I and Roller Type II (Figure 1-3). The experimental design used was a randomized complete block design (RCBD) with three replications. The complete specification and dimensions of all rice mills were recorded by disassembling the machine parts.

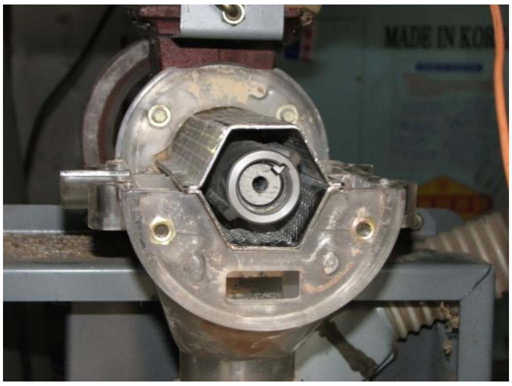

Figure 1. Fiction type rice miller type I Type I & II

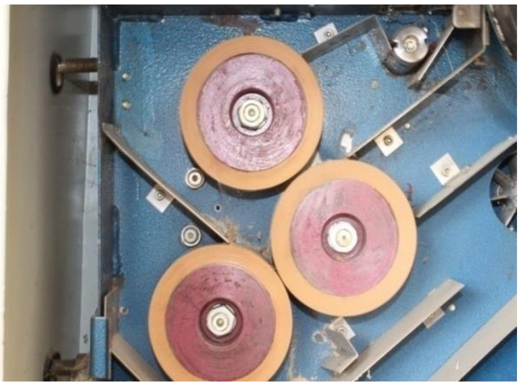

Figure 2. Rubber roller rice machine

Figure 3. Friction type rice milling type II

For each replication, 5 kg paddy samples were used and the time taken to complete milling was recorded. The samples for the laboratory tests were collected randomly during the replication operation by placing an empty plastic bag at regular intervals during the milling process.

Broken rice grains were observed using the grain grader (Sataka Co., Ltd) in the laboratory. The parameters of the milling process were calculated using the following equations:

$$Milling\ Capacity\ \left(\frac{kg}{h}\right) = \frac{Weight\ of\ sample\ paddy\ (kg)}{Milling\ time\ (h)} \quad (1)$$

$$Milling\ Recovery\ (\%) = \frac{Weight\ of\ Milled\ rice\ (kg)}{Weight\ of\ Sample\ paddy\ (kg)} \times 100 \text{..(2)}$$

$$Head\ rice\ recovery\ (\%) = \frac{Weight\ of\ milled\ head\ rice\ (kg)}{Weight\ of\ milled\ rice\ (kg)} \times 100 \text{.......................................(3)}$$

$$Head\ yield\ (\%) = \frac{Head\ rice\ recovery\ (\%) \times Milling\ recovery\ (\%)}{100} \text{..(4)}$$

$$Milling\ degree\ (\%) = \frac{Weight\ of\ brown\ rice\ (1000\ nos) - Weight\ of\ milled\ rice\ (1000\ nos)}{Weight\ of\ brown\ rice\ (1000\ nos)} \times 100 \text{......(5)}$$

2.3 Statistical analysis

Microsoft Excel spreadsheet (Microsoft Office 2010) was used to calculate the mean and standard deviation for both the pre-milling and post-milling conditions. An unpaired t-test was conducted between the two varieties of two altitudes for pre-milling parameter evaluation. A two-way ANOVA was run for four different machines and the two varieties. All the analyses for t-test and ANOVA were carried out using the data analysis tool package in MS Excel. A post-hoc test for separation of means was conducted after the ANOVA test.

3. Results and Discussion

3.1 Pre-milling recoveries

The head brown rice recovery for high and low altitude varieties were 54.00±0.41% and 83.68± 0.45%, respectively on manual peeling. There was a significant difference at $P<0.05$ between the varieties. The crack percentage was 29.44±0.45% and 5.37±0.45% for high and low varieties, respectively as shown in Figure 4.

The above result showed that the rice grains had gone through too much stress and hence had huge cracks and were broken before milling in the machine, especially for the high-altitude variety. Factors like weather during harvesting and drying methods might have played a significant role in lowering the head rice recovery. Especially in Paro, located at a higher altitude, the crop was harvested in late October, and the paddy was laid out in the paddy field for natural drying, thereafter, exposing them to extreme weather conditions. It is a normal practice for harvesting and threshing paddy in Paro. Kunze (2008) found that the low moisture-containing grain (dried) reabsorbs moisture from any source having moisture to which it is exposed, and when compressive stresses at the surface exceed the tensile strength of the grain at the centre, a fissure develops. Most breakage in rice processing can be attributed to grains that were fissured before milling according to his study. Earlier studies also prove that the major factors responsible for fissuring are rice variety, management of post-harvest operations and drying conditions which include drying methodology (Ban, 1971; Bautista, Siebenmorgen, & Cnossen, 2000; Cnossen & Siebenmorgen, 2000; Kunze, 1979; Kunze & Choudhury, 1972).

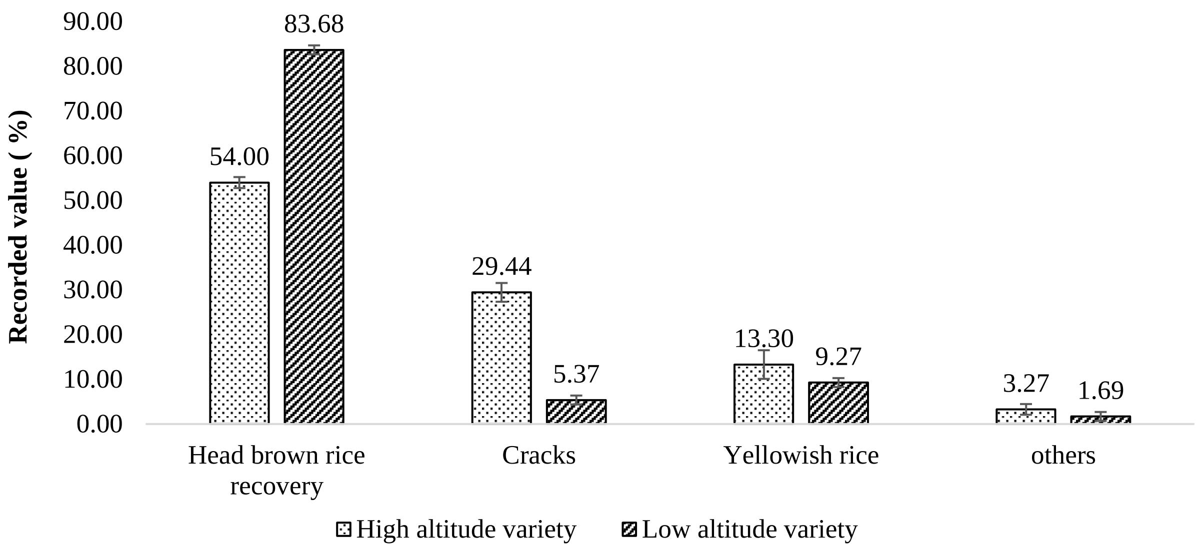

Figure 4. Characteristics of pre-milled rice on manual peeling. Error bars represent standard error of means.

3.2 Machines' physical structures

The dimensions of all the machines and their peripheral speeds recorded in the test are as in Table 1. The peripheral speed varied from 1.30 to 3.32 m/s among the machines. The higher the peripheral speed of the machines, the higher was the percentage of broken rice on milling.

Table 1**.** Specification of four different rice milling machines used in the experiment

Name of Rice mill	Milling shaft		Shaft shape	Screen shape	Clearance (mm)	Motor capacity (hp)	Peripheral speed (m/s)
	Diameter (mm)	Length (mm)					
Friction Type I	70	305	3 straight beads on shaft	Round	11	7.5	3.32
Friction Type II	48	186	4 straight beads on shaft	Round	5	3	1.31
2 Rubber rollers with polisher	25	145	2 helical beads on the shaft	Hexagonal	5	1	1.62
3 Rubber rollers with polisher	25	145	2 helical beads on the shaft	Hexagonal	5	1	1.62

3.3 Milling recovery

The milling recoveries indicated that fairly 30% of the paddy was lost during the milling process as husk and bran. Statistically, there were significant differences among different machines, between varieties and also their interactions at $P<0.05$. The percentage of milling recovery was comparatively higher for low altitude variety compared to that of higher altitude variety in all machine types. The husk percentage was lower for the low altitude variety.

3.4 Head yield evaluation

The percentage of head yield obtained on the milling is shown in Figure 5. Statistically, there was a significant difference among different machines, between varieties and also their interactions at $P<0.05$ for the head yield.

The absence of broken or cracked features in grain is very important for the quality of rice. When the intact length of rice is more than ¾ of its whole length, then it is referred to as head rice and is the main criterion for rice quality (BSB, 2018). Das et al. (2016) also found that the Engleberg rice huller commonly used in Bangladesh had a 2% higher loss in whole rice over improved rice mills. In our case, it was more in percentage due to the milling degree which was used for whitening purpose. However, the loss percentage trend observed was similar to that reported in the Engleberg rice huller.

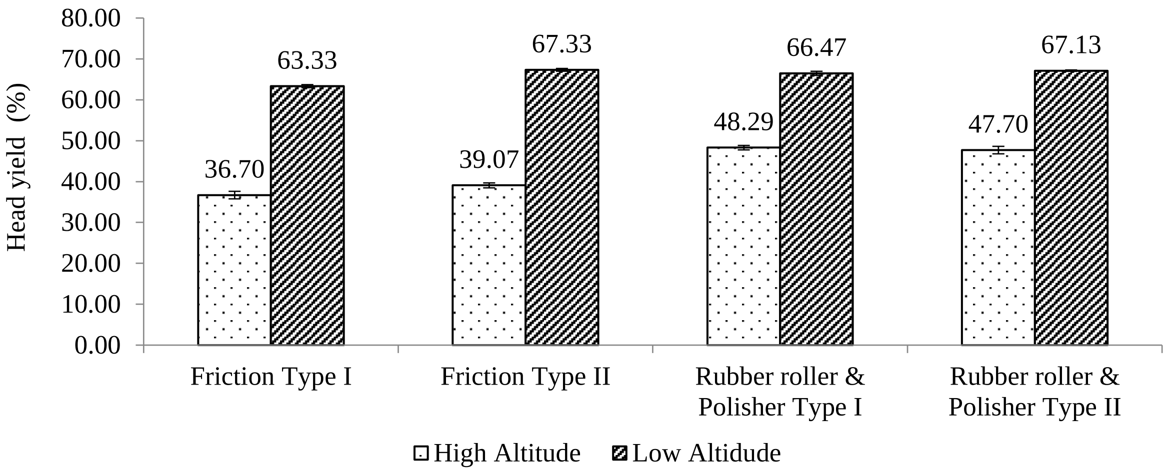

Figure 5. Rice head yield recorded in four different milling machines and two rice varieties grown at low and high-altitude areas (Error bars represent SEM)

Table 2. Unpaired t-test with Bonferroni correction with unequal means for variety and machine interactions

Treatment	Friction I x Friction II	Friction I x Roller I	Friction I x Roller II	Friction II x Roller I	Friction II x Roller II
High altitude rice variety	*	*	*	*	*
Low altitude rice variety	*	*	*	NS	NS

Each variety within the same column with single * is significantly different at $P\leq 0.05$ by unpaired t-test (n=3). NS represents statistically not significant.

Table 2 indicated that there were significant differences in high altitude variety for every milling machine tested. However, there was no significant difference at $P \leq 0.05$ for low altitude rice variety among machines (Friction II x Roller I and Friction II x Roller II). This may be because the peripheral speed of Friction II which was made in Korea was less compared to Friction II which was Indian made. Higher peripheral speed affects the head rice recovery.

Table 3. Unpaired t-test with Bonferroni correction for each machine type on two varieties

Treatment	Friction rice mill Type I	Friction rice mill type II	Roller I (2 rollers with polisher)	Roller II (3 rollers with polisher)
High altitude & Low altitude rice varieties	*	*	*	*

The two varieties within rows with single * are significantly different at $P \leq 0.05$ by unpaired t-test (n=3).

There was a significant difference in the head recovery between the varieties grown in extreme altitudes. The analysis also showed that the two varieties had a significant difference in head rice recovery on each machine type tested at $P \leq 0.05$. This might be that the grains were already stressed but were not observed during the pre-milling experiment and the damage was expressed only after the milling in respective machines.

4. Conclusion

The results from this study do not support our initial hypothesis of lower quality of machines being the main factor contributing to the high percentage of breakage in local rice. The head brown rice recovery for high and low altitude varieties were 54.00±0.41% and 83.68± 0.45%, respectively from the manual peeling experiment, indicating that other prominent factors resulted in this difference in head rice recovery. Statistically significant differences at $P<0.05$ between the varieties on manual peeling were observed. The crack percentages were 29.44±0.45% and 5.37±0.45% for high and low altitude varieties, respectively. Factors like weather during harvesting and drying methods might have played a significant role in lowering head rice recovery through the formation of grain fissures. At high altitudes, paddy was harvested in October and was laid out in the paddy field for natural drying, exposing them to daily extreme weather conditions. The machine with higher peripheral velocity of 3.32m/s had the lowest head yield recovery compared to other machines with lower peripheral velocities. The head yield was also higher for low altitude variety after milling in machines compared to high altitude variety. Thus, this study recommends changing the drying and threshing methods presently practised in Paro by harvesting and threshing simultaneously to avoid the adverse impact of cold weather. Further, the newly introduced and promoted combined harvesters may have reduced the cases of broken rice which needs to be studied. The primary limitation of the present study is that only one variety of rice from colder and warmer regions was included for evaluation of broken percentage of rice and head rice recovery in the milling machines. The effect of different rice varieties on head rice recovery within the region was not evaluated. Hence, the influence of rice varieties on head rice recovery in two different altitudes needs to be studied in the future.

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