Head rice yield of paddy dried in two stage and conventional drying methods

Md. Abdul Wazed [1, 2], N. H. M. Rubel Mozumder [3], Md. Sazzat Hossain Sarker [2*]

(1. Department of Food Science and Engineering, German University Bangladesh (GUB), Gazipur-1702, Bangladesh;
2. Department of Food Engineering and Technology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur-5200, Bangladesh;
3. Department of Food Science and Nutrition, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur-5200, Bangladesh)

Abstract: This study aimed to investigate the impact of two options of two stage drying technique such as fluidized bed drying, tempering and followed by sun drying method and fluidized bed drying, tempering and followed by fixed bed drying method on quality of BRRI dhan28 rice variety in terms of head rice yield (HRY). Moist paddy was dried in fluidized bed dryer (FBD) as first stage drying to reduce moisture from 25%-27% to 18%-19% using drying temperatures of 120, 130, and 150 ℃ at bed thicknesses of 8, 10, and 12 cm. The samples were immediately tempered and dried in second stage drying by fixed bed dryer using 40 ℃±1 ℃ temperature maintaining bed thickness as 30 cm for the further reduction of moisture to 13%-14% (wb). Sun drying method was followed as second stage drying and for complete drying of control sample. In addition, HRY was also compared to existing industrial paddy drying complexes. The results revealed that HRY of rice samples obtained from different drying methods was comparable. The HRY obtained in the first option was better than the control and even existing industrial drying method. The highest HRY (65.57%) of milled rice was obtained in the first option and comparatively lower (53.43%) in the second option of two stage drying. On the other hand, the samples dried in the sun drying and industrial drying using Louisiana State University (LSU) dryer yielded 52.77% and 51.25% HRY, respectively. Therefore, the two stage drying technique can be used for drying of high moisture paddy to obtain quality dried rice.

Keywords: two stage drying, fluidized bed drying, fixed bed drying, sun drying, head rice yield.

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1 Introduction

Drying of paddy is a very important issue in all paddy-producing countries especially in humid tropical climates. Paddy is normally harvested with high moisture contents, 20% to 35% on dry basis (db). Igathinathane et al. (2008) reported that harvested paddy contained high moisture between 20% and 25% on wet basis (wb) in tropical countries and during the rainy season it becomes as high as 22%-26% (wb). After harvesting, paddy needs to be dried in order to prevent quality reduction. High moisture content of paddy should be reduced to 12%-14% (wb), which is considered as adequate for milling and safe storage and further storage as milled rice. Delay in drying or improper drying reduces grain quality and grain wastes become significant (Khodadadi et al., 2012).

Food security is a worldwide problem that has called the attention of Governments and of the scientific community. It particularly affects developing countries. The scientific community has had increasing concerns for

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***Corresponding author: Md. Sazzat Hossain Sarker,** Professor, Department of Food Engineering and Technology, Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200.
Mobile: +8801705950003, Email: mshsarker_hstu@yahoo.com

strategic understanding and implementation of food security policies in developing countries like Bangladesh. Most commonly used indicators in the assessment of food security conditions are food production, income, total expenditure, food expenditure, share of expenditure of food, calorie consumption and nutritional status etc. (Riely et al., 1999). Major food crops in Bangladesh are rice, wheat and maize. The production of rice, wheat and maize were 34,718 metric tons, 1,016 metric tons and 3,569 metric tons, respectively in 2019 (BBS, 2020). This indicates that crop sector is dominated by rice and it is the major source of calorie intake in Bangladesh with a per capita consumption of 181.3 kg per year (BBS, 2020). Bangladesh is the most densely populated country in the world with unfavorable land-population ratio and this has resulted in poor food security. Consequently government policies have been directed towards rapid diffusion of high yielding and hybrid varieties including provision of modern inputs needed to support such strategy.

Rough rice (Oryza sativa L.) or paddy is one of the principal cereals used by the world's inhabitants and it is the second largest produced cereal in the world. In Bangladesh, it is considered as one of the staple cereal crops and is consumed daily in most homes. It is grown on about 71% of the total agricultural area and 77% of cropped area. Besides, rice farming is the main source of income and employment of the rural people. About 56% of area planted is irrigated and the average yield of rice is 1,220 kg per acre (BBS, 2020). The average yield of rice in Bangladesh is low as compared to the average yields with similar agro-climatic conditions in other countries (Timsina et al., 2010). The government of Bangladesh therefore, encourages the farmers to produce more rice by increasing farm productivity and technical efficiencies and more food and feed available by minimizing the post-harvest losses and hence food security can be improved.

Post harvest treatment such as drying is an important step to produce high quality rice. In Bangladesh, paddy drying problem is common during the peak harvesting season of Boro rice in the months of April to May. During this season, farmers get difficulty in drying their cereals due to large quantities of harvest within short time which has, in turn, led to reducing paddy quality and increasing post harvest losses due to microbial infestation. Paddy drying is often a problem in Bangladesh due to sudden and irregular rain and cloudy weather in summer, and fog and short day in winter (Bala et al., 2010). A study showed that the traditional and some commercial grain dryers consumed considerable time and energy in their operations and the available dryers are very expensive. Therefore, there is need to develop suitable drying technique that would lead to time reduction of grain drying without compromising efficiency and also give low operating cost (Kunii and Levenspiel, 1991). Post-harvest losses can be minimized and the quality of dried product can be improved by adopting the present two stage drying method for drying of high moisture paddy employing fluidized bed dryer followed by fixed bed dryer and sun drying method.

Two stage drying concept is one of the techniques that consists of an initial rapid drying stage followed by a slow drying stage. Usually, the fluidized bed, spouted bed, and Louisiana State University (LSU) dryers are used as the first-stage dryers for rapid moisture reduction from high-moisture paddy in Asian rice processing industries. Meanwhile, the in-store dryer or fixed bed dryer, ambient air ventilation or sun-drying methods are widely used for further or complete moisture reduction to 13%- 14% moisture content for safe storage of paddy (Sarker et al., 2013). Two stage grain drying method has been suggested by many researchers as one of the most successful drying techniques (Izadifar and Mowla, 2003). In two stage drying technique, high moisture of paddy grain is rapidly reduced to a more manageable level (around 13%-14% wb) using fast drying rate (Bunyawanichakul et al., 2007). In the first stage of two stage drying system, high moisture paddy grain would be dried by air at high temperature and high velocity to medium moisture level (18%-19% wb). Subsequently, in the second stage of drying, ambient air temperature and low airflow would be used to reduce the grain moisture to the safe level (12%-14% wb).

Drying methods have direct effect on quality of dried paddy. Fluidized bed dryer (FBD) that has high drying rate, as the first stage drying has been suggested by many researchers in order to obtain high head rice yield (HRY).

However, drying with a fluidized bed dryer is recommended to reduce moisture level around 18%–19% (wb) for acceptable head rice. Previous researchers asserted that the fluidized bed dryer is an efficient dryer for first-stage drying. On the other hand, in terms of product quality, Bhattacharya et al. (1971) suggested that the breakage of rice during milling could be considerably reduced if a two-stage drying process was applied.

HRY is one of the primary indices used to quantify the milling quality of rice. Rice breakage during milling causes a significant economic loss since broken rice often has 1/2 to 1/3 the value of whole milled rice. Hence, it is critical from an economic standpoint to maintain HRY as high as possible. Although, the average moisture content of the paddy rice at harvest influences HRY but it was not affected by harvest moistures between 15% and 22% (Siebenmorgen et al., 1992).

Even though two stage drying was reported employing FBD and LSU dryer yet this drying technique employing FBD as the first stage dryer followed by sun drying and FBD followed by fixed bed dryer as second stage dryer were not found in the literature. Introducing FBD with existing sun drying or fixed bed dryer might be an alternative drying method in Bangladesh condition. Therefore, this attempt was to assess the effect of two options of two stage drying on HRY. Thus, a suitable quick drying technique could be developed for quality dried rice.

2 Materials and methods

In this experiment, paddy sample of BRRI dhan28 variety was used as the test material to dry in the fluidized bed dryer, fixed bed dryer, and sun drying method.

2.1 Field visit and data collection from existing industrial drying complexes

A field visit was carried out to collect data on HRY of existing paddy drying system so that performance of proposed two stage drying systems can be compared. Necessary data were collected from different rice processing complexes (10 numbers of mills) from Pulhat, Gobindopur and Bottoli of Dinajpur districts. The respondents (at least five numbers) were mill owner, manager and technicians in each mill. Both sun drying (having floor capacity of 7 ton to 20 ton) and LSU dryer (having capacity of 1.8-3.6 ton hr^{-1}) are found to be used in the mill yard.

2.2 Sample preparation for drying experiments

Dried paddy with moisture content 13%-14% (wb) was purchased from local market of Dinajpur. These were manually cleaned removing impurities such as leaves, broken stalks, chaffs, immature and unfilled grains. Then, the paddy was remoistened by soaking in water at room temperature for 10-12 hours according to Khanali et al. (2012) to make the moist paddy of 25%-27% (wb) initial moisture content. The research was conducted in the Department of Food Engineering and Technology, HSTU, Dinajpur during the period of 2018-2019.

2.3 Experimental procedure

The two options of two stage drying method were accomplished in this investigation: (a) First option: Fluidized bed drying, tempering and followed by sun drying, (b) Second option: Fluidized bed drying, tempering and followed by fixed bed drying. A previously designed and fabricated lab scale fluidized bed dryer as shown in Figures 1 and 2 was used to dry the paddy samples (3-7 kg) from a high moisture level of 25%-27% (wb) to 18%-19% (wb). The fixed bed dryer as shown in Figure 3 and sun drying method were used in the second stage drying for further reduction of moisture from 18%-19% (wb) to 13%-14% (wb). In addition, one sample was dried completely by sun drying method which was used as control sample. This control sample was used to compare the performance of the proposed drying technique with it and existing industrial drying.

2.3.1 First stage drying of paddy samples in Fluidized bed dryer (FBD)

Fluidized bed drying experiment was carried out using three temperatures of 120, 130 and 150 ℃ at three bed thicknesses of 8, 10 and 12 cm. The air flow rate ranged from 0.061 to 0.087 $m^3 s^{-1}$ and the corresponding bed air velocity was 1.9 to 2.7 m s^{-1} (Wazed et al., 2021). Firstly, the blower was switched on 5-10 minutes before running the electric heater. The heater bank was so properly regulated to raise desired drying air temperature. Air temperature was measured by digital thermometer. The calculated amount of holdup paddy samples for 8, 10 and 12 cm bed thickness were then loaded into the fluidized-bed drying chamber by inlet port then drying was completed maintaining estimated drying time that was recorded by a stopwatch. The drying process was continued until the estimated drying time, which was found experimentally earlier by trial method for reducing paddy moisture from initial to desired final moisture content of 18%-19% (wb). Paddy sample was then discharged from outlet port of drying chamber. Moisture content of dried paddy was determined by oven drying method. Fluidized bed dried sample was tempered at grain temperature in a plastic bucket for 30 minutes and then cooled to ambient temperature.

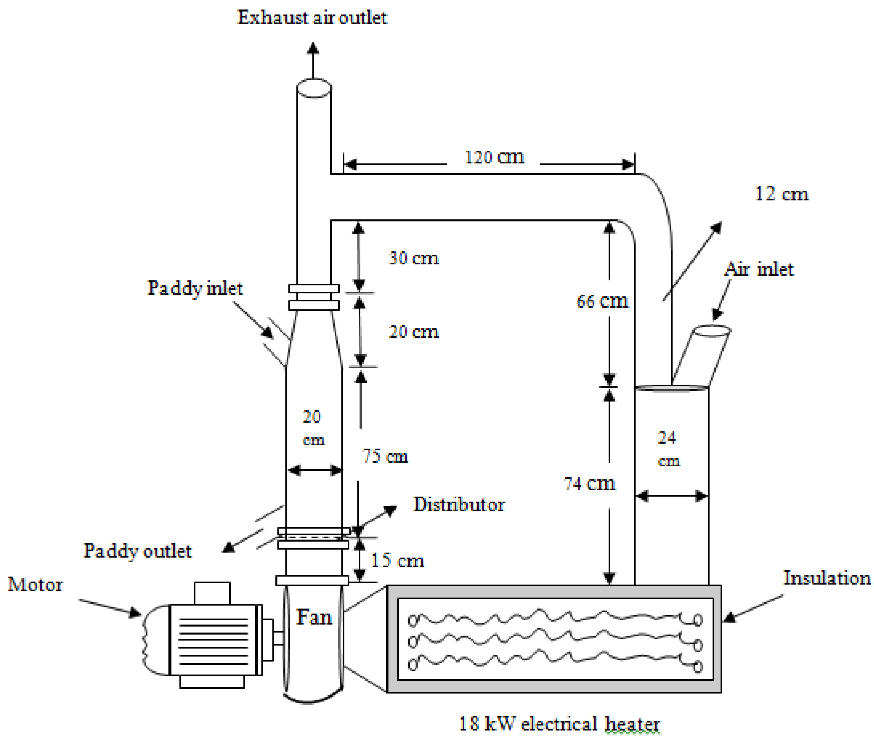

Figure 1 Schematic diagram of the experimental fluidized bed dryer

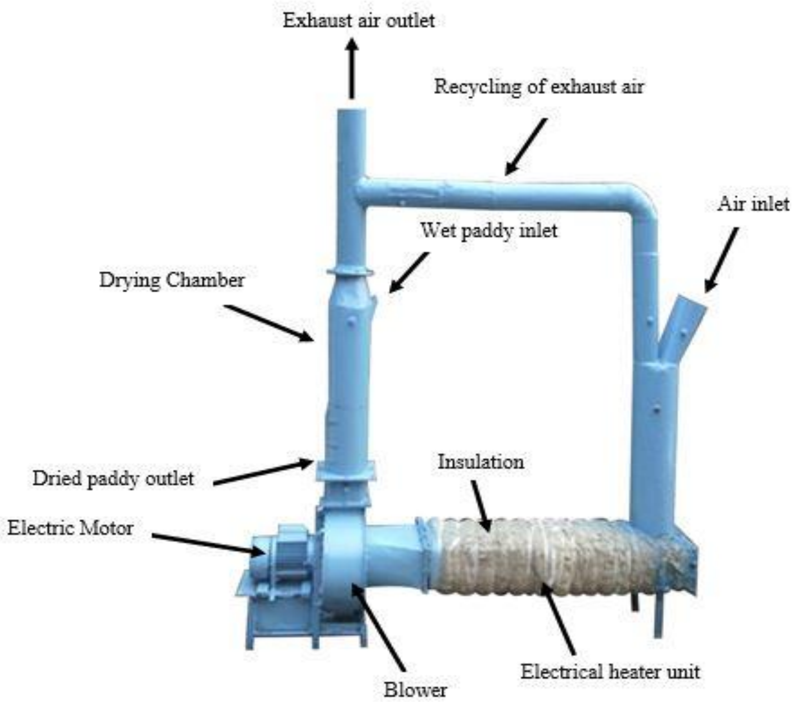

Figure 2 Photographic view of the experimental fluidized bed dryer

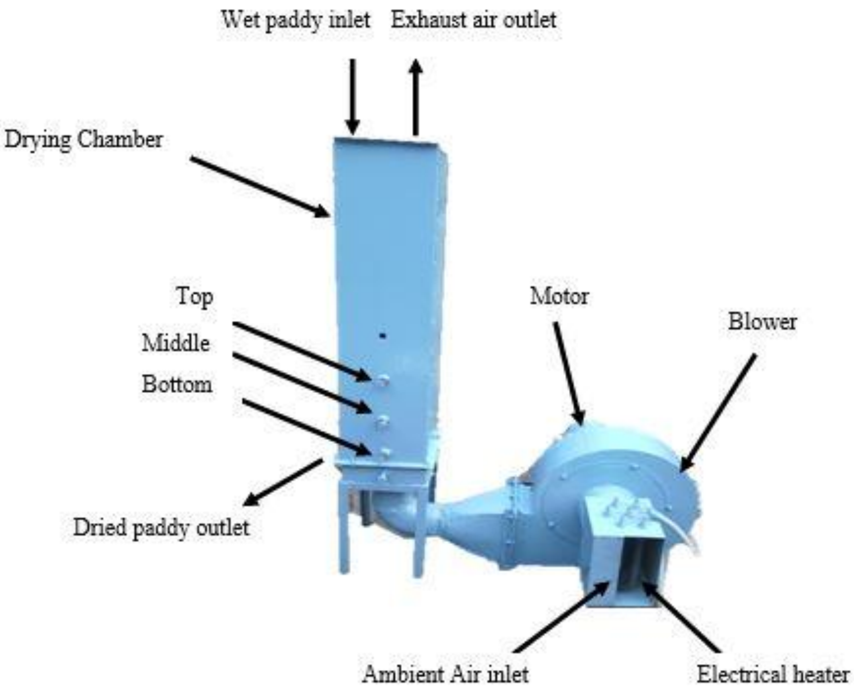

Figure 3 Photographic view of an experimental fixed bed dryer

2.3.2 Second stage drying of fluidized bed dried samples in fixed bed dryer

The paddy samples that had been previously dried in the fluidized bed dryer were further dried using lab scale fixed bed dryer as second stage drying from 18%-19% (wb) to around 13% (wb) moisture content. The dryer consist of a drying chamber was 20 cm × 20 cm × 100 cm with holding capacity of about 30 kg. Drying temperature and bed thickness were considered 40 ℃ ±1 ℃ and 30 cm, respectively based on previous researchers (Elepano et al., 2005, Sarker et al., 2013, Wazed et al., 2021) suggestions while the air flow rate was 0.025 $m^3\ s^{-1}$ and the corresponding bed air velocity was 0.63 $m\ s^{-1}$.

The blower was switched on few minutes before running the electric heater until steady and constant drying air temperature of 40 ℃±1 ℃ was raised. Then the previously dried and tempered samples were fed into the drying chamber. The representative paddy samples were taken at 30 minutes interval from the sampling holes located at three different positions (top, middle and bottom) of the drying chamber and moisture content of sample was determined by using digital grain moisture meter (GMK-303RS, Korea). The drying process was continued until final moisture content of 13%-14% (wb) was obtained. After that, the samples were collected from the top, middle and bottom layer and then mixed properly because industry level drying process usually concern with the quality of mixed paddy of all layers of fixed bed dryer. Finally, the dried samples were stored at ambient temperature packing in plastic bags.

2.3.3 Second stage drying by sun drying method

The fluidized bed dried paddy samples were further dried by sun drying method spreading on plastered pavement. Paddy layer thickness was maintained at 2-3 cm. Air temperature and relative humidity were 27 ℃-33 ℃ and the 56%-70%, respectively during drying period. During sun drying, the paddy was stirred at 20 minutes interval for uniform drying. The moisture content was determined at 30 minutes interval. The drying process was continued until the moisture content of the samples reduced to around 13% (wb).

2.3.4 Drying of control sample

Complete sun drying was carried out to dry the control paddy sample following the same procedure as mentioned in section 2.3.3. Control drying was carried out to compare the milling quality of rice with other drying methods.

2.4 Milling of dried sample

Milling of dried paddy samples was carried out at the Rice Milling Research Laboratory of Bangladesh Rice

Research Institute (BRRI), Gazipur. The milling process involved dehusking, polishing and grading. Before starting milling test, the final moisture content of paddy samples were determined. The moisture content of the dried samples ranged between 13% to 14% (wb).100g of dried and cleaned paddy was dehusked with a De-husker (JLGJ 2.5, Korea) while the bran was removed with a Rice Polisher (JNMS 15, Korea) running for 45 seconds for each amount of dehusked brown sample.

2.5 Assessment of quality of dried rice

The head rice yield (HRY) was defined in this study as the ratio of head rice mass to dried paddy mass. HRY was determined according to Wazed et al. (2021), Sarker et al. (2013, 2014), Tirawanichakul et al. (2012), Cnossen and Siebenmorgen (2000), and Islam et al. (2006) using the following equation:

$$\%\ \text{Head rice yield} = \frac{\text{Weight of head rice (kg)}}{\text{Weight of dried paddy sample (kg)}} \times 100 \quad (1)$$

2.6 Statistical analysis of milling data

The statistical analysis was carried out by using single factor experiment in completely randomized design (CRD). The only factor was drying option (method) which has eight levels such as six two stage drying options, control drying, and industrial drying method. The statistical software package SAS 9.3 version was used to calculate the mean values, standard error mean (SEM) and analysis of variance of obtained values on rice quality as HRY. Meanwhile, Duncan's Multiple Range Test (DMRT) analysis was employed to determine the differences in head rice yield among the drying methods at $p \leq 0.05$.

3 Results and discussion

3.1 Milling quality in existing industrial drying complexes

Base line survey results on the status of drying and milling of rice in Dinajpur district of Bangladesh is given in Table 1. Both parboiled and raw rice are found to be processed in the visited rice mills. LSU dryer that was continuous mixing type dryer, found to be used in the mills. Total drying time varied from 8 to 12 hours in the LSU dryers. The average milling result in terms of HRY was compared with two stage drying technique and control drying (Sun drying method).

3.2 Quality evaluation of dried paddy

3.2.1 Head rice yield obtained from first option of two stage drying applying fluidized bed dryer followed by sun drying method HRY is one of the crucial parameters of dried paddy. Figure 4 indicates the percentages of HRY obtained from the first option of two stage drying technique. It can be seen that the HRY of dried paddy was ranged between 55.67%-65.57%.

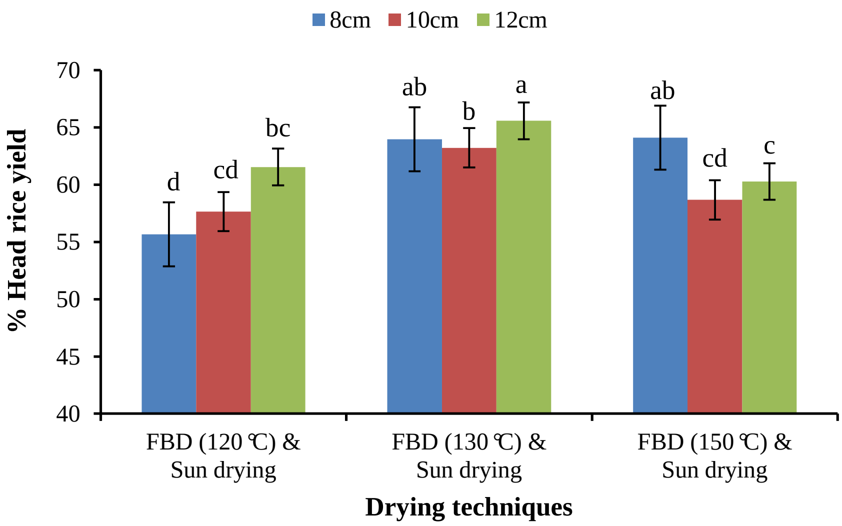

Figure 4 The effect of fluidized bed drying operating parameters on HRY during in first option of two stage drying of paddy

[1st stage: FBD- Temperature 120°C, 130°C and 150°C; bed thickness: 8, 10 & 12 cm; Air velocity: 1.9 - 2.7 m s^{-1}. 2nd stage: Sun drying- Temp: 27 °C -33 °C, relative humidity: 53%-70%; Air velocity: 0.05-0.1 m s^{-1}]

Table 1 Status of rice drying and milling of rice mills in Dinajpur district

Serial No.	Name and location of the mills	Dryer Capacity (ton h^{-1})	Drying time (hr)	% HRY
1	Two Brothers Auto Rice Mills, Sadar, Dinajpur	3.6	8-10	*51.15±0.23
2	Nilufa Auto Rice Mill, Sadar, Dinajpur	1.8	9-10	50.07±0.27
3	Friends Auto Rice Mills, Sadar, Dinajpur	2.2	10-12	52.15±0.17
4	Tanjum Auto Rice Mills, Sadar, Dinajpur	2.0	8-10	53.10±0.11
5	Raj Auto Rice Mills, Sadar, Dinajpur	3.0	9-10	49.85±0.47
	Average			51.25±0.25

Note: Mean values±standard error mean (SEM); HRY: Head rice yield

The highest HRY (65.57%) was achieved from the paddy dried by first option using drying temperature of 130 ℃ at 12cm bed thickness. This HRY was higher than the values reported by Soponronnarit et al. (1996a) in drying of high moisture paddy (30% db) at 130 ℃ drying air temperature using commercial fluidized bed paddy dryers. This HRY was also comparable with HRY obtained by Thompson and Mutters (2006). On the other hand, the lowest HRY was obtained in using 120 ℃ temperature at 8 cm bed thickness, and the value was also higher than the value reported by Soponronnarit et al. (1996b). Thompson and Mutters (2006) and Karbassi and Mehdizadeh (2008) reported the similar result in drying of same moisture content paddy by using higher temperature (130 ℃) in FBD. It could be assumed that this resulted from gelatinization of starch in paddy kernel that caused the paddy to be tough thus breakage was found to be reduced. Consequently, HRY was found to be increased. A similar explanation has been pointed out in the studies as reported by several authors (Rao and Juliano 1970; Rordprapat et al., 2005; Soponronnarit et al., 2005; Taechapairoj et al., 2003).

3.2.2 Head rice yield obtained from second option of two stage drying (Fluidized bed drying, tempering and followed by fixed bed drying method)

Figure 5 shows the percentage of HRY for the paddy samples obtained from the two stage drying using fluidized bed drying followed by fixed bed drying.

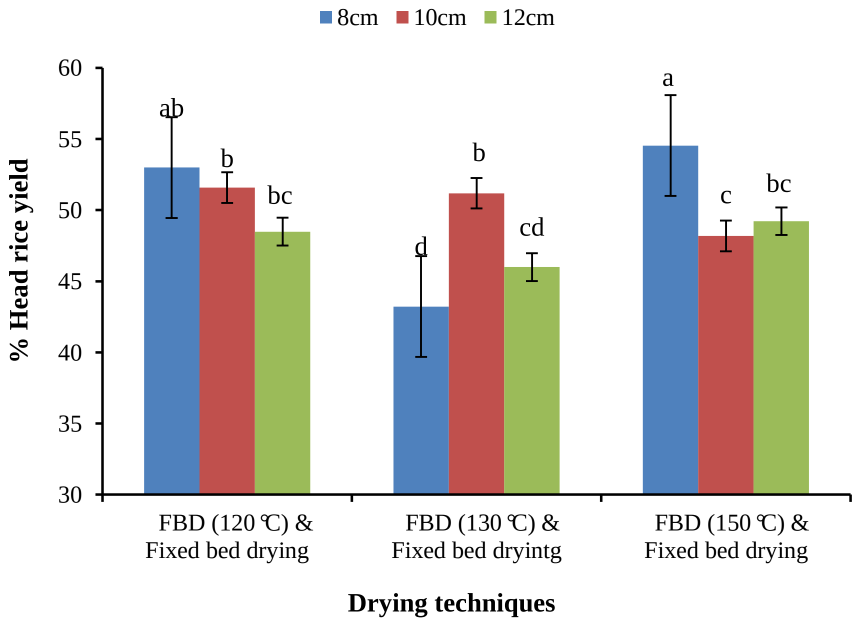

Figure 5. The effect of fluidized bed drying operating parameters on HRY during in second option of two stage drying of paddy

[1st stage in FBD: Temperature 120°C, 130°C and 150°C and paddy bed thickness 8, 10 and 12 cm; Air velocity: 1.9-2.7 m s^{-1}. 2nd stage in Fixed bed dryer: Temp: 40 °C, Bed depth: 30 cm and air velocity: 0.63 m s^{-1}]

Table 2 Comparison of the HRY of paddy dried by control, industrial and the best combination of two stage drying technique

Drying methods		Drying Parameters	HRY
		Bed thickness (cm) / Drying air temperature (°C)	
Two stage drying	FBD + Sun drying	12/120	*61.54±2.81[b]
		12/130	65.57±0.16[a]
		8/150	64.11±0.73[ab]
	FBD + Fixed bed drying	8/120	53.43±0.31[c]
		10/130	51.04±0.75[c]
		8/150	52.04±0.48[c]
Control drying		Temperature:27°C -31°C Relative humidity: 53%-70% and air velocity: 0.05-0.1 m s^{-1}	52.77±0.07[c]
Industrial drying (LSU dryer)		Drying temperature: 60°C-70°C	51.25±0.25[c]

Note: *Mean values ± standard error mean (SEM). a-c, quality grade letters: The different letters within the column means that the values are significantly different ($p \leq 0.05$).

FBD: Fluidized bed dryer; Fixed bed drying temperature: 40°C ±1°C, Bed thickness: 30 cm and bed air velocity: 0.63 m s^{-1}.

When paddy was dried in FBD using drying temperature of 150℃ at 8 cm bed thickness, the highest HRY (54.54%) was achieved which was similar with the values as reported by Prachayawarakorn et al. (2011). Paddy with high moisture content (27%, wb) dried using higher temperatures by FBD and fixed bed dryer gave higher HRY. On contrary, the lowest HRY was obtained while using 130℃ in fluidized bed drying at 8 cm bed thickness. This low HRY might be due to the non-uniformity of moisture content in the paddy bed and fluctuation of temperature and air velocity in the drying chamber. Besides, paddy with similar moisture content dried by fixed bed dryer as second stage using higher temperatures yielded lower HRY corresponding to similar results as mentioned by Sarker et al. (2013).

3.2.3 Comparison of the HRY of paddy dried by two stage drying method

A comparison on HRY obtained from two options of two stage drying, clearly indicated that two stage drying employed with FBD and sun drying yielded higher HRY than two stage drying using FBD and fixed bed drying. Lower HRY obtained in fixed bed drying suggests that fluidized bed drying at high temperatures has the positive effect on increasing HRY of dried paddy. So, fluidized bed drying is favorable for drying of high moisture paddy.

3.2.4 Comparison of the HRY of paddy dried by control drying, industrial dryer and the best combination of the two stage drying technique

Table 2 displays the percentages of HRY obtained from the control, industrial and proposed two options of two stage drying technique under the best combination of drying operation conditions (Drying air temperature and bed thickness).

A comparison on HRY obtained from the three methods such as control, industrial and first option of two stage drying method namely fluidized bed drying followed by sun drying revealed that the HRY obtained from the two stage drying technique was comparatively higher than that of control and industrial drying. The results were also similar to the milling characteristics observed by Pan et al. (2007) and Takai and Barredo (1981). It is also clear that the proposed two stage drying option yielded almost same quality of milled rice in comparison to existing industrial drying methods. Similarly, Tirawanichakul et al. (2004) and Prachayawarakorn et al. (2005) reported that fluidization techniques had been producing increased HRY compared to conventional drying methods. Nonetheless, the bed thickness and temperature combination of 12 cm/120℃ yielded lesser HRY compared to 12 cm/130℃, which could be ignored due to higher standard error mean. Thus, the two stage drying options can be practiced for achieving quality rice. Practicing tempering after fluidized bed drying could increase HRY, as suggested by many researchers (Prachayawarakorn et al., 2005).

Further, comparison on HRY obtained from control drying sample, industrial drying and two stage drying option by fluidized bed drying followed by fixed bed drying revealed that the HRY in the two-stage drying was slightly lower than those of the control sample but higher than that of industrial drying. The HRY of paddy dried by this drying option was almost similar in different bed thickness and temperature combination.

However, it can also be observed in Table 2 that the HRY was varied significantly among the two stage dried paddy, when the paddy was dried to be almost the same final moisture content. It is also clearly seen in Table 2 that HRY was maximum in case of first option of two stage drying as 12 cm/130 ℃, which was similar to the previous findings (Taweerattanapanish et al., 1999). Even though a lower HRY was obtained by using the combination of 10 cm/130^{o}C in second option of two stage drying, which might be due to the non-uniformity of moisture content in the paddy bed, caused by a very low air flow used in fixed bed dryer. Nevertheless, the loss of HRY of paddy obtained in this study using two options of two stage drying techniques is minimum, which might be the tempering effect after first stage drying. Previous study demonstrated that the improvement of HRY after tempering is due to the fact that the moisture gradient and stresses that had occurred during drying has been relaxed during tempering (Cnossen et al., 2003).

Besides, the control sample (paddy dried by sun drying method) yielded 52.77% head rice, which is quite similar or lower than that of second option of two stage drying methods, which indicated that the paddy dried with FBD and fixed bed dryer did not affect the HRY. Comparatively, similar outcomes were also reported by Soponronnarit et al. (2001). At industry level the amount of HRY obtained was lesser. Over polishing to make more fine rice might be the reason of lower HRY in the industry level. The previous researchers also reported that HRY decreased linearly as milling duration increased, or as more bran was removed (Reid et al., 1998). In conclusion, based on quality in terms of HRY, any option of proposed two stage drying technique can be used for drying of high moisture paddy. In depth study can be carried out to find out the best combination of drying temperature and bed thickness for drying of various initial moisture content paddy using FBD and fixed bed dryer for obtaining better quality rice.

4 Conclusions

Quality of dried rice in terms of HRY did not vary so much between the two options of two stage drying technique, but higher HRY was found from the first option of two stage drying where drying operation was accomplished by fluidized bed drying followed by sun drying method. On the other hand, a comparable HRY was found from the second option which was compared with the complete sun drying and industrial drying method using LSU dryer. The results also showed that at least 5% HRY can be increased by using fluidized bed drying followed by sun drying method compared to existing commercial drying methods. Even though three fluidized bed drying temperatures of 120^{o}C, 130^{o}C and 150^{o}C at any thickness of 8, 10 and 12 cm gave the acceptable quality of milled rice but 130^{o}C at 12cm yielded the highest quality of rice which may be recommended temperature and bed thickness.

Thus two-stage drying practice is found to be more suitable than the existing drying systems as it can raise the capacity of the drying complex and maintaining the quality of dried rice in terms of HRY. Therefore, two stage drying technique presented in this paper can be adopted as pilot scale for drying of high moisture paddy in Bangladesh.

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