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Study on the drying performance and milling quality of dried paddy using inclined bed dryers in two different paddy mills located in MADA and IADA KETARA

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Abstract

The drying performance of industrial inclined bed dryer (IBD) and the milling quality of dried paddy was evaluated and compared in two main granary areas of Muda Agricultural Development Authority (MADA) and Integrated Agricultural Development Areas (IADA KETARA). A mix of MARDI's paddy variety (MR 220 CL2 and MR 219) was used and the study on both granary area of MADA and IADA KETARA were carried out in local paddy mills located at Yan, Kedah and Besut, Terengganu respectively. The results indicated that the average drying rate in MADA was 119.93 kg water removed/hr whereas only 73.67 kg water removed/hr was recorded in IADA KETARA. Therefore, normalized water removal value of paddy mill in MADA was found higher than paddy mill in IADA KETARA. In terms of milling quality, average percentage of head rice yield of paddy mill in MADA and IADA KETARA was 76.89% and 73.87% respectively. The milling quality analysis of rice resulted from ANOVA found that there was no significant difference in the HRY and total broken between IBDs in both locations.

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Introduction

Oryza sativa L., the most widely grown rice, is the staple food of an estimated 3.5 billion people worldwide (International Rice Research Institute, 2013). Rice production and consumption are among the highest in Asian populations. Rice provides up to 50% of the dietary caloric supply for millions living in poverty in Asia and is, therefore, critical for food security (Muthayya *et al*., 2014). Paddy, which is also known as rough rice or defined as rice in the husk after threshing is the base feedstock and needs to be dried into its acceptable condition before processing to become rice. Paddy is normally harvested at grain moisture content (M.C %) between 20-25% wet basis in tropical countries (Imprasit *et al*., 2001). At this moisture level, microorganism activity has drastically occurred and contributed to high rate of growth and respiration (Weerachat *et al.,* 2010). Therefore, the paddies needed to be dried to achieve 12-14% moisture content before proceeding to the milling process for good quality and characterization of rice product (Tirawarichakul *et al*., 2004). The marketing value of rice as an agriculture product depends on its good physical and qualities after processing (Kanchana *et al*., 2012).

Drying is an important process in rice production since it can prolong the storage period of paddy before proceeding to the next stage of milling process. Drying has a significant effect to the rice quality since any delay in drying or incomplete drying and also uneven drying will result in qualitative and quantitative of losses. This includes contributing to the production of yellowish and discoloration of rice due to mould development and heat-up from respiration. Improper drying can also reduce the milling yield (head rice yield) caused by the high temperature and re-wetting of grains. Moreover, it also can cause damage due to the insect or microorganism activity at higher M.C level. Drying is an intensive-highly energy consuming process (Jittanit *et al.*, 2010). Other than using a huge amount of energy, it also can cause a change to physical, mechanical and chemical characteristics of the final product (Harchegani *et al*., 2012). Generally, in commercial scale production, the drying process is carried out by blowing and heating air over the grains which will result the paddy to lose moisture rapidly. Furthermore, moisture movement inside paddy kernel is exposed to dry and humid environments that will cause desorption and adsorption of moisture respectively during the drying process (Prakash *et al*., 2011).

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So far, there has been a great advancement of drying technology for paddy in case to find the best drying technique that is energy-efficient with providing good and high quality rice (Jittanit *et al*., 2010). Among them are combined microwave or infrared- hot air drying (Sangdao *et al*., 2011), super-heated steam drying (Soponronnarit *et al*., 2006) and spouted bed drying which have been classified as efficient drying methods for rice quality (Evin *et al*., 2008). However, all of those techniques used for industrial purposes are still limited (Jittanit *et al*., 2010). Generally, Asian rice processing industries tend to choose fluidized bed dryer, Louisiana State University (LSU) dryer and inclined bed dryer as their key paddy drying unit operation (Sarker *et al*., 2013). Nevertheless, the most joint dryer used for paddy dryer in Asian region is the fixed deep bed dryer either in the form of rectangular bins such as flat bed and inclined bed or circular bins (Ibrahim *et al*., 2014). Fluidized bed and spouted dryer are known as efficient dryer for first stage drying with the ability to reduce moisture content fast in very high temperatures (Sarker *et al*., 2013). However, in commercial rice mills in Malaysia, inclined bed dryer (IBD) found to be used as single-stage complete drying and this can be seen in certain drying complexes of Padiberas Nasional Berhad (BERNAS) - the national paddy custodian of Malaysia. Drying bed of IBD is inclined and this promoted advantages for easy and faster discharge of paddy after drying. This dryer is typically used for the drying of high moisture content of 20-26% wet basis and the moisture gradient of final product between top and bottom layers after drying in fixed bed dryer is normally higher with 3-4% of MC (Sarker *et al*., 2014).

Inclined Bed Dryer (IBD), also identified as tilted bed dryer (TBD) is considered an advanced intermediate drying system and has similar performance as flat bed dryer. Tilt bed drying bins require an enough amount of paddy to fill the bed. Otherwise, the depth of paddy is uneven and drying cannot perform effectively (Norman, 1987). Moreover, this dryer have advantage that they are self-levelling and self-emptying with a proper system of delivery and discharging paddy. Thus, this advantage can greatly minimize or reduce the requirement of labour for drying and also the drying floor is easier to maintain since there is no necessary for labour to stand on the perforated floor for filling and emptying the drying bed. The inclination of the bed should be adjusted at 43-45°. This is because, lesser angles require some labour for levelling and emptying the dryer meanwhile greater angles makes it difficult for the retention boards at the top surface in order to maintain uniform depth in the bed (Norman, 1987).

It is important for the rice milling plants to achieve even and uniformity of their drying processes in order to improve their drying operations and to assure the effectiveness of drying. For that reason, this study is aimed at evaluating the drying performance and quality of final dried paddy resulted from industrial inclined bed dryer.

Materials and Methods

The drying studies of industrial inclined bed dryer were carried out at two local paddy mills located in MADA and IADA KETARA area. Three dryers at each paddy mill were used for data collection throughout the study. The experiments in MADA and IADA KETARA area were carried out on January 2015 and May 2015 respectively. The structure and design of dryer in both mills had not much different and had a holding capacity of about 15 ton per batch. The dryer consists of a bed area of about 9.82 m x 3.06m. Unlike 3 IBDs in KETARA which were side by side, IBD 15 at MADA was quite distanced from the other two dryers. In fact, IBD 15 has a huge gap between paddy beds and ceiling compared to IBD 2 and 10. Both paddy mills used hot water generator to supply hot water to heat exchanger in order to produce heated air for drying. Following the real practice in MADA and IADA KETARA paddy mills, inlet temperature setting were set at 42˚C and 40˚C respectively. The range of paddy bed thickness was also varied from 0.94 to 1.28 meter and from 0.81 to 0.98 meter for IBD in MADA and IADA KETARA respectively. Schematic diagram of the IBD can be shown in Figure 1.

Freshly harvested paddy which consisted of MR 220 CL2 and MR 219 produced in particular local region (MADA and IADA KETARA) was used for the experiment. The drying experiments of three IBDs were done concurrently and the temperature and relative humidity of ambient air during drying were recorded. The ambient temperature and relative humidity were recorded using EBRO data logger (EBI 20TH1) with accuracy ±0.5°C. Each IBD was divided into three compartments where the samples were collected for moisture content determination. The three compartments were considered as near to blower, middle and far from blower as shown in Figure 2. Time interval of 1 hour was used at the beginning of drying (the first 12 hours) and reduced to 30 minutes interval towards the end of drying process. The samples were collected on the surface of the paddy bed and centre of each compartment as commonly practiced by the mill operator. Once the

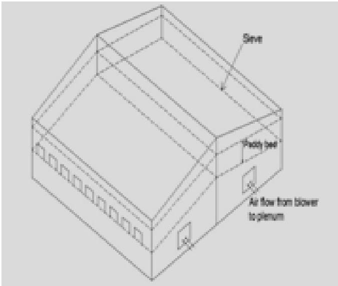

Figure1. Schematic diagram of IBD

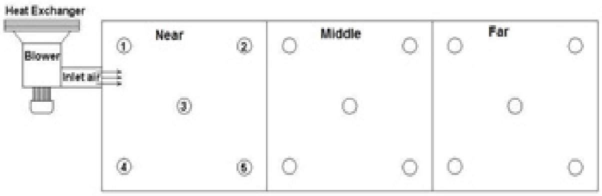

Figure 2. Actual Industrial Inclined Bed Dryer (plan view) and sampling points

drying completed, 45 samples of dried paddy were collected from 3 IBDs based on 5 different spots per compartment and 3 compartments per dryer (near, middle and far). Each sample was meant for three replications of determining final moisture content of dried paddy. Prior to drying, percentage of impurities in paddy bed and bulk density were measured. 10 g from each sampling point in paddy bed was used to determine the average percentage of impurities in IBD. Bulk density was determined using mass/volume relationship, by filling an empty container of predetermined volume and tare weight with the grains by pouring from a constant height, striking off the top level and weighing (Ghasemi *et al*., 2008). Approximately 50 g of paddy was taken at each sampling point based on three different compartments in IBD throughout drying process. The bed surface sampling was done using a common scoop whereas depth sampling was carried out using double tube sampling spears. Moisture content of the paddy was analyzed on a moisture analyzer (SATAKE SS6, Japan) with (±0.5%) accuracy and measuring range of 10-40%. Moisture content of the paddy samples were done straight away after sampling and then packed in re-sealable packet accordingly. The amount of moisture content in paddy is designated on the basis of the weight of water. Equation 1 and 2 are the formulas that represent moisture content in dry basis and wet basis respectively. According to (Wilhelm *et al*., 2004), two ways of expressing moisture content can be described by equation 3 whereas equation 4 is used to calculate the amount of moisture removed in paddy.

$$\%MC_{db} = \frac{W_w}{W_d} \cdot 100 \qquad (1)$$

$$\%MC_{wb} = \frac{W_w}{W_w + W_d} \cdot 100 \qquad (2)$$

$$\%MC_{db} = \frac{MC_{wb}}{100 - MC_{wb}} \cdot 100 \qquad (3)$$

$$M_w = M_c\left[(W_i - W_f/100 - W_f)\right] \qquad (4)$$

where MC_{db} is the moisture content dry basis, MC_{wb} is the moisture content wet basis, W_w is the weight of water (g), W_d is the weight of dry matter (g), M_w is the mass of water loss, M_c is the mass of product to be dried, W_i is the initial moisture content and W_f is the final moisture content. On top of that, mass water removal from each IBD was also normalized by the initial total mass of water in the bed. The inlet air velocity of dryers was measured by Vane Anemometer (TESTO 416, Germany) with ±0.2 m/s + 1.5% of reading accuracy. The cross section area at the point of air velocity measurement was first calculated. Total volume air flow rate and bed air velocity were calculated using continuity equation as in Equation (5) according to (Jittanit *et al.,* 2010).

$$Q = A \times V \qquad (5)$$

where Q,A and Vare total volume air flow rate, cross-sectional area of bed and air velocity.

Control sample preparation

For control samples, ambient air drying (AAD) method was employed in which paddy samples were spread at 1-2 cm bed thickness on plastic mats under shed area. The samples were taken from the same batch of every single IBD which had the initial moisture content between 21-25% wet basis. Moisture content reduction of the control samples were also monitored and recorded.

Statistical analysis

The statistical software package Mini Tab 6 was used for the analysis of variance (ANOVA) for the drying uniformity evaluation.

Rice milling quality evaluation

Samples of dried paddy collected from different spots were mixed to represent paddy sample of each compartment and IBD. The evaluated rice milling quality included head rice yield (HRY), percentage of broken rice and total rice recovery. The moisture content of the samples before milling test were determined and recorded. The dimension of the

Table 1. Drying performance of IBDs in IADA KETARA and MADA

Location of paddy mill	IBD No.	M_i (%,wb)	M_f(%,wb)	Mass paddy in IBD (kg)	Drying time (hr)	Drying rate, (kg water removal/hr)	Drying capacity, (ton/hr)
IADA KETARA	26	20.81±1.16	13.13±0.47	14444.35	19.00	61.17	0.63
	27	23.25±1.73	13.80±0.44	14773.36	17.33	86.25	0.69
	28	23.25±1.73	13.70±0.72	11769.87	15.50	73.59	0.58
MADA	10	23.81±0.61	13.30±0.90	16213.72	18.00	101.69	0.74
	2	23.62±0.51	13.20±0.26	14601.83	17.25	91.42	0.67
	15	23.51±0.34	12.83±1.44	17080.07	11.83	166.69	1.19

Table 2. Percentage of impurities before and after pre-cleaning at paddy mill in IADA KETARA and MADA

Location of paddy mill	IADA KETARA			MADA		
IBD No.	IBD 26	IBD 27	IBD 28	IBD 2	IBD 10	IBD 15
Percentage of impurities before pre-cleaning (per 100 g) (%)	19.34	16.6	15.6	14.85	17.40	15.36
Percentage of impurities after pre-cleaning (per 100 g) (%)	9.01	8.31	13.40	10.00	6.87	5.77
Average impurities after pre-cleaning (%)	10.24±2.76			7.55±2.19		

milled rice was also determined. The quality analysis was done at Postharvest laboratory of MARDI Pendang, under Rice and Industrial Crops Centre. Comparison on milling quality of rice between control drying of ambient air drying (AAD) and IBD was then evaluated.

Results and Discussion

Drying behavior and moisture reduction of paddy in IBD

The samples for moisture reduction measurement during drying were taken at the surface of a bed which is normally practiced by the dryer operator. It was found that the average drying time for IBD in MADA was about 15.70 hours whereas the IBD in IADA KETARA took 17.27 hours to dry paddy to final moisture content of 13-14%. Therefore, drying rate for IBD in MADA was higher than IBD in IADA KETARA. From our observation, dryer operator normally measures moisture content of paddy after 8 hours of drying as there was not much difference in moisture reduction for the first 8 hours. Although the drying process was carried out simultaneously with the same drying parameters, the drying time could also be affected by other factors such as ventilation system, percentage of impurities inside paddy bed and also bed thickness. Referring to Table 1, it is obvious that IBD 15 in MADA was the fastest to dry paddy compared to other IBDs. This is also proven with the highest value of normalized water removal calculated for IBD 15. IBD 15 which was located at the end of the IBD's row with high gap between ceiling and bed resulting in better outlet air flow and shorter drying times. On top of that, IBD 15 also had the lowest percentage of impurities of 5.77%. Drying capacity of IBD 15 has exceeded the drying capacity range (0.66 to 1.03 ton/hr) of previous study by Sarker *et al.* (2014). In IADA KETARA, the fastest drying period was from IBD 28 as shown in Table 1. This could be due to under capacity of paddy mass in IBD hence shorten the drying time. Nevertheless, IBD 28 had the highest percentage of impurities than the other two IBDs. In terms of efficiency of paddy pre-cleaning, paddy mill in MADA was better than paddy mill in IADA KETARA and this can be clearly seen in Table 2. There was no substantial effect of air bed velocity to the total drying time as the velocity was quite close to each IBD with a range of 0.25-0.27 m/s. The same finding was also reported by Sarker *et al.* (2013). Higher temperature setting of 42˚C at IBD in MADA had increased the drying rate compared to 40˚C inlet temperature set at IBD in IADA KETARA. Using hot water heat exchanger, inlet air temperature was consistently supplied throughout the drying process.

Nevertheless, the optimum steady air temperature and air flow could be affected by the deposition of dust to the heat exchanger if not regularly monitored its condition. Mean value ± Standard error mean (SEM). Same letters in italic for different quality attributes in each column mean that the values are not significantly different ($p \geq 0.05$)

The uniformity analysis of final moisture content of dried paddy in IADA KETARA and MADA can be seen in Figure 3. At MADA paddy mill, significant difference ($p \leq 0.05$) in the average final moisture content of paddy at (near to blower) compartment was achieved in IBD 10 and 15. The same significant different was also found in IBD 27 and 28 in IADA

Table 3: Comparison on physical quality of rice between IBDs and ambient drying in IADA KETARA and MADA

IADA KETARA			
	Head rice yield (%)	Total broken (%)	Milling recovery (%)
Drying approach			
Control(AAD)	70.43±9.51a	29.57±9.51a	66.67±1.44a
IBD 26	77.22±1.25a	22.78±1.25a	66.26±0.53a
IBD 27	73.92±3.23a	26.08±3.23a	65.49±1.19ab
IBD 28	70.47±2.78a	30.00±3.29a	63.38±0.46b

MADA			
	Head rice yield (%)	Total broken (%)	Milling recovery (%)
Drying approach			
Control(AAD)	78.50±0.87a	21.50±0.87a	67.91±0.19a
IBD 2	75.50±0.60a	24.50±0.60a	68.87±0.24a
IBD 10	77.70±1.08a	22.27±1.06a	68.30±0.51a
IBD 15	77.47±0.69a	22.53±0.69a	69.33±0.33a

Mean value ± Standard error mean (SEM). Same letters for different quality attributes in each column mean that the values are not significantly different (p≥0.05).

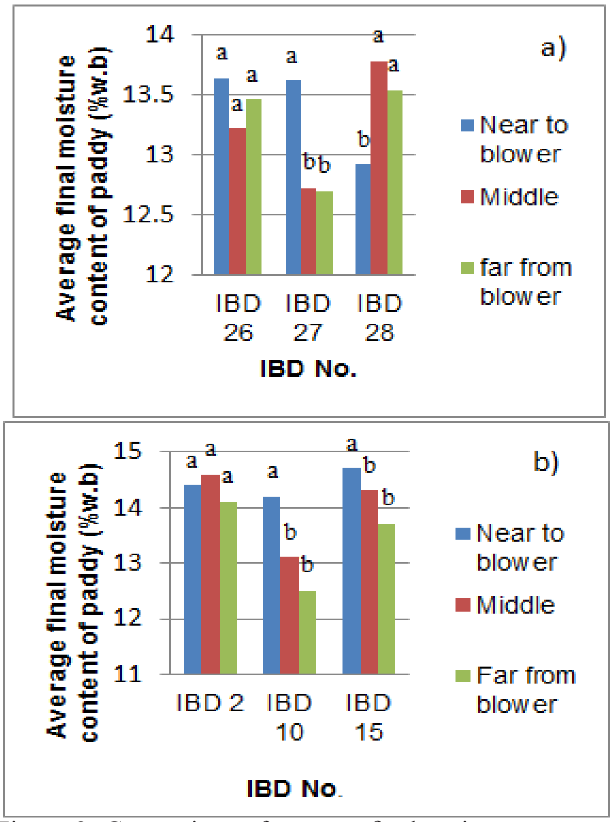

Figure 3. Comparison of average final moisture content obtained from different compartments in IBD (a) IADA KETARA (b) MADA. [The different letters indicate that the samples are statistically different according to Tukey HSD test (P<0.05)]

KETARA paddy mill. It was probably due to compactness and high density of paddy at (near to blower) compartment which might cause difficulty to air flow. According to the mill operator, final moisture content of paddy at (near to blower) is normally higher than other compartments. Almost similar results were also reported by Valerian *et al.* (2014). However, there was no significant difference of final moisture content within compartments in IBD 2 and IBD 26. It is understood that the depth of paddy in IBD bed was varied throughout the compartment hence there are possibilities of uneven final moisture content of dried paddy.

Table 3 shows milling results which consist of HRY, broken rice/ grain and milling recovery resulted from control drying of ambient air drying (AAD) and three different IBDs from MADA and IADA KETARA area respectively. In MADA paddy mill, milling recovery for all IBDs was more than 68% well-milled rice whereas in IADA KETARA, the milling recovery was between 63-67%. Almost the same range of milling recovery was also reported by Sarker *et al.* (2014). However, both paddy mills had an acceptable percentage of milling recovery set by BERNAS. Nevertheless, in a well-operated modern mill, it is possible to achieve a milling recovery of 68-70% (Ray, 1999). In general, the broken rice for both areas was found more than 20%, but still in acceptable value. Broken rice when 30% greater will be recognized as failure; either at stage of pre-harvesting or post-harvest handling. The moisture contents of the final dried samples before milling test were 12-14% w.b. In MADA paddy mill, AAD samples showed a slight decrease of broken grain than mechanical drying but the difference was insignificant. Besides broken rice, HRY was also monitored. The HRY when drying naturally using AAD treatment was slightly higher than drying with IBDs. This was due to lower breakage of grain in AAD. In contrast, total broken rice resulted from AAD in IADA KETARA was higher compared to IBDs. In addition there were significant differences in milling recovery between IBDs. Nevertheless, there was no significant difference in the HRY and total broken between IBDs in both locations. The HRY is much related with pre- and post harvest fissures development in the kernel as well as post harvest drying and handling of paddy (Yadav and Jindal, 2008).

Conclusion

In this study, inlet air temperature of 40-42˚C had proven to reduce drying time with no significant effect on the milling quality of dried paddy. Both paddy mills in MADA and IADA KETARA had achieved their minimum figure of milling quality dried paddy. Generally, IBDs in MADA performed better in terms of drying capacity compared to IBDs in IADA KETARA. However, there are other factors such as percentage of impurities prior to drying, optimum thickness of paddy bed and adequate ventilation system that should also be taken into consideration. It can be concluded that the percentage of impurities should be as lower as 5% for effective drying. Optimum thickness of paddy bed has to be set according to dryer capacity to avoid overload and longer drying time. IBD 15 had shown an example of lower percentage of impurities in IBD and better air flow contributes to higher drying rate and milling recovery. Therefore, factors that contribute to the inefficient drying should be monitored closely and understood by the operators and millers.

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