International Food Research Journal 23(Suppl): S23 - S29 (December 2016)

Journal homepage: *http://www.ifrj.upm.edu.my*

# Energy usage and drying capacity of flat-bed and inclined-bed dryers for rough rice drying

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**Article history**

*Received: 13 November 2016*
*Received in revised form: 2 December 2016*
*Accepted: 4 December 2016*

**Keywords**

*Flat-bed dryer*
*Inclined-bed dryer*
*Energy consumption*
*Drying capacity*
*Head rice yield*

**Abstract**

The evaluation of a dryer performance in terms of energy consumption, drying capacity and quality of final product is the main concern of rice milling industry at any time. A study was implemented to investigate on the benefits of common drying practices by studying the drying performances of flat-bed and inclined-bed dryers which are popular in rice industry in Malaysia and neighbouring countries. For this purpose, flat-bed dryer (FBD) and inclined-bed dryer (IBD) were designed, fabricated and operated in the laboratory based on actual industrial drying conditions. The results revealed that inclined-bed drying significantly increased drying capacity (ton $m^{-2}$ $h^{-1}$) of up to 25 % at drying temperature of 42-43°C and almost 29 % at 38-39°C drying air temperature compared to flat-bed drying. Furthermore, overall drying energy consumption in IBD was found to vary between 78.6 to 91.97 kW.h $ton^{-1}$, while for FBD the energy consumption was more than 200 kW.h $ton^{-1}$ for both levels of drying air temperatures. Both dryers were found to produce rice with desired/ acceptable commercial quality index, even though the head rice yields of FBD were higher than that of IBDs.



## Introduction

In tropical countries, such as Malaysia, rough rice or paddy (Oryza Sativa L.) is harvested at high moisture content normally around 20-25% (wb), and drying of the freshly harvested paddy to final moisture content of 13-14% (wb) is one of the most critical process to produce high quality milled rice (Igathinathane *et al*., 2008; Dong *et al*., 2009; Ibrahim *et al*., 2013). Although there are different efficient methods which can be used for producing high quality rice such as spouted-bed drying, super-heated steam drying and infrared-hot air drying but, it seems that rice industries have lots of limits for using these new methods (Soponronnarit *et al*., 2006; Das *et al*., 2009; Sangdao *et al*., 2011; Tajaddodi, 2012).

Asian rice industries, which produce about 90% of total rice in the world, are mostly willing to use fixed bed dryer in the form of flat-bed (FBD), inclined-bed (IBD) and circular bin which among them, inclined-bed dryer is very popular in Malaysian milling industries (Ramziath *et al*., 2013; IRRI, 2012). The dryer with inclined-bed is used mostly as a single stage dryer with 100 cm depth of bed to dry rough rice with high moisture content. The main reason that rice industries prefer IBD is because of easy unloading operation of this dryer that significantly shortens post-drying operation time as well as decreases the high cost of handling large amount of grain. Researches have shown that drying of rough rice is a high energy consuming process for the rice industries and it is known as a key dryer index of market value; therefore, any drying practice that can decrease the drying cost will be attractive for milling manufactures. Furthermore, since rice is a thermal sensitive bio-material and drying is always related to temperature, the quality of milled rice can easily and widely be affected during drying operation (Jittanit *et al*., 2010). Thus, conducting studies on dryer performance and also on potential drying technique which produce high quality rice within shorter time, low energy consumption and less overall cost should be seen as an important achievement leading the rice industries to their desirable operation.

Generally, the optimization of any dryer has two main goals which are energy cost minimization and drying capacity maximization. It should be noted that mostly increasing the drying capacity is preferred in any industrial drying operation; however, when drying capacity can surpass harvesting rate, cost minimization will be preferred first (Islam *et al*., 2004). In recent years, there have been various studies carried out to find optimum drying techniques for producing high quality rice (Prachayawarakron

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*et al*., 2005; Jittanit *et al*., 2010). Srzedinicki and Driscoll (2008) stated that high temperature drying in one of techniques to reduce energy requirements for drying. Ibrahim *et al*. (2013) and Tajaddodi (2012) studied drying performance of laboratory flat-bed dryer and their results revealed that using different air flow direction will significantly reduce energy consumption and also can increase the drying capacity and quality of rice when applied to flat-bed dryer. Furthermore, Sarker *et al*. (2013) and Ibrahim *et al*. (2014) investigated overall energy requisite and rice quality with industrial IBD in Malaysia; although their observations showed that there was considerable inconsistencies during actual drying operations in terms of drying temperature, air flow rate and drying time, which justify the need for in depth study of this popular dryer. Whilst it is important for rice industries to understand different aspects of these dryers in order to optimize their drying system to achieve higher drying efficiency, however information on important drying aspects of these common dryers such as energy usage and drying capacity are very scarce especially for IBDs. As such, the aims of this study were (1) to investigate the drying capacity of two popular drying practices (flat-bed and inclined-bed dryers) in order to help milling industries to improve their drying operations, and (2) to evaluate the energy consumption of the two dryers in drying rough rice at two industrial air drying temperatures, (3) to study head rice yield (HRY) percentage and whiteness as the indicators of milled rice quality with IBD and FBD.

## Materials and Methods

### *Fresh sample preparation procedure*

Freshly harvested paddy of variety “MR219”, the most common variety in Malaysia, was purchased from state of Pulau Pinang. Foreign material in rice bulk such as rice straw, stone, leaves was removed by laboratory air screen cleaner (Kamas Westrup LA-LS). Then cleaned rice was sealed in plastic sacks and stored in the refrigerator (5-8°C) to safe moisture level. At least 12 hours before each drying experiment, the rice was removed from refrigerator in order to equilibrate to room temperature. This step would eliminate any transient heat transfer effect on rough rice drying rates. Then initial MC of rice at the room temperature was measured by oven method before each drying operation.

### *Experimental procedures*

Laboratory scale flat-bed and inclined-bed dryers were designed and fabricated based on actual industrial IBD dryer design of 100 cm bed depth, but with drying bed cross-section of 0.5 m x 0.5 m and 110-140 Kg rice capacity. **Figure 1** represents the schematic of actual designed IBD dryer. It is noted that all section is the same for FBD except the drying chamber. Dryers contain perforated bed floor above the air plenum at bottom of drying chamber which is flat for FBD and with 40 angel for IBD. Several sampling holes were made at appropriate places on one side wall of dryer for paddy sample collection/ extraction from the drying chamber. Also on the wall opposite to the sampling wall of dryer, perforated PVC tubes (25cm length×1cm inner diameter) were placed inside the dryer at similar levels as the sampling holes. Then data logger’s thermocables was located inside these PVC tubes to monitor temperature during the drying process. The heater with 2000W capacity and blower with 750W capacity have been selected in this experiment. Furthermore, two units of kW.h meters were attached to the dryer for recording electrical energy use by heater and fan/ blower separately. Air velocity was measured hourly by thermal anemometer (TESCO 4235, Italy) with ± 0.03 m $s^{-1}$ accuracy. The Kett Single Kernel Moisture Tester model PQ-520 with an accuracy of ± 0.5 % was used to determine moisture content of grain samples.

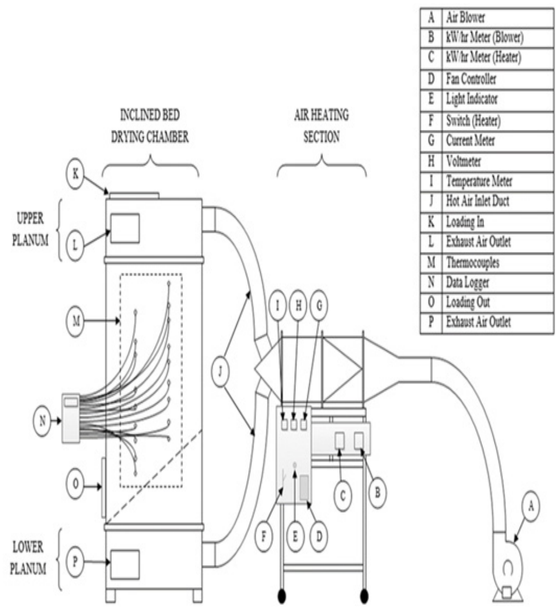

Figure 1. Schematic diagram of drying system.

Two different temperature levels 38-39°C and 42-43°C was applied in order to meet the rice drying parameters in Malaysian milling industries. (IRRI, 2012; Sarker *et al*., 2014). Also, the air flow rate equal to 43-44$m^3.min^{-1}.t^{-1}$ have been chosen for conventional drying with both IBD and FBD. It is noted that samples were taken hourly from different layers of the rough rice bed during the drying, until the top layer reached final moisture content of 13±0.5 (wb). At the end of drying experiments about 600gr of rice sample was collected from all designed holes of dryer's chamber. All samples were placed in sealed plastic bags and were kept in ambient environment until reaching room temperate. Finally, they were stored in refrigerator at a temperature of 5-8°C to be ready for quality tests.

*Drying capacity analysis*

Drying capacity is the most important economic factor for optimizing rice drying operation in milling industry because any improvement in drying capacity of a dryer will result in greater income for rice industries (Islam *et al*., 2004). The equation 1 was used to calculate drying capacity of IBD and flat-bed dryer.

$$\text{Capacity (ton m}^{-2}\text{ h}^{-1}) = \frac{\text{Weight of wet grain per unit area (ton m}^{-2})}{\text{Total drying time (h)}} \quad (1)$$

*Analysis of specific electrical energy consumption (SPEEC)*

Energy required for drying process is another main concern of the rice industries, which portray the efficiency of a dryer. The SPEEC (kW.h ton$^{-1}$) is total electrical energy consumed by all motors (blower and heater in this study) associated with a dryer for drying one tonne of moist paddy to final moisture content. High SPEEC value for a dryer signifies a weak performance of a dryer. Therefore, SPEEC was determined in current study for flat-bed and inclined-bed dryers, which was calculated by Equation 2 and Equation 3:

$$\text{SPEEC (kW.h ton}^{-1}) = \frac{E_T}{W} \quad (2)$$

Where $W$ is total weight of wet paddy to be dried in ton.

$$E_T = E_h + E_b \quad (3)$$

Where $E_T$ is the total electrical energy (kW.h) of dryer, $E_h$ is the electrical energy of heater and $E_b$ is the electrical energy consumed by blower.

*Head rice yield (HRY) analysis*

HRY is considered as a commercial indicator of rice physical quality and is measured as the mass percentage of head-rice (kernels that are at least three-fourth of the whole kernel length) after complete milling compared to the weight of original rough rice kernels (Wimberly, 1983; Champagne, 2004).

To determine HRY, equal amounts of dried paddy were collected from several locations of the bed through sampling holes and mixed together to represent the final dried rough rice sample. Then samples were placed in sealed plastic bags and stored in refrigerator for further quality test. Consequently 125 g. of dried and cleaned sample (triplicate) was dehusked with testing husker (THU-35A, Satake Engineering CO., LTD) and then the bran was removed from brown rice with Satake testing mill (TM 05C, Australia). Finally, head rice was separated from broken rice by Satake Test Grain Grader (TRG 05B, Australia). Then Head rice yield was calculated by the Equation 4:

$$\text{Head rice yield (\%)} = \frac{B}{A} \times 100 \quad (4)$$

Where B is whole kernel weight (g) and A is total weight of paddy rice.

*Whiteness degree analysis*

Whiteness degree was measured by with Satake Rice Milling Meter (MM1D, Australia) for three replications of samples after rice polishing. Whiteness is defined as a second indicator of rice milling quality.

*Statistical analysis*

The experiments were performed in a completely randomized design. Each drying method was conducted in triplicates and differences in HRY, drying capacity and energy consumption were tested for significance using analysis of variance techniques (ANOVA) and Multiple Ranges Duncan's test was used to differentiate between the mean using the statistical software of SPSS16.0 (SPSS, Inc., USA). A level of significance of $p < 0.05$ is used throughout the analysis.

## Results and Discussion

*Drying curves for FBD and IBD at two industrial drying temperatures*

Figure 2a, 2b, 3a and 3b show drying curves (moisture content versus drying time) for IBD and FBD at both levels of temperatures. As shown in figures, variation of moisture drop was exhibited during all drying process. Moisture removal is rapid in the first part of drying because moisture is removed from the husk first; while it takes longer time to remove deeper moistures from kernels. Therefore, as figures show at the last hours of drying, rate of drying is significantly lower than early hours of

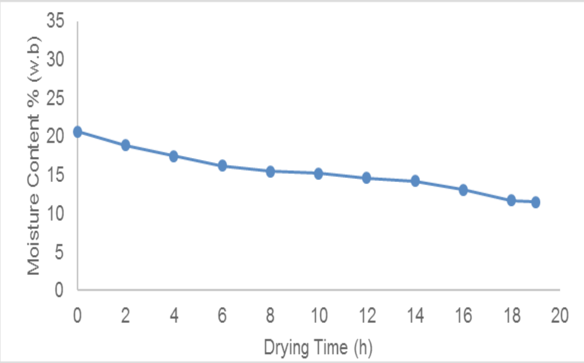


Figure 2a. Drying Curve of FBD at 38-39°C .

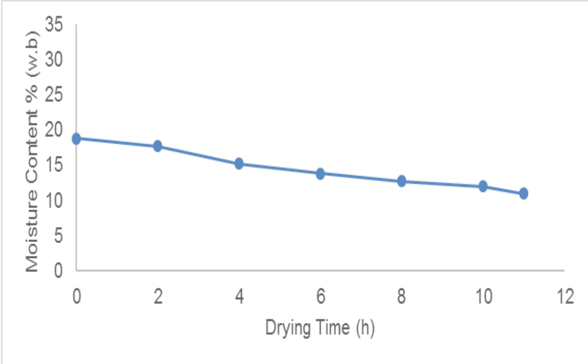


Figure 2b. Drying Curve of FBD at 42-43°C .

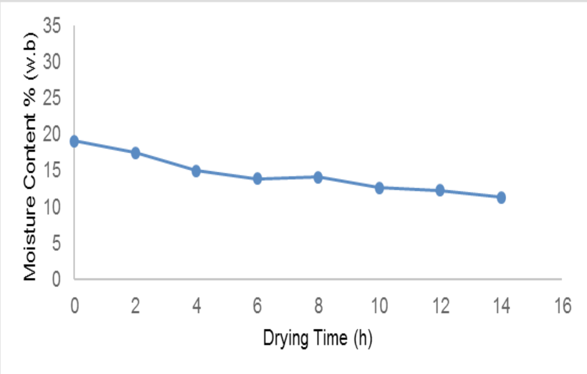


Figure 3a. Drying Curve of IBD at 38-39°C.

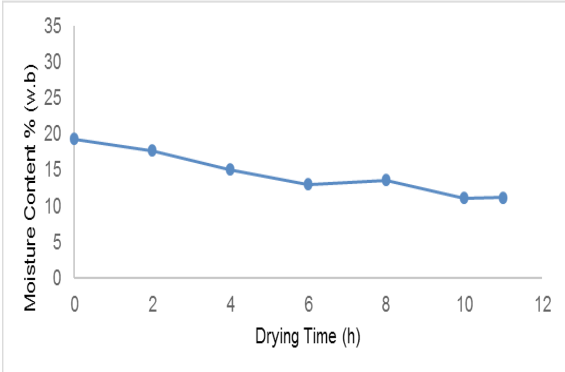


Figure 3b. Drying Curve of IBD at 42-43°C.

drying. Similar results have been reported for drying of wheat and rice grain by researchers (Sarker *et al*., 2014). Moreover, results revealed that rice dried with higher drying rate in IBD compared to FBD. This consequently resulted in significantly shorter drying time in IBD compare to FBD in both drying temperature as figures show.

Meanwhile looking at drying behaviour in Figures 3a and 3b reveal that moisture absorption/condensation as well as serious over dryness (MC below 12% w.b) have been found in IBD. Researches revealed that these undesirable phenomena adversely affect the milling quality and market value of milled rice. (Sarker *et al*., 2014).

*Drying capacity for FBD and IBD at two industrial drying temperatures*

Table 1 represents drying capacity and drying time for both dryers at two levels of temperatures. Results indicate that rice drying duration with IBD is significantly shorter than flat-bed drying for both levels of temperature. Furthermore, using IBD with higher temperature was found to decrease drying duration by 45% compared to IBD at 38-39°C. It can be observed that any decrease of drying time would result in improving drying capacity of dryers. IBD with 42-43°C had significantly higher drying capacity of 0.055 ton m$^{-2}$ h$^{-1}$ among all treatments ($p \leq 0.05$). While the lowest drying capacity is 0.028 ton m$^{-2}$ h$^{-1}$ due to flat-bed drying with 38-39°C. As shown in Table 1, drying of rice with inclined-bed dryer leads to increasing the drying capacity by 28.57% and 25% at 38-39°C and 42-43°C respectively.

Table 1. Drying capacity and drying time for FBD and IBD at 38-39°C and 42-43°C.

| Temperature (°C) | Drying capacity (ton m$^{-2}$ h$^{-1}$) | | Drying time (h) | |
|---|---|---|---|---|
| | FBD | IBD | FBD | IBD |
| 42-43 | 0.044$^{Ba}$ ± 0.004 | 0.055$^{Bb}$ ± 0.004 | 12.000$^{Aa}$ ± 1.000 | 10.000$^{Aa}$ ± 1.000 |
| 38-39 | 0.028$^{Aa}$ ± 0.001 | 0.036$^{Aa}$ ± 0.001 | 19.000$^{Bb}$ ± 0.000 | 14.500$^{Ba}$ ± 0.500 |

Mean values of three replicates are given with their standard deviation. Means with different capital letters within a column are significantly different at $p < 0.05$. Means with different small letters within a row are significantly different at $p < 0.05$.

Furthermore, Table 1 reveals that rice drying capacity by IBD and FBD at 42-43°C was significantly higher than at 38-39°C, 0.055 ton m$^{-2}$ h$^{-1}$ and 0.044 ton m$^{-2}$ h$^{-1}$ ton for higher temperature, 0.036 ton m$^{-2}$ h$^{-1}$ and 0.028 ton m$^{-2}$ h$^{-1}$ at lower temperature for IBD and FBD respectively. This is also related to significantly shorter drying time when higher temperature was applied to both dryers. Sarker *et al*. (2014) also stated that based on observation of actual inclined-bed drying, higher drying temperature in Simpang Empat complex in Malaysia resulted in more drying capacity compared to Bukit Besar complex with 38-39°C drying temperature; 0.03 ton $m^{-2}$ $h^{-1}$ and 0.021 ton $m^{-2}h^{-1}$ respectively. Consequently, drying capacity was improved by using IBD and also by increasing drying temperature up to 42-43°C. It must be noted that any improvement in drying capacity will increase the income of rice milling industries and also reduce the postharvest losses related to late drying.

*Specific electrical energy consumption for flat and inclined bed dryers*

Total specific electrical energy requisite calculated for both FBD and IBD is shown in Figure 4. The results revealed that the electrical energy requirement for operating the blower and heater in IBD ranged from 91.27 to 77.81 kW.h ton-1 at 42-43°C and 38-39°C, whilst it is doubled (above 200 kW.h ton-1) for FBD in both applied temperatures. We can conclude that the shorter drying duration by IBD significantly affects the overall energy requirement for drying of rice leading to huge cost saving for producing this popular grain. Moreover, Figure 4 illustrates that drying at higher temperature with both dryers required more electrical energy to remove moisture from rice grains, however it is significantly faster. Simulation results of Zare *et al*. (2006) also indicated that drying with higher air flow and air temperature consumed more specific thermal energy.

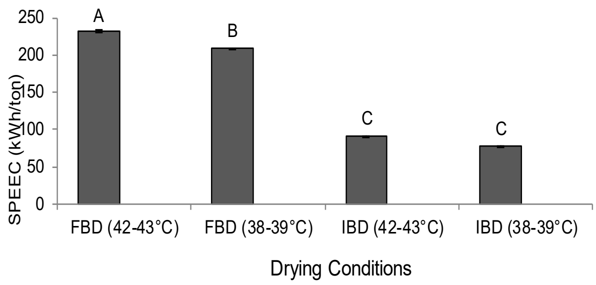


Figure 4. Specific electrical energy consumption of FBD and IBD at 38-39°C and 42-43°C. [Means followed by the different letters within a column are significantly different ($P < 0.05$)].

*Head rice yield*

Figure 5 shows the results of HRY percentage for samples in flat-bed and inclined-bed dryers for two applied temperatures. It can be observed that drying with FBD produced rice with higher head rice yield percentage compared to IBD at both temperature levels ($p \leq 0.05$). Nevertheless, the HRY percentage of dried rice of both dryer were in desirable commercial milling quality range of 40-60% (Siebenmorgen and Laning, 2014). The higher percentage of whole rice kernel from flat-bed dryer could be related to less moisture gradient in final products. Moisture gradient of paddy rice was about 4.5 % (wb) in inclined-bed dryer while that in flat-bed dryer was more uniform with final moisture gradient of almost 3 % (wb) only. High moisture gradient can promote moisture absorption among dried grain after drying which will lead to more fissuring of rice kernel (Abud-Archila *et al*., 2000; Cnossen *et al*., 2003; Sarker *et al*., 2014). Consequently, more breakage will occur for dried rice during and after milling. Furthermore, rice grains at the bottom layer of inclined-bed dryer became over dried faster, sometimes the final moisture content was almost 9 % (wb). Thus, over-drying is another reason which led to breakage of grain after milling and decreased the overall HRY percentage (Sarker *et al*., 2014).

Moreover, Figure 5, demonstrates that there are no significant differences between HRY for two drying temperatures in both flat-bed and inclined-bed dryer ($p > 0.05$). Thus, drying with higher temperature can be recommended for both dryers since it will produce milled rice with desirable commercial milling quality within shorter drying time.

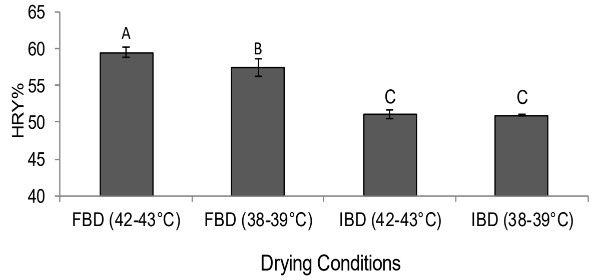


Figure 5. Head rice yield (%) from FBD and IBD at 38-39°C and 42-43°C. [Means followed by the different letters within a column are significantly different ($P < 0.05$)].

*Whiteness degree*

Figure 6 illustrates the whiteness degree for all treatments in this study. Results reveal that dried rice from IBD was found to have significantly greater whiteness degree of 37.60% and 41.675% at 38-39°C and 42-43°C respectively, while flat-bed drying produced milled rice with lower degree of whiteness. Moreover, it can be observed also that whiteness of milled rice was degraded when higher temperature was applied for rough rice drying in both IBD and flat-bed dryer. Bunyawanichakul *et al*. (2005) also found that whiteness degree of rice decreased with increasing grain drying temperatures and drying durations. The rice yellowing is mostly due to increase in physical and chemical transformations induced by heating, and also translocation of colour from the rice bran and husk to the endosperm (Dillahunty *et al*., 2001; Inprasit and Noomhorm, 2001).

Research by Sugunya *et al*. (2004) also obtained the same results which showed that drying rough rice at low temperatures (< 40°C) will result in the highest degree of rice whiteness. Although it must be noted that all milled rice in this study were still in acceptable range of whiteness trade quality of 40 % ± 5 (Sarker *et al*., 2014).

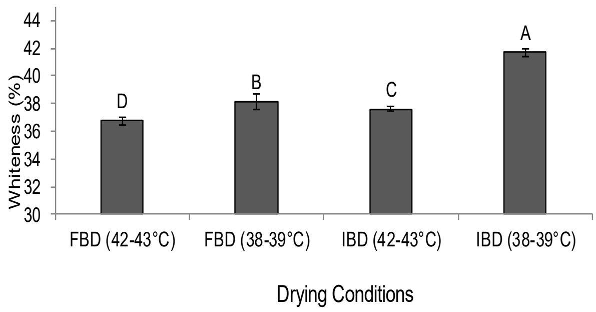


Figure 6. Whiteness degree (%) from FBD and IBD at 38-39°C and 42-43°C. [Means followed by the different letters within a column are significantly different (P < 0.05)].

## Conclusion

Flat-bed and inclined-bed drying performances in terms of drying duration, drying capacity, energy requisite and also rice milling quality are presented in this paper. We can conclude that drying with inclined-bed dryer consumed almost less than 90 kW.h ton$^{-1}$ power to dry rough rice from 20% moisture content to 13% (wb). Furthermore, drying capacity increased up to 25% for both levels of temperatures compared to flat-bed drying. In addition, drying with higher temperature (42-43°C) will remove moisture from rough rice faster which lead to significantly greater drying capacity compared to 38-39°C, up to 52.77% and 57.14% for IBD and flat-bed dryer respectively. Although all experiments in this study produced milled rice with acceptable trade quality index, but flat-bed dryer produced rice with more uniformity and less breakage.

Findings evidently proved that IBDs are quiet beneficial in reducing the huge cost of drying operation through increasing rice drying capacity as well as reducing the huge energy consumption compare to common FBD. Moreover, this result can guide rice milling industries to improve efficiency of their flat-bed and inclined-bed dryers by adjusting appropriate temperature. The findings should be beneficial for rice industries as well as dryer manufacturers which always willing to find the best drying practices in order to achieve maximum efficiency of drying operations to be successful in this competitive industry.

## Acknowledgements

The authors wish to express their sincere thanks to Padiberas Nasional Berhad (BERNAS), Malaysia, for the financial support and also a heartiest gratitude also goes to the Food Analysis Laboratory of UPM-BERNAS for facilitating the milling test.

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