

## BAU-STR dryer for rough rice drying at farmers and small trader's level in Bangladesh

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### ABSTRACT

Mechanical intervention in each stage of post-harvest rice processing is essential to reduce cost and minimize post-harvest loss. Drying is an important post-harvest operation for long term storage, maintaining rice quality and reducing postharvest loss. BAU-STR was tested at the Department of Farm Power & Machinery, Bangladesh Agricultural University, Mymensingh during Boro and Aman 2015 harvesting seasons to understand the effectiveness and potential of using at farmers' level as an alternative to sun drying. The temperature profile of the dryer proved that hot air temperature uniformly distributed throughout the dryer, and also the rough rice dried uniformly and reached at desired level of moisture content within 4 to 5 hours. The moisture removal rate was 2.4 and 2.0 %hr<sup>-1</sup> during Boro and Aman season, respectively. The drying efficiency was found 55.3 and 48.6% during Boro and Aman season, respectively. The milling recovery was found more in BAU-STR (73.0±1.3%) compared to the sundried rough rice sample. Head rice yield was found 66.9% for BAU-STR and 63.9% for the sundry method. The germination rate was above 80% in both seasons for BAU-STR and sundried method. The drying cost of paddy was found Tk. 0.87 kg<sup>-1</sup> and Tk. 0.74<sup>-1</sup> for diesel and electricity operated dryer, respectively. In terms, benefit-cost ratio and payback period BAU-STR dryer are recommended for drying of rough rice at the farm level. The dryer could be used successfully as cost saving and user friendly technology to eliminate drying problems in the rural area of Bangladesh.

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### I. Introduction

Bangladesh is an agriculture primarily based country during which the majority of the individuals earn their livelihoods from farming and agriculture-related activities. Rice is that the main staple crop of Bangladesh accounting for seventy-six of total cropped space and ninety fifth of cereals production. Bangladesh is currently producing about fifty-two million tons of rough rice (FAO, 2015) to feed concerning 161 million people (UN, 2015). Post-harvest loss reduction will play an important role in national food security in Bangladesh furthermore within the world. The post-harvest system consists of a series of operations that cover the period from harvesting operation through to consumption. An

economical post-harvest system aims to attenuate losses and maintain the standard of the crop until it reaches the ultimate consumer. Food security and financial gain increases when the amounts of food losses are decreased. The implementation of an economical post-harvest system in any community should give evenhanded profit to all or any those concerned within the system in terms of a socio-economic view (Grolleaud, 2001). Drying is the method that reduces grain moisture to grade wherever it's safe for storage and milling operation. It's the foremost vital operation once gathering a rice crop. The percentage of moisture content in rice grain contains in the rage of 20-25% at the harvesting time. Rough rice includes a high respiration rate and is prone to attacks by micro-organisms, insects and alternative pests. The quality of grain with high grain moisture content deteriorated for there's natural respiration within the grain. Wet paddy promotes the event of insects and molds that are harmful to the grain. High moisture in grain additionally lowers the germination rate of rice. Therefore, drying of rough rice is vital to stop insect infestation and quality deterioration of rough rice grain and seed. Any delays in drying, incomplete drying, or uneven drying can end in qualitative and quantitative losses.

Drying of agricultural products in Bangladesh is often chosen by traditional open sun drying techniques. It's a standard observe wherever rough rice is exposed to sun and wind within the yard or field. The radiation heats the grains furthermore because the encompassing air and so will increase the speed of water evaporating from the grains. However, there's no management on the drying rate. Open sun drying may be a well-known food preservation technique. The drying rate is extremely slow and it typically results in poor interior quality to dependence of climate. Global climate change makes weather unpredictable and surprising precipitation may result in delayed drying, re-wetted grains and quality deterioration. This ends up in harm that cut back the standard and value of rough rice. Drying of rough rice may be a major drawback in Bangladesh due to rain and gloomy weather in Boro (April – June) and short day and foggy weather in Aman (October – December) season. For reducing drying losses and increasing the quality of storage of rough rice, it's necessary to adapt suitable drying technology at farmers and trader's level in Bangladesh. In this regard, the BAU-STR dryer would be an effective drying technology alternative to traditional open sun drying techniques for rough rice. Therefore, the objective of the study was to analyze technical and economic performance of BAU-STR dryer compared to open sun drying technique throughout Boro and Aman seasons in Bangladesh.

## II. Materials and Methods

### Experimental site

The performance evaluation of BAU-STR dryer was conducted at the workshop of Department of Farm Power and Machinery, Bangladesh Agricultural University (BAU), Mymensingh during Boro (April to June, 2015) and Aman (October to December, 2015) harvesting season to understand the effectiveness and potential of using at farmers' level as an alternative to sun drying.

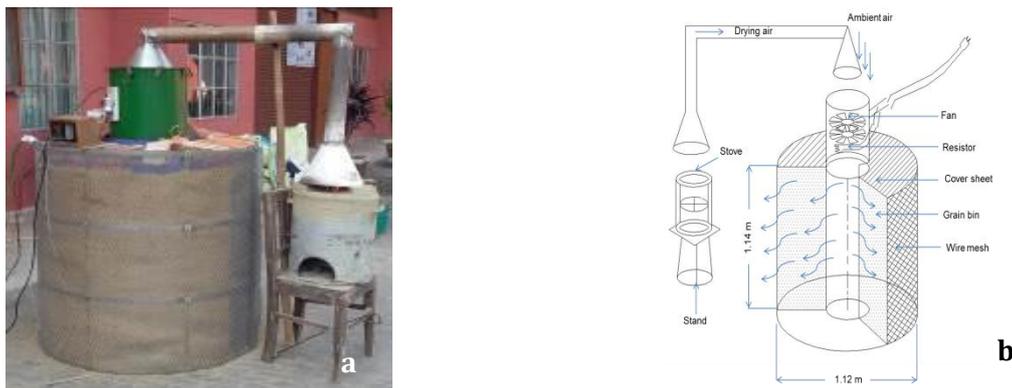
### Description of BAU-STR dryer

A photographic and schematic view of the dryer is shown in [Figure 01](#). This dryer consists of 2 perforated homocentric cylinders with grains within the circular area. Air is passed from the inner cylinder through walls with bottom and upper closed to dry the grains within the circular area. An axial flow blower is employed to suck the burning air from the stove (Chula) through hot air pipe and force the air radially through perforated inner cage. The dimension (0.40 m diameter x 1.14 m height) of inner bin was mounted and outer bin was adjusted in step with sample size. The blower (0.40 m x 0.40 m) was placed to suck hot air from heat supply and spending through the inner bin. A stove (0.36 m diameter x 0.40 m length) was used as a heat supply. Domestically accessible rice husk block is employed as fuel in an exceedingly moveable domestically created stove.

### Experimental Set-up of the dryer

Inner bin of dryer was placed in the level space of Farm Power and Machinery workshop, BAU at first. The outer grain bin was fixed around the inner bin as per required volume of grain. Then eight *K type* thermocouples were set up in different points of the dryer to get the temperature reading during drying operation in real time ([Figure 02](#)). The grains were delivered within the circular area of the dryer in such a way so that equal quantity of rough rice contained altogether sides. The axial flow blower was placed on the top of the inner bin of the dryer and a hard polythene sheet was placed to protect hot air leaking from the dryer. A stove was placed in one aspect of the grain bin and firing was done

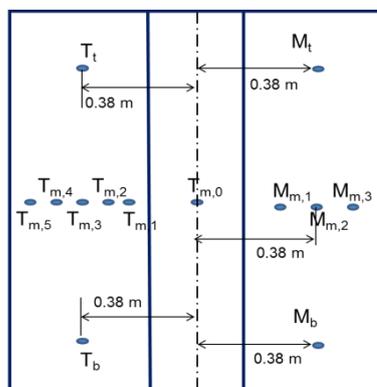
exploitation rice husk block. Then the hot air supply channel was fixed with the help of bamboo stand which was tied by wire.



**Figure 01. BAU-STR dryer (a) photographic view and (b) schematic view**

To determine the spatial distribution of temperature eight sensors were used in vertical and horizontal axis namely  $T_{m1}$ ,  $T_{m2}$ ,  $T_{m3}$ ,  $T_{m4}$ ,  $T_{m5}$ ,  $T_t$ ,  $T_b$ , and  $T_{m0}$ , respectively (Figure 02). The sensor  $T_{m0}$  was set up in the center point of inner bin and other seven sensors were set up at the distance of 0.26, 0.32, 0.38, 0.44 and 0.50 m from the center line of inner bin of the dryer in Boro and Aman season. The top ( $T_t$ ) and bottom ( $T_b$ ) sensor were set up middle and 0.28 m apart from upper and bottom surfaces of the grain bin. The thermocouples were connected to data logger (Model-FLUKE 2635A Hydra series Data bucket) which was attached with a computer to get continuous temperature reading at 10 second interval during the drying operation. The air velocity through the blower was measured by using a digital anemometer (Model- Testo 416, accuracy:  $(\pm 0.2 \text{ m/s} + 1.5\% \text{ of mv})$ ), at the suction and delivery point of the blower. The ambient air temperature and relative humidity were measured by using a data logger (Model-TRH- 1000, temperature accuracy:  $\pm 0.6^\circ\text{C}$  @  $25^\circ\text{C}$ ,  $\pm 2^\circ\text{C}$  from  $-40^\circ\text{C}$  to  $70^\circ\text{C}$  and  $\pm 4\%$  RH between 20 to 80% RH).

The moisture content was measured in three out of five locations named  $M_1$ ,  $M_2$  and  $M_3$  maintaining 0.29, 0.38 and 0.47 m distance from the center line of inner bin during drying operation in Boro season. Another two out of five locations top ( $M_t$ ) and bottom ( $M_b$ ) were fixed at middle and 0.28 m apart from the upper and bottom surfaces of the grain bin. The moisture content of rough rice was measured using a digital moisture meter (Model-RiceterL, accuracy:  $\pm 0.2\%$  105C, measurement range 11-30% for rough rice) after collection of rough rice sample with the help of steel made sample collector. Data were collected every half an hour interval. The collected sample of rough rice was also used to measure moisture content in the oven dry method ( $105^\circ\text{C}$  for 24 hrs). The performance analysis of BAU-STR dryer in terms of drying rate and drying efficiency was done to adopt in farmer's and traders' level for perfect drying and safe storage of rough rice in Bangladesh. Three batches of drying operation were performed in a day. One person was required to deliver fuel (rice husk briquette) every 4-5 minutes interval and another person's needed for loading and unloading of rough rice.



**Figure 02. Thermocouple arrangement of dryer (T=temperature sensor, M=moisture sensor, t=top, m=middle and b=bottom position)**

### Data analysis

**Moisture content of rough rice:** The moisture content was measured from five locations of grain bin in BAU-STR dryer. The amount of water in rough rice is represented by the moisture content of the grain. Initially, moisture detached from grain interior to the grain surface then moisture vaporized from the surface to close air. Moisture content is usually expressed in percentage. The quantity of moisture removed ( $M_w$ ) from rough rice can be found out using the relationship (Forson, 2007) as Eq. (1)

$$M_w = \frac{M_p(M_i - M_f)}{(100 - M_f)} \quad (1)$$

Where,

$M_w$  = the mass of water removed from wet rough rice (kg)

$M_p$  = the initial mass of the rough rice to be dried (kg)

$M_i$  = the initial moisture content of rough rice on wet basis decimal

$M_f$  = the final moisture content of rough rice on wet basis decimal

**Drying rate:** Drying rate of rough rice sample varies with the initial moisture content and drying air temperature. Drying rate was measured using following Eq. (2).

$$DR = \frac{(M_i - M_f)}{DT} \quad (2)$$

Where,

DR = Drying rate, percentage of moisture content per hr

$M_i$  = Percentage of initial moisture content of rough rice on wet basis

$M_f$  = Percentage of final moisture content of rough rice on wet basis

DT = Drying time, hr

**Drying efficiency:** The performance of dryer was determined using drying efficiency equation as well the total energy supplied to the drying space and the total energy utilized by the drying space to remove accepted moisture content. The energy supplied by the stove and the total energy output was measured during drying operation. The drying efficiency of dryer is defined as the ratio of energy used to evaporate the moisture from the rough rice to the energy input to the dryer (Eq. 3).

$$\eta = \frac{W L_g}{E_t} \quad (3)$$

Where,

W = the weight of water evaporated, kg

$L_g$  = the latent heat of evaporation of water, MJkg<sup>-1</sup>

$E_t$  = total energy consumption (input), MJ

**Total energy consumption:** The total energy consumption of dryer was measured from the sum of electrical power required by the fan and the calorific energy required by the burner in BAU-STR dryer. The total energy consumption of BAU-STR dryer was calculated with the Eq. (4)

$$E_t = (MC + E_e) \quad (4)$$

Where,

$E_t$  = Energy consumption, MJ

M = Amount of fuel used, kg

C = Net calorific value of fuel, MJ kg<sup>-1</sup>

$E_e$  = Electrical energy used, MJ

Considered the net calorific value of fuel (briquette) = 14.2 MJ kg<sup>-1</sup>

### Seed germination rate

Seed grain needs a high proportion of individual grains with germination properties. The viability of grain is directly coupled to the temperature earned by grains throughout drying (Kreyger, 1972). Higher grain temperature over 43°C for drying rough rice seed will lose seed vigor. At first, purity test was conducted to get pure seed, other seed and inert matter from each sample. 400 (four hundred)

numbers seed were taken for germination test. Germination test was conducted in plastic box following International Seed Testing Rules (ISTA, 1999) using sand media. Four hundred seeds were taken randomly from each of the samples. Plastic containers were used to hold the media (sand) for the test. The sterile sand was used at field capacity. The media (sand) was placed at the bottom of each container maintaining about 60 mm thicknesses. One hundred seed was placed in each container at a uniform distance. There were four replications for each of the testing rough rice samples. The container filled with seeds was exposed to the air under the laboratory conditions of temperature (25-30°C) and relative humidity (70-80%). The seedlings were observed for growth measurement after 5 and 15 days interval. The normal seedlings, abnormal seedlings, sprouted seeds and dead seeds were counted in each observation. Germination rate was measured using Eq. (5)

$$\% \text{ of germination} = \frac{\text{Number of normal seedling} \times 100}{\text{Total number of seeds}} \quad (5)$$

### Rice quality assessment

Milling quality tests were performed by shelling 100 gm rough rice from each dried sample to determine head rice yield with five replications. At first, dried and cleaned rough rice were dehusked with a laboratory rubber roller rice huller (Model- JLGJ2.5 test rough rice husker, capacity(g/time): 50-500, Rate of husking (%):>=99.9, Power(kw): 0.37, dimension size (Lx W x H, mm): 710x360x690, Zhejiang Zhancheng Machinery Co., Ltd.), then the bran was removed with a polisher (Zhejiang, China (Mainland) Brand Name: HUANSHA, Model Number: JNMS 15, Type: Grain Processing Equipment, Product name: Iron roll rice whitener, Processing: Whitener) running for four minutes for each amount of dehusked brown rice samples. Head rice yield was defined as the ratio of head rice mass to original cleaned dried rough rice mass. The percentage of milling recovery was calculated as the weight of total milled rice (including head rice and broken rice) divided by the weight of dried rough rice sample and multiplied by 100. Whiteness, color and shape information of milled rice were measured using SATAKE GRAIN SCANNER (Model- RSQI10A). Shape and colour analysis of milled rice were calculated by weight ratio.

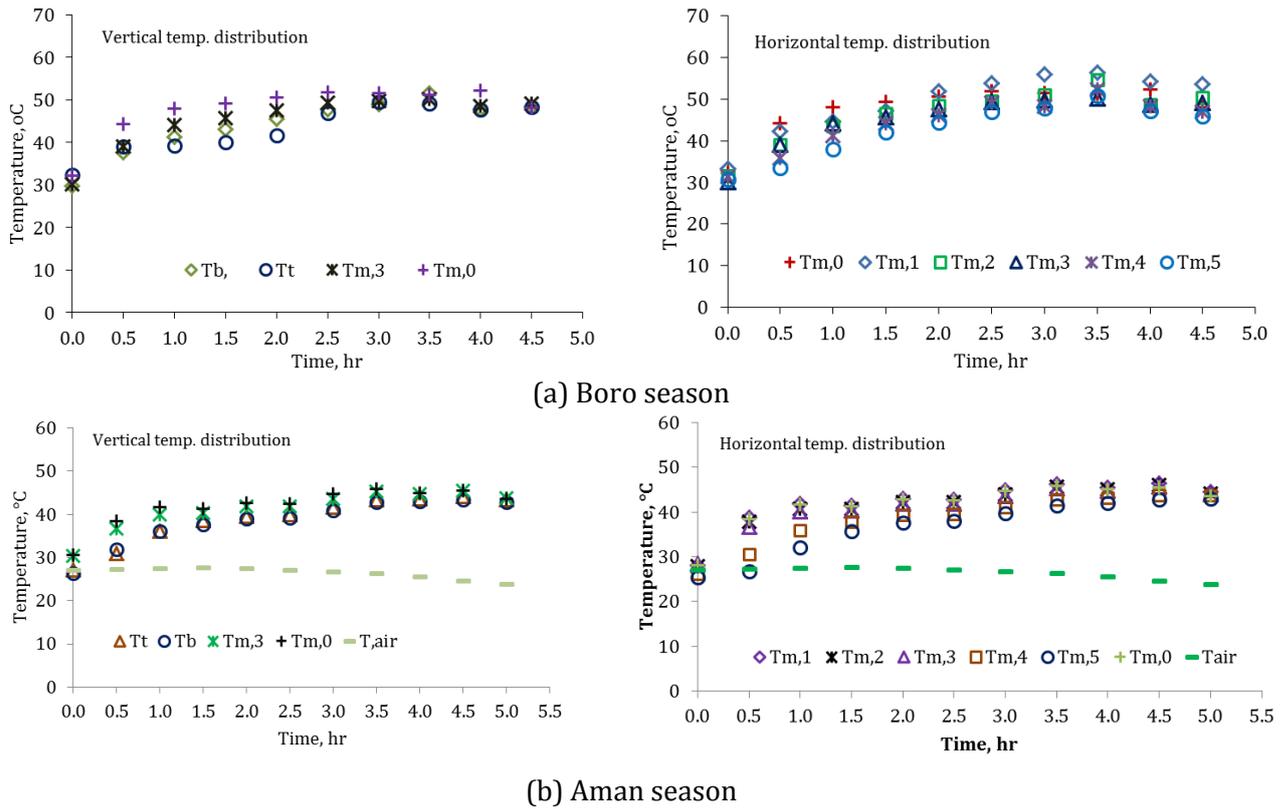
### Financial cost calculation procedure

Financial cost calculation was done for BAU-STR dryer considering fixed cost and variable cost. Fixed costs are independent of use. Fixed costs include depreciation, interest on the machinery investment, taxes, insurance and shelter. On the other hand, operating cost of a dryer is reflected by the variable cost such as fuel, lubrication, daily service, power and labor used by the power source and the dryer. Benefit-cost ratio was also measured which refers the ratio of benefits to costs (expressed either in present or annual worth). The payback refers to the period within which the costs of investment can be covered by revenues. In other words, it is the length of time required for the stream of cash proceeds produced by an investment to equal the initial expenditure incurred.

## III. Results and Discussion

### Temperature profile

The vertical and horizontal drying air temperature variations were observed in Boro and Aman season during drying process of BAU-STR dryer (Figure 03). The figure shows that temperature was around 30°C at the starting point of the drying in all locations in all cases and then increased above 40°C in every location after one hour. The grain temperature increased rapidly initially and then increasing rate was nearly stable till the completion of drying operation. Similar trend of temperature profile was observed for vertical and horizontal temperature distribution. There were little differences in temperature among the vertical locations (Figure 03) as because  $T_t$ (top),  $T_{m,3}$  (middle) and  $T_b$ (bottom) sensors locations were at the equal distance from the center line of the inner bin from where burning air was flowing into grain stack. However, temperature was varied primarily among the parallel locations because distances from the center line of the inner bin were not the same. The drying air temperature at  $T_{m,5}$  was much lower than temperature at  $T_{m,1}$  after half an hour of starting drying operation (Figure 03). After two to three hours, temperature distribution of all parallel sensors locations became almost equal.

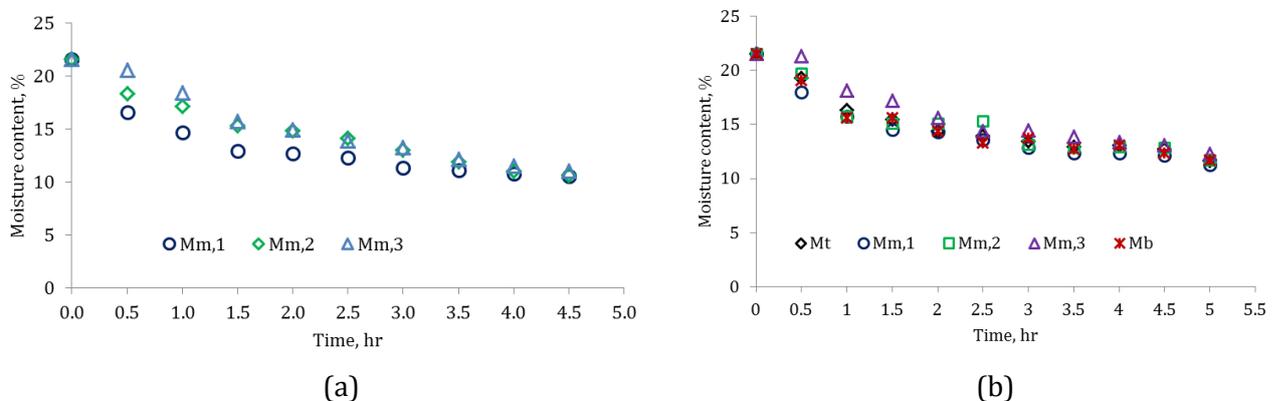


**Figure 03. Vertical and horizontal drying air temperature variations at different locations during (a) Boro and (b) Aman season (T-temperature sensor, t-top, m-middle, b-bottom, o-outer point of dryer)**

It proves that hot air temperature uniformly distributed all over the drying section. Similar results have been reported for rough rice seed drying in the hybrid dryer (Hossain et al., 2012). However, variations of the hot air temperature over time rely upon the potency of steady fuel supply for generating same hot air temperature that must be taken care of.

**Moisture profile**

The typical drying curves for Boro and Aman season at middle layer of dryer are shown in Figure 04. The general trend, moisture content level of grain was reduced with the drying time. The moisture removal rate decreases continuously with drying time (Figure 04).



**Figure 04. Change of moisture content at different distance at middle layer from the center of the dryer during drying operation during (a) Boro and (b) Aman season (M-moisture, m-middle, t-top and b-bottom)**

The drying temperature was more in Boro season compared to Aman season. The resultant drying time reduced in Boro season compared to Aman season. Similar results are reported on drying of Thai Hom Mali rough rice (Dungporn et al., 2012), parboiled wheat (Kahyaoglu et al., 2012) and garlic slices

(Madamba et al., 1996). The grain was dried uniformly and reached same and desired level of moisture content (less than 12%) in four to five hours.

### Performance of dryer

The BAU-STR dryer was evaluated in terms of drying capacity, moisture removal rate, drying efficiency, and physical quality of dried rough rice. The rough rice was dried from 21.6% to 10.7% and 21.5% to 11.7% in Boro and Aman season, respectively (Table 01). The higher drying air temperature with high ambient air temperature and lower relative humidity directly affected the drying time. The resulted drying time of Boro season is found less than that of Aman season for same moisture content. The moisture removal rate and drying efficiency were found more in Boro compared to Aman season due to high drying temperature and energy use efficiency in BAU-STR dryer (Table 01).

**Table 01. Performance of dryer in Boro and Aman season**

Season	Hot air temp. °C mean±std	Initial moisture content, %	Final moisture content, %	Drying time, hr	Drying rate, % mc hr <sup>-1</sup>	Drying capacity, kg batch <sup>-1</sup>	Drying efficiency, %
Boro	45.8±2.9	21.6	10.7	4.5	2.4	500	55.3
Aman	40.2±1.9	21.5	11.7	5.0	2.0	500	48.6

### Germination rate of dried sample

Seed germination test was conducted after drying in BAU-STR dryer with sun drying method on the floor. It is observed that the average germination rate (normal seedlings) of BAU-STR and sun dried rough rice is 86 and 84%, respectively (Table 02). The germination rate of BAU-STR dried rough rice is satisfactory in both seasons. In normal weather, there is no considerable difference in germination rate between BAU-STR dried rough rice and sun dried rough rice sample. But in adverse weather especially in boro season germination rate will be decreased lack of sunny day. The germination rate (>85%) of selected rice varieties is satisfactory in terms of normal and abnormal seedlings. MacDonald, (1997) suggested that a drying air temperature of 43°C is accepted as the safe upper limit for drying seeds without damage which is closely similar to study temperature.

**Table 02. Germination rate of dried rough rice sample**

Method	Sprouted seed	Dead seed	Abnormal seedlings	Normal seedlings
BAU-STR dried sample	4	4	6	86
	6	3	5	86
Sun dried sample	5	3	8	84
	4	4	4	88

### Rice quality assessment of milled rice

Head rice yield of sample depends on drying air temperature, fissuring rigidity, post drying duration and temperature as well as grain thickness (Jindal and Siebenmorgen, 1994; Siebenmorgen et al., 2005; Wiset et al., 2001). Milling recovery of dried rough rice sample in BAU-STR and sun-dried samples are shown in Table 03. There is no significant variation between the experimental value and BRRI measured value of milling recovery. Rice quality in terms of whole grain, broken grain, damaged grain and hardness is satisfactory in BAU-STR and open sun-dried rough rice sample.

Shape and colour characteristics of milled rice in BAU-STR and open sun-dried sample are shown in Table 04 and Table 05. Shape and colour characteristics of milled rice were analyzed using standard calibration curve. The average value of L\*, a\* and b\* were recorded after milling process of BAU-STR sun dried rough rice. The drying temperature has highly significant effect on L\*, a\* and b\* values of rough rice. The changing of L\*, a\* and b\* values at high temperature was increased with increasing drying temperature, the husk surface of rough rice became darker and the differences of the sample colour increased during drying operation. The L\* value of BAU-STR dried rough rice was lower than open sun-dried sample of rough rice. The a\* and b\* values of BAU-STR dried rough rice were more than that of sundried rough rice sample. This result is similar to that of (Golipour et al., 2015). Hardness is another important physical property that maximizes the milling yield of dried rough rice. The observed

value of BAU-STR dried sample was the highest degree of hardness followed by sundried sample, respectively. The variation in hardness of rice is due to the compact arrangement of starch granules. The results are similar to [Mir et al. \(2013\)](#). So it is evident in terms of milling yield BAU-STR dryer is better than open sun drying method.

**Table 03. Milling recovery of dried rough rice**

Method	Milling recovery, %	Head rice yield, %	Broken rice, %	Hardness, N
BAU-STR dried sample	73.0±1.3	66.9	6.1	29.5
Sun dried sample	72.3±1.3	63.9	8.4	27.3

**Table 04. Shape characteristics of milled rice**

Parameters	BAU-STR dried sample	Sun dried sample
Accepts, (%)	87.6	78.3
Defects, (%)	12.4	21.7
Total no. of rice	853	730
Whole kernel, (%)	89.5	87.1
Unbroken rice, (%)	91.7	88.4
Broken rice, (%)	8.3	11.6
Area	7.5	8.0
Width	1.8	1.9
Length	5.3	5.5
Aspect ratio	2.9	2.9
Perimeter	12.0	12.4

**Table 05. Colour characteristics of milled rice**

Parameters	BAU-STR dried sample	Sun dried sample
L*	60.0	61.9
a*	4.2	4.1
b*	4.9	3.0
Whiteness	35.5	40.3
Immature kernels	0.0	0.0
Red kernels	1.2	0.9
Yellow kernels	1.4	0.2
Chalky kernels	2.1	9.4
Damaged kernels	1.5	0.5
Glutinous rice	0.0	0.0
Red	141.8	144.2
Green	134.9	139.0
Blue	124.8	131.3
Outline distortion	0.0	0.0
Degree of Inflection	0.1	0.1
Chalky ratio	0.1	0.1
Immature part	0.9	1.9

### Financial analysis

Economic analysis for BAU-STR dried rough rice sample is given in [Table 06](#). The purchase price of BAU-STR (diesel generator operated) and BAU-STR (electricity operated) dryer was BDT 60000 and BDT 40000 with economic service life 10 years. The operating cost of rough rice drying was found Tk. 0.87 per kg (diesel generator operator) and Tk. 0.74 per kg (electricity operated) in BAU-STR dryer, respectively whereas in traditional sun drying methods the operating cost was Tk.1.0 per kg. The payback period of BAU-STR dryer was found 0.28 and 0.17 years. It is evident from the economic analysis that the BAU-STR dryer is economically profitable. It would be more economical if the dryer could be used for other crops such as maize and rough rice seeds.

**Table 06. Financial analysis of different types of dryer**

Description	BAU-STR (Diesel generator operated)	BAU-STR (Electricity operated)
Operating cost, Tk. kg <sup>-1</sup>	0.87	0.74
Sun drying cost, Tk. kg <sup>-1</sup>	1.0	1.0
Gross benefit of the dryer, Tk. yr <sup>-1</sup>	223125	236455
B/C ratio	1.91	2.35
Net present value, Tk.	34174	43763
Payback period, yr	0.28	0.17

#### IV. Conclusions

Spatial distribution of hot air temperature and moisture content reduction rate of grain indicated that blower equally delivers the burning air through the grain stack. Milling yield was found higher in BAU-STR dried sample than that of open sun drying samples due to the highest degree of hardness. The germination rate of the dried sample was found above 80%. BAU-STR dryer was cheap and profitable drying method compared to the traditional sun drying method. Mechanical intervention like BAU-STR dryer would be an effective drying technology alternative to traditional sun drying in terms of drying rate and drying efficiency. It could be used at small holder farmers and small trader's level and can be used anytime, especially in the rainy season and cloudy weather to reduce post-harvest loss and maintain the quality of rough rice.

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