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Experimental investigation of solar bubble dryer for rough rice drying in Bangladesh

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ABSTRACT

Drying is important for long term storage, maintaining quality and reducing drying loss of rough rice. Solar bubble (SB) dryer 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 potentiality of the dryer at farmers' level as an alternative to open sun drying. SB experiment shows that the temperature was distributed uniformly throughout the dryer which was very much dependent on solar radiation. The hourly moisture removal rate was 0.6 and 0.4 % during Boro and Aman season, respectively. The drying efficiency was found 25.2 and 12.3% during Boro and Aman season, respectively. The milling recovery was found 71.5±1.0% for SB dryer and 72.3±1.3% for sundried rough rice. Head rice yield of rough rice was lower (53.6%) in SB dried product compared to sun drying method (63.9%). The germination rate was more than 80% in both seasons for SB dryer and sundried method, respectively. The operating cost of drying was observed Tk. 1.48 per kg. The SB dryer can be applicable for drying rough rice at farm level in Bangladesh.

Keywords: *Solar bubble dryer, Drying rate, Drying efficiency and Rough rice*

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I. Introduction

Bangladesh is an agricultural country where agriculture donates 16.33 % of the GDP to the Bangladesh economy. About 61 % of the total agricultural area and 75 % of the cropped area is covered by rice in Bangladesh. Rice farming is the main source of income and employment of the agricultural people. The average yield of rice under irrigation conditions is 2.81 tons per ha which are low compared to the average yields obtained in other countries with similar agro-climatic conditions (Majumder et al., 2016). Post-harvest loss reduction can play a vital role in national food security in Bangladesh as well

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as in the world. The post-harvest system consists of a set of operations that cover the period from harvest through to consumption. An effective post-harvest process aims to minimize post-harvest losses and maintain the quality of the crop until it reaches the consumer. Food security and income increase with the reduction of food losses. From a socio-economic point of view, the implementation of an efficient post-harvest system in any community must provide equitable benefit to all those involved in the system (Grolleaud, 2001). Post-harvest loss occurs at every stage in rice production supply chains like harvesting, threshing and cleaning, drying, storage, processing/milling, marketing and consumer level. Dying is the process that reduces the grain moisture content to a level where it's safe for storage and milling. It's the foremost critical operation in post-harvest process after harvesting a rice crop. At harvest, rough rice grain contains moisture content between 20 to 25% (wb). Rough rice features a high respiration rate and is vulnerable to attacks by micro-organisms, insects and other pests. At high grain moisture contents, there's natural respiration within the grain that causes deterioration of the rice. High moisture 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, the drying of rice is critical to stop insect infestation and quality deterioration of rice grain and seed. Harvested grain with high moisture content must be dried within 24 hours to 12% for safe storage and germination (IRRI, 2013).

The drying of agricultural products in Bangladesh is normally carried out by the traditional sun drying method. It is a traditional practice where rough rice is exposed to sun and wind in the yard or field. The radiation heats the grains also because of the surrounding air and thus increases the speed of water evaporating from the grains. However, there is no control over the drying rate. Open sun drying may be a well-known food preservation technique and offers an inexpensive and straight forward method of drying. The drying rate is very slow and often results in poor interior quality due to dependence on weather conditions. Climate change makes weather very unpredictable and unexpected rainfall may result in delayed drying, re-wetted grains and quality deterioration. This leads to damage that reduces the quality and market value of rough rice. Improper or delayed drying leads to a loss in grain quality, in addition to the estimated 14% loss from cutting through storage (Bala et al., 2010). For reducing post-harvest losses especially in drying operation and increasing quality of storage rough rice, it's necessary to adapt low cost rough rice drying technology at farmers and little trader's level in Bangladesh. Solar bubble (SB) dryer is used in other developing countries. It would be effective rough rice drying technology alternative to traditional sun drying. Therefore, the objective of the research was to investigate the technical and financial performance of the solar bubble (SB) dryer in drying rough rice.

II. Materials and Methods

Experimental site

The performance evaluation of SB 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 in order to understand the effectiveness and potentiality of using dryer at farmers' level as an alternative to sun drying.

Description of solar bubble dryer

The Solar Bubble (SB) dryer is the new drying technology with a drying floor, solar panel and 12 volt battery (Figure 01). The SB dryer is mobile and completely independent from fuel or the power grid. It comes in different sizes and 1t batch capacity. The SB dryer uses energy from the sun in two ways. First the drying tunnel may be a solar collector to convert the energy contained among the sun rays getting into the clear prime of the drying tunnel to heat, that magnified the temperature of the drying air for quicker drying. Second it is equipped with a photovoltaic system consisting of a solar array, a deep cycle rechargeable battery and a controller to get electricity that drives a little blower to maneuver hot air through the drying tunnel, inflate the tunnel, and take away the water evaporated from the grains placed inside the tunnel. A simple roller dragged on ropes hooked up to the ends beneath the tunnel is employed for admixture the grains while not the necessity to open the tunnel. A rake for internal mixing is also available. Moisture content measuring meter, temperature reader, humidity measuring meter, solarimeter and air flow meter are used as additional accessories for drying operation.

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The SB dryer improves the normal sun drying process, during which farmers spread the paddy within the open under the sun, by protecting it from animals, insects, contamination and rain. The drying tunnel also provides a buffer for the temperature and protects the grains from overheating, because it is common during sun drying at noon. It eliminates the re-wetting of grains during rain and losses due to animals, spillage and cars running over the grains if they are spread on roads. Depending on the weather the drying rate during daytime is 0.5-1% per hour. Drying time depends on the weather and therefore the initial moisture content of the grains. Skin-dry grains are often dried to 14% moisture content within a sunny day. Wetter grains and through cloudy days the drying might take two or three days. During rain and in the dark when the ratio of the air is high, the drying process stops, but by keeping the tunnel inflated the grains are often safely kept inside the dryer, while they have to be collected and bagged within the traditional sun drying.

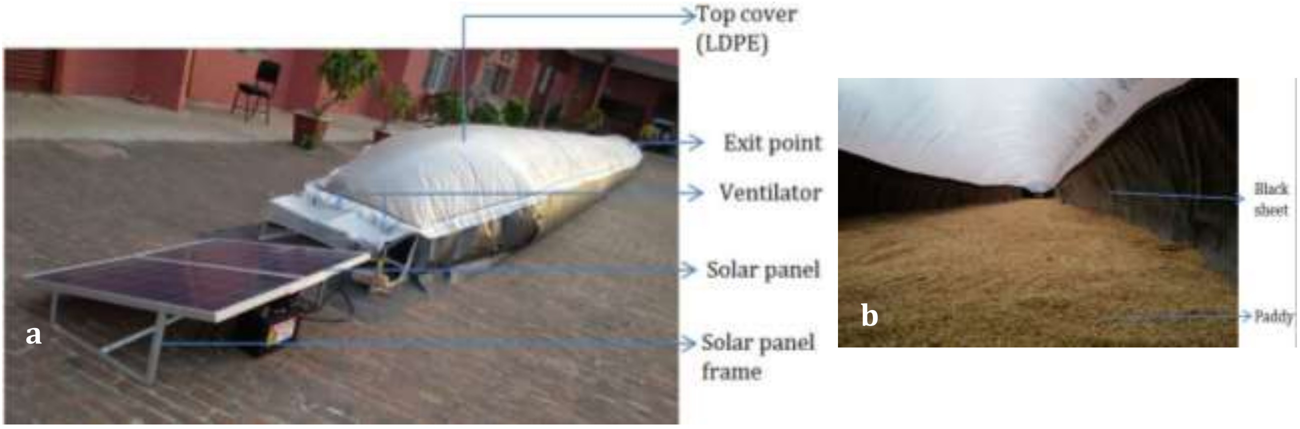

Figure 01. SB dryer (a) top view and (b)inside view

Experimental Set-up of the SB dryer

Solar Bubble (SB) dryer was spread out on the floor according to its length, uncovered the open ended zipper and the black plastic sheet of SB placed in the floor in a uniform way so that grains are placed in equal thickness. The rough rice grains were delivered on the black sheet of SB dryer so that grains were distributed equally in all places of the drying floor. A measuring scale and wooden leveler were used for maintaining uniform grain thickness on drying floor. Fourteen *k-type* thermocouples were set up at different location for recording temperature according experimental design (Figure 02). The all of fourteen thermocouples were connected to data logger which was attached with a computer to get continuous temperature reading at 10 second interval during drying operation. Then, zipper was closed and started drying operation. Two ventilators were set up (12V, 0.254m diameter with casing) with the help of a collapsible aluminum bars frame. The connected black and transparent polythene sheets were joined with ventilators with the help of rope. Two solar panels (100 W per panel) were fixed by an aluminum bar in the north-south direction at 45° angle to get maximum sun light collection. A solar battery (12V 70Ah deep cycle battery) was placed near the panel connected with solar panel and ventilators by a charge controller (SRNE-SR-SL10A) to receive charge during sunny day and vice-versa during the night or cloudy weather. Then, the ventilators were started to make the dome like shape of the polythene plastic roof and drying operation.

Before the drying operation, initial moisture content of rough rice, weight of rough rice, air flow rate, ambient temperature, relative humidity, initial reading of thermocouple and solar radiation readings were recorded. During drying operation, moisture content, drying air temperature, relative humidity and ambient temperature reading were recorded following same procedure and instruments as mentioned above every half an hour interval. Solar meter (Model- SL 100, accuracy: 5% of measurement, measuring range: 1Wm^{-2} to 1300 Wm^{-2}) was used to measure sun light during drying operation. The experiment was conducted with three trials in Boro and Aman, 2015 harvesting season.

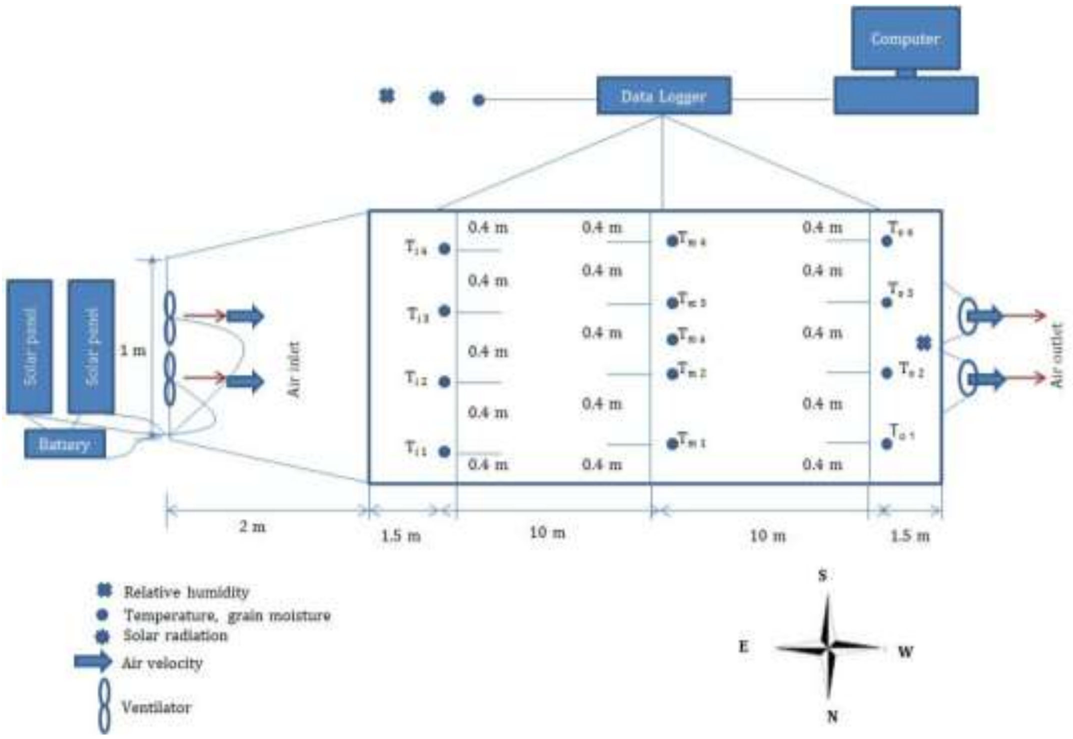

Figure 02. Layout of SB dryer experimental set up

Data analysis

Moisture content of rough rice: The moisture content was measured from twelve locations of SB dryers, respectively. The amount of water in rough rice grain is represented by the moisture content of the grain. At first time moisture removed from grain interior to the grain surface and then moisture evaporated from the surface to surrounding air. Moisture content is usually expressed in percentage. The quantity of moisture removed (Mw) from rough rice can be found out using the relationship (Forson, 2007) as Eq. (1)

$$M_W = \frac{M_p(M_i - M_f)}{(100 - M_f)} \qquad (1)$$

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).

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

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: Dryer performance was measured using drying efficiency equation as well the total energy supplied to the drying chamber and the total energy utilized by the drying chamber to remove desired moisture. The energy supplied by the heat source and the total energy output was determined in SB dryer. The drying efficiency 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).

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

Where,

W = the weight of water evaporated, kg

L_g = the latent heat of evaporation of water, MJ kg^{-1}

E_t = total energy consumption (input), MJ

Total energy consumption: The total energy absorbed from sunshine and the total energy output was determined in SB dryer during drying operation. Total energy consumption was calculated by the following equation

$$Et = \frac{Rs \times A \times t}{10^{\wedge}6} \quad (4)$$

Where,

E_t = Energy consumption, MJ

RS= Solar radiation, W m^{-2}

A = Drying area of SB dryer, m^2

t = Time required for drying, s

Seed germination rate: Seed grain requires a high proportion of individual grains with germination properties. The viability of grain is directly linked to the temperature attained by grains during drying (Kreyger, 1972). Higher grain temperature over 43°C for drying rough rice seed will lose seed vigor. The deterioration of the seed vigor in rice crops accounted for 20% of the yield losses (Shenoy et al., 1988). 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 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)

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

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): 710 x 360 x 690, 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. 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 SB 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). If the B/C ratio is greater than unity,

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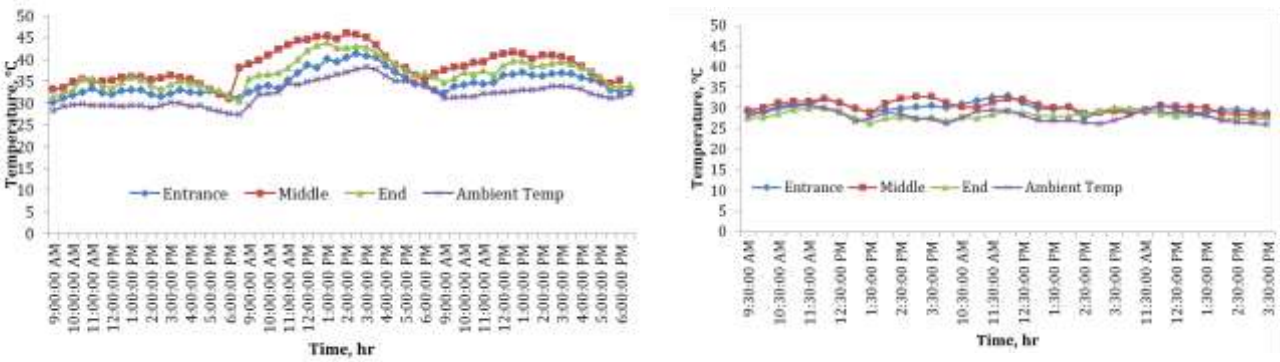
then it will be economically accepted. The payback refers to the time period within which the costs of investment can be covered by revenues. In other words, it is the length of time required for the stream of cash proceeds produced by an investment to equal the initial expenditure incurred.

III. Results and Discussion

Temperature distribution

Drying operation was continued until rough rice reaches desired moisture content. The measurement were taken both manually and automatically from 9:00 to 18:00 hrs and rest the time only data logger were open for recording temperature during the drying process. Figure 03 shows the relationship of drying air temperature variation at different locations of SB dryer with ambient air temperature in Boro and Aman season. It is observed that the temperature inside the drying chamber was greater than that of ambient temperature of air by an average of 4.6°C in three trials during Boro season. In addition, temperature difference between ambient air and inside the drying chamber was observed higher in Boro season compared to Aman season due to high ambient air temperature (Figure 03). Seveda (2012) reported that the maximum temperature gradient between the ambient air and drying air inside the dryer was observed in summer month and minimum was observed in winter month for drying industrial product in a solar tunnel dryer. The maximum temperature variation occurs in mid-afternoon from 11:00 to 14:00 hrs. This resulted in a maximum variation of drying air increases the drying rate of rough rice. It is indicated that the temperature was relatively higher at middle point of the dryer compare to entrance and end point with no significant difference. It proves that 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).



(a) Boro season (b) Aman season

Figure 03. Air temperature variations at different points of the SB dryer

Moisture distribution

The typical drying curves at middle points of SB dryer for Boro and Aman season are shown in Figure 04a and b. The rough rice moisture content was determined in two ways: manually using moisture meter and an electric oven for half-hourly samples. The trend of moisture removal profile with passage of time throughout the SB dryer was uniform because of thin layer drying by direct sunlight. The initial moisture content was more in Boro season compared to Aman season. The resultants drying time reduced in Aman season compared to Boro season. It can be seen from Figure 04, the moisture content reduces in day time but increases in next morning because of entering high humid air over the grain layer at night time. The re-wetting phenomena of the grains occurred during the night time if the drying is not completed in one day (Ashfaq et al., 2015). The similar results are reported on drying of Thai Hom Mali rough rice (Doungporn et al., 2012). It was difficult to achieve moisture content less than 14% during SBD drying because of equilibrium moisture content which depends on the temperature and relative humidity of the surrounding air.

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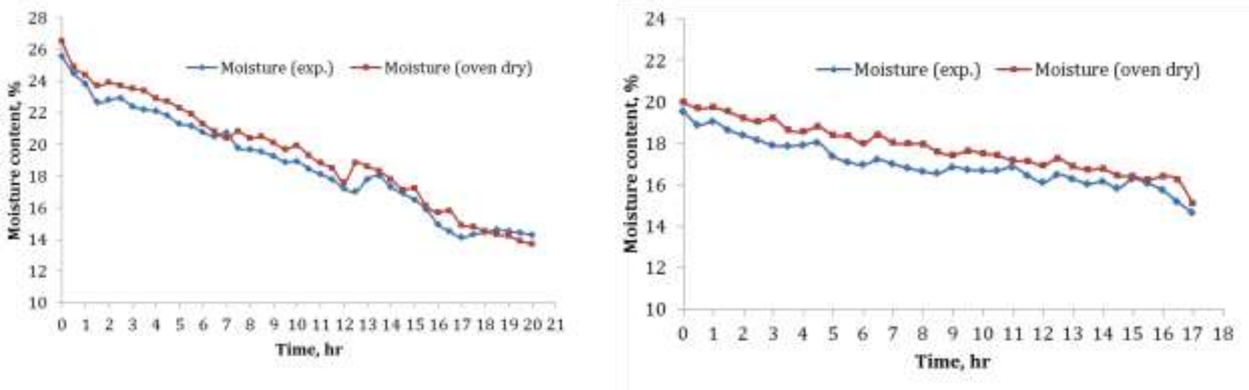

(a) Boro season (b) Aman season

Figure 04. Change of moisture content at middle position of dryer

However, it was observed that during drying operation, vaporized moisture pushes out through exhaust port of dryer from upper grain level and condensed in black sheet/drying floor from lower grain level. The rough rice samples were stirred half an hour interval with plastic rake. It was laborious and difficult to stir rough rice inside the drying chamber properly with plastic rake. Mechanical or roller type stirring mechanism was also used in the bottom of the dryer for proper and convenient stirring. Hence two labors were used for stirring manually two times per day to reduce moisture condensation on black polythene sheet.

Drying performance

Dryer performance of SB dryer was evaluated in Boro and Aman season compared with traditional sun drying method. The rough rice was dried from initial moisture content 25.6 and 20.1% to final moisture content 13.7 and 14.5% in both seasons. The total drying time for Boro and Aman season was required 19.8 and 16.7 hours, respectively. The initial moisture content in Boro season was higher compared to Aman season. The resulted drying time required more in Boro season compared to Aman season. The average moisture removal rate and drying efficiency were found more in Boro season followed by Aman season, respectively (Table 01).

Table 01. Performance of SB 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	Drying capacity, kg/batch	Drying efficiency, %
Boro	39.0±1.9	25.6	13.7	19.8	0.6	1000	25.2
Aman	29.0±2.1	20.1	14.5	16.7	0.4	1000	12.3

The moisture removal rate and drying efficiency was varied in different trials due to variations of sunshine hour, temperature and relative humidity. The initial moisture content of sample was also an important factor in drying period. The less initial moisture content required less drying time. The resulted drying time of Aman season was found less than that of Boro season. The moisture removal rate was increased with the increasing drying temperature of rough rice. Ashfaq et al. (2015) evaluated that mean drying rate for the solar assisted rough rice dryer was 0.83 kg hr^{-1}. The drying rate and drying efficiency were varied in different trials due to variations of sunshine hour, temperature and relative humidity. On the other hand, drying rate and drying efficiency were observed less in Aman season than that of Boro season due to effect of cold and foggy weather as well as low temperature. (Aghbashlo et al., 2015) explained that the drying rate was higher when the drying air temperature provided by the solar collector was high is due to intensive heat and mass transfer followed by a high rate of water evaporation.

Seed germination rate

Seed germination test was conducted after drying in SB dryer with sun dried sample. It is observed that the average germination rate (normal seedlings) of SB dryer and sun dried rough rice is 92 and 86%, respectively (Table 02). The germination rate of SB dried rough rice is satisfactory in both seasons. The germination rate (>85%) of selected rice varieties is satisfactory in terms of normal and

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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 with study temperature.

Table 02. Germination rate of dried rough rice sample in different drying method

Treatments	Sprouted seed	Dead seed	Abnormal seedlings	Normal seedlings
SB dried	-	3	3	94
Sample	3	1	6	90
Sun dried	5	3	8	84
Sample	8	4	4	88

Rice quality assessment

Head rice yield of rough rice 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, shape and colour of dried rough rice sample in SB dryer and sun dried sample are shown in Table 03 and Table 04. There is no significant variation between the experimental value and BRRI measured value of milling recovery. The percent of broken rice in SB dried rough rice sample is more than that of open sun dried sample due to uneven drying of rough rice. Lack of adequate stirring mechanism, moisture condensed in the bottom level of drying floor thereby moisture gradient was observed between top and bottom layer of grain bin which leads breakage of milled rice. Significant differences were also observed in hardness value of milled rice due to high moisture content.

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 SB and 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 SB and open sun dried rough rice was more or less similar. The a* and b* values of dried rough rice were also similar. Hardness is another important physical property which maximizes the milling yield of dried rough rice. The observed value of open sun dried sample was the highest degree of hardness followed by SB dried sample. The variation in hardness of rice is due the compact arrangement of starch granules. The results are similar to Mir et al. (2013).

Table 03. Milling recovery and shape characteristics of milled rice

Parameters	SB dried rough rice	Sun dried rough rice
Milling recovery, %	71.5±1.3	72.3±1.3
Head rice yield, %	58.6	63.9
Broken rice, %	12.9	8.4
Hardness, N	22.6	27.3
Accepts, (%)	62.7	78.3
Defects, (%)	37.3	21.7
Total no. of rice	775	730
Whole kernel, (%)	73.4	87.1
Unbroken rice, (%)	75.0	88.4
Broken rice, (%)	25.0	11.6
Area	7.4	8.0
Width	1.9	1.9
Length	5.0	5.5
Aspect ratio	2.7	2.9
Perimeter	11.7	12.4

Financial analysis

Economic analysis for SB dried rough rice sample is given in Table 05. The purchase price of SB dryer was BDT 1,83,000 with economic service life 10 years. The operating cost of rough rice in SB dryer was recorded Tk. 1.48 per kg with a payback period of 3.47 yrs while the operating cost in open sun drying method was observed Tk 1.20 per kg. The cost of drying was higher in SB dryer due to high initial investment and low drying rate. Ashfaq et al. (2015) mentioned that the operating cost of solar

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assisted rough rice dryer was obtained Tk 0.90 per kg while the operating cost of drying by using open sun drying method ranged from Tk. 1.5 to 2.0 per kg.

Table 04. Colour characteristics of milled rice

Parameters	SB dryer	Sun drying
L*	62.5	61.9
a*	4.1	4.1
b*	2.9	3.0
Whiteness	41.1	40.3
Immature kernels	0.0	0.0
Red kernels	0.6	0.9
Yellow kernels	0.3	0.2
Chalky kernels	12.0	9.4
Damaged kernels	0.4	0.5
Glutinous rice	0.0	0.0
Red	146.2	144.2
Green	141.0	139.0
Blue	133.4	131.3
Outline distortion	0.1	0.0
Degree of Inflection	0.2	0.1
Chalky ratio	0.2	0.1
Immature part	1.8	1.9

Table 05. Financial analysis

Description	Value
Operating cost, Tk. kg^{-1}	1.48
Sun drying cost, Tk. kg^{-1}	1.20
Gross benefit of the dryer, Tk. yr^{-1}	81336
B/C ratio	1.02
Net present value, Tk.	445
Payback period, yr	3.47

IV. Conclusion

The SB dryer was able to dry the rough rice from initial moisture content about 25% to final moisture content of 14%. The experimental result shows that the temperature was distributed uniformly throughout the dryer. Temperature inside the dryer was very much dependent on solar radiation/ sunlight hour though it was very difficult to get during harvesting season due to rainy or foggy weather. Stirring with rake and tube mixer could be simultaneously used to reduce moisture condensation in the bottom part of the grain layer. In rice quality assessment, the result showed that the milling yield was found within the range of acceptable ranges by the millers and final consumers. The germination rate was found above 80% for all dried sample. The SB dryer is appeared as a simple and flexible technology alternative to sun-drying method.

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