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SOLAR BUBBLE DRYER: ALTERNATIVE TO SUN DRYING FOR REDUCING DRYING LOSSES

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Abstract

The Solar Bubble Dryer (SBD) is a latest low cost drying technology and flexible alternative to sun drying. Technical performance was investigated by observing moisture content and temperature distribution at different points of the dryer. The moisture distribution was uniform and its content was reduced initially from 19.5, 20.6 and 20.3% to 14, 15.6 and 14%, respectively in the 1st, 2nd and 3rd trial of the dryer. The temperature distribution was almost same but it was sometimes lower than the ambient temperature. The drying rate, drying capacity and drying efficiency were found to be 3.9 kg/hr, 1000 kg/batch, and 12.3%, respectively. Every trial took 3 - 5 days but it was difficult to achieve desired moisture of 12.0%. The average germination rate of SBD dried paddy (89.66%) was more than that of sun-dried paddy (84%). The milling recovery was found 71% for SBD dried paddy and 72.4% for sundried paddy. The percentage of broken rice in SBD dried paddy sample was more than that of sun-dried sample because of high moisture content (14.5%) and less hardness (22.5 N). The operating cost of paddy drying in SBD dryer was found Tk. 1410.9 per ton whereas that of traditional sun drying methods was found Tk.1047.3 per ton. Although, drying by SDB is not profitable over traditional drying, it has advantage to protect drying loss of fresh harvested paddy during unpredictable weather condition in rainy season.

Keywords: Drying efficiency, Drying loss, Drying rate, Solar Bubble Dryer

Introduction

Bangladesh is an agriculture based country and its economy depends on agriculture. Paddy is the main staple crop in our country and second crops in the world. Bangladesh is now producing about 34.6 million ton of rice (USDA, 2021) to feed about 168.22 million of people (BBS, 2020). Freshly harvested paddy has high moisture content up to 20-25% (IRRI, 2013). Paddy has a high respiration rate and is susceptible to attacks by micro-organisms, insects and other pests. Proper or incomplete drying or ineffective drying results in qualitative or quantitative loss. Harvested grains with high moisture should be dried at 14% -18% for storing for 2 to 3 weeks, otherwise, mold damage and discoloration occur and respiratory damage occurs. Grain should be dried at 12% -13%

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moisture content to protect against insect infestation for 8 to 12 months of storage and 9% or less moisture content to protect seed viability (IRRI, 2013). Due to low temperature and high relative humidity, world is facing a problem to moist paddy deterioration after harvesting. In order to reduce post-harvest losses, farmers harvested raw paddy early and sell it in the market, which reduces the farmer's income. Country's food security heavily relies on its ability to safely store its food, feed-grain and seed stocks.

An efficient drying method is necessary to supply continuously for growing population and to ensure high quality marketable products. The amount of post-harvest loss in traditional process is cutting and handling 1-5%, sun drying 3-5%, open storage 5-10%, village milling (Angle bar huller) 20-30% whereas combine harvesting and machine threshing is 1-5%, mechanical drying 1-2%, sealed storage 1-2% and commercial milling 5-10% (Hodges *et al.*, 2011). Most traditional method in sun drying of grain is unhygienic due to grain quality deterioration by uncontrolled factor and damage by bird. Due to industrialization and export of manpower, it is difficult to dry the grain during peak season, especially during Boro and Aus seasons. To address these problems, SBD is a modern drying innovation that minimizes the effects of unpredictable weather to commodities during its drying stage. The SBD is the latest drying technology that aims to provide a simple and flexible alternative to sun drying. Therefore, the aim of the study was to evaluate the performance of Solar Bubble Dryer. It improves the traditional sun-drying process and eliminates all losses due to spillage, animals, the weather, and vehicles running over the grains.

Materials and Methods

Experimental site

The SBD is currently being tested on rice by IRRI's national partners in the Philippines, Cambodia, Myanmar, Vietnam, Indonesia, Thailand, and Nicaragua. In the contexts on Bangladesh the performance evaluation of SBD was conducted at the workshop of Department of Farm Power and Machinery, Bangladesh Agricultural University (BAU), Mymensingh.

Description of the dryer

SBD is made of two plastic sheets one is black and other is transparent. The black one is at the bottom where the grains are placed and a transparent one as roofing. Both sheets are connected by a zipper. The SBD uses solar energy from the sun in two ways. Firstly, the transparent plastic sheet serves as a solar collector to convert energy from the sun's rays (entering through the transparent top of the drying chamber) to heat, therefore increasing the temperature of the air for faster drying. Secondly, the SBD is equipped with a photovoltaic panels system that consists of solar panel for generating electricity a rechargeable deep cycle battery for use at night. The dryer has two ventilators placed at the air inlet at one end of the dryer to inflate and hold up the polyethylene plastic sheet, thus providing the dome shape (Fig. 1).

The ventilators also move the air inside the dryer, ensuring a homogenous distribution of heat and reducing the moisture content. The drying air leaves the dryer at the other end through an adjustable outlet. On a typical sunny day, the surface of the grains heats up so much that users need to increase the frequency of stirring the grains. A simple roller with ropes attached to both of its ends is periodically dragged underneath to mix the grains without the need to open the tunnel. A rake is available to mix the grain on the drying chamber. The capacity of the dryer is 1000 kg. Detail specifications of the SBD are given in Table 1.

Fig. 1. Pictorial views of Solar Bubble Dryer (SBD)

Table 1. Specification of the dryer

Parameters	Product Specification
Drying area, m^2	50
Overall dimension (L×W), m	26 × 2
Packed dimension (L×W×H), m	1 × 1.1 × 0.3
Packed Weight, kg	95 (without battery)
Components: SBD body	
Capacity (Maximum), kg	1000
Top cover	UV-resistant LDPE
Drying floor	Reinforced PVC
Zipper	Heavy duty zipper (open ended)
Electronic Components	
Wiring Harness	MC4: #14 standard wire
Solar panel	
Frame	Aluminum bars
Charge controller	SRNE (SR-SL10A)
Solar battery	12V 70Ah deep cycle battery (sold separately)
Unit(s)	2 panels, 100W per panel
Ventilator	
Frame	Collapsible aluminum bars
Unit(s)	2 units, 12V, 0.254m diameter with casing
Mixing	
Rake mixer	0.025m diameter aluminum tube
Roller mixer	2.4m G.I. Pipe

Technical parameter of the dryer were measured by computing the moisture content of paddy (%), temperature ($^{\circ}C$), relative humidity (%), air flow rate (ms^{-1}), solar radiation (Wm^{-2}).

Experimental set-up and procedure of test

The dryer was set-up in a drying floor, solar panel with 12-volt battery. Black sheet of SBD was placed on the drying floor in a uniform way according to its length and grains are placed in equal thickness about 35 mm. A measuring scale and wooden leveler were used for uniform grain thickness on drying floor. Fourteen *k-type* thermocouples were set up at different location for recording temperature according experimental design (Fig. 2). To get continuous temperature reading at 10 second interval the thermocouples were connected to Fluke data logger which was attached with a computer during drying operation. Then zipper was closed and drying operation was started. The evaporated moist air was passing through the outlet with the help of two ventilators (12-V, 0.254m diameter with casing) which was associated with a collapsible aluminum bars frame. The ventilators were attached with black and transparent polythene sheets in inlet portion with the help of rope. Two solar panels (100 W per panel) were fixed by an aluminum bar in the south facing direction at 45° angle to get maximum solar radiation collection. A solar battery (12-V 70Ah deep cycle battery) was used as auxiliary operation during sunny day and vice-versa during night or cloudy weather. The battery was connected with solar panel and ventilators by a charge controller (SRNE-SR-SL10A) to control the voltage. Then, the ventilators were started to make the dome like shape of the polythene plastic roof and drying operation.

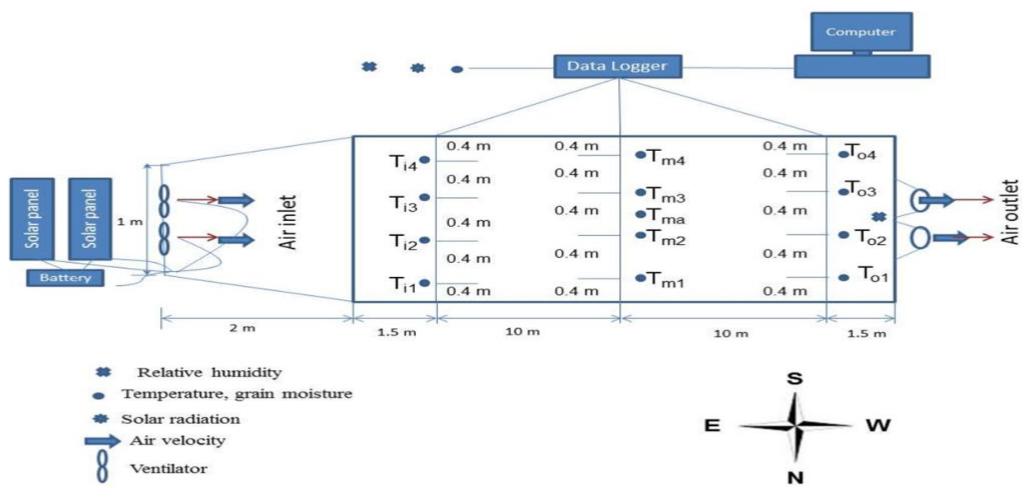

Fig. 2. Experimental layout of the dryer (T-temperature sensor, i-inlet, m-middle, o-outlet and measurement in meter)

The drying time of three trials were considered when the solar radiation was available enough for drying operation to investigate the technical performance of solar dryer (Bala *et al.*, 2005). The dried samples were spread out at night in the dryer and only one ventilator run by the battery as auxiliary operation, then drying was continued the next morning. The total length of the dryer was 25 meter whereas the heating area was 2 meter and 23 meter was used for spreading grain. The initial moisture content of paddy, weight of paddy, air flow rate, ambient temperature, relative humidity and solar radiation readings were recorded before drying operation and every half an hour interval similar data were recorded during drying operation. The grain temperature reading was recorded in every 10 seconds interval by using FLUKE (Model-FLUKE 2635A Hydra series Data bucket) data logger. A computer was attached with data logger to receive the recorded data in real time. An electrical balance (Model- ES-HA precision balance scale, accuracy: ± 3d) was used to weight paddy. The moisture content of paddy was measured manually by using a Riceter L (Model-Riceter L, accuracy: ± 0.2% at 105^{o}C, measurement range 11-30% for paddy rice) moisture meter after collection of paddy sample. The paddy sample was collected from three different locations inside the dryer in every half an hour interval. The collected paddy samples were also used to measure moisture content using oven dry method. A desiccator was used to store paddy sample for oven drying. The ambient temperature and relative humidity was measured by using TRH-1000 (Model-TRH 1000, temperature accuracy: ± 0.6°C @ 25°C, ± 2°C from -40°C to 70°C and ± 4% RH between 20 to 80% RH) data logger. Testo (Model- Testo 416, accuracy: (± 0.2 m/s + 1.5% of mv) anemometer measured the air flow rate at the outlet point of the dryer. The air flow rate was measured to check how swiftly evaporated grain moisture passes through the outlet point. Solarimeter (Model-SL 100) was used to measure solar radiation during drying operation.

Seed germination

Seed germination rate was determined through germination tests after drying. The viability of grain is directly linked to the temperature attained by grains during drying. When the drying temperature is above 43^{o}C, the seed loses its vigor. The deterioration of the seed vigor in rice crop accounted for 20% of the yield losses (Shenoy *et al.*, 1988). At first, 100 (one hundred) gram dried paddy sample were taken from SBD. Then purity test was conducted to get pure seed, other seed and inert matter from each sample. The germination rate was calculated using the number of germinated or germinated seeds in 100 pure seeds taken from the dryer as a sample. The germination test was conducted in sand medium with a plastic pot. The sand medium was soaked with water within 12 hours. After that the plastic pot was filled with the moist sand medium. Then the 100 number of pure seed was placed carefully without overlapping. Finally the pot was kept in proper environment for sprouting. The number of germinated seeds was counted after 5 days for each entry. The germinated seedlings root and shoot length was measured after 14 days. Germinated seedlings were recorded for each entry and the germination percentage computed**.** The germination rate was calculated by the following equation.

$$\text{Germination rate, (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds planted on tray}} \times 100$$

Milling test

Timely harvesting, threshing, drying, and stored properly can result in the production of good quality milled rice. Delays in drying, and moisture migration in storage can result in broken and discolored milled rice. The initial moisture content of paddy and drying air temperature influence the drying rate and head rice yield obtain at

43^oC to 45^oC temperature was considerably higher than sun drying (Chouw and Athapol, 2001). At first, 100 gram dried paddy sample was cleaned for milling recovery test. Five replications were taken for the test. A laboratory rubber roller rice husker (Model-JLGJ2.5, Rate of husking (%): ≥99.9) was used to dehusked the cleaned paddy. Then an iron roll rice whitener (Model- LNMS 15) was running four minutes to clean the bran from the dehusked paddy. Definitions are provided to clarify terms commonly used in reference to milling yield measurement.

Head rice yield was defined as the ratio of the total head rice to the total rough rice.

$$\text{Head rice yield (\%)} = \frac{Mass\,of \text{ head rice}}{\text{Mass of rough rice}} \times 100$$

Percentage of milling recovery was calculated as the ratio of the milled rice (head rice and broken) to the total rough rice.

$$\text{Milling recovery (\%)} = \frac{Mass\,of \text{ milled rice}}{\text{Mass of rough rice}} \times 100$$

Data analysis and calculation

The measuring data were collected in a data sheet and analyzed with the help of MS Excel software. The energy was absorbed from solar radiation and the total energy output was determined in dryer during drying operation. Moisture content of paddy was determined by two methods, one is direct method and other is indirect method. In the experiment moisture content was calculated by direct method using an oven and other was indirect using a manual moisture meter. All the sample of paddy was dried in the oven for 24 hrs at 130^0C to determine the initial and final moisture content of paddy (Cnossen *et al.,* 2001). Dryer performance was measured using drying efficiency equation as well as 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 solar radiation and the total energy output was determined in SBD. The drying efficiency of dryer is defined as the ratio of energy used to evaporate the moisture from the paddy to the energy input to the dryer. It was calculated with the following equation:

$$\text{Drying efficiency } \eta = \frac{WL}{E_t}$$

Where, W = the weight of water evaporated (kg), L = the latent heat of evaporation of water (MJ/kg), and E_t = total energy consumption (MJ).

The total energy consumption of SBD dryer was measured from the solar radiation of the sunshine. Then the drying area of the SBD dryer was calculated. After that the drying time was calculated. The total energy consumption was calculated with the following equation:

$$E_t = \frac{R_s \times \text{A} \times \text{t}}{10\text{\textasciicircum}6}$$

Where, E_t = energy consumption (MJ); R_S= solar radiation, (Wm^{-2}); A = drying area of SBD (m^2) and t = drying time (s)

Fixed cost and variable cost are considered for economic analysis. Depreciation, taxes, interest on the capital investment, insurance and shelter were considered as fixed cost which is independent of use. Alternatively, the variable cost such as fuel, lubrication, daily service, power and labor used by the power source and the dryer were considered as operating cost of the dryer. Benefit-cost ratio and payback period were also measured.

Sun drying method

The performance of SBD was compared with traditional sun drying method. Paddy was dried in open sun shine and simultaneously in every SBD trial. Same initial weight and moisture content of paddy were used in sun drying with 30 mm grain thickness. In case of sun drying, two labors were engaged for stirring the paddy at half an hour interval when the sun light was available. The moisture content of paddy, the ambient temperature and relative humidity were measured for sun drying method.

Results and Discussion

Temperature and solar radiation during SBD drying operation

The technical performance evaluation of SBD dryer is in terms of temporal distribution of temperature and moisture content. The Fig.3 is shown that the ambient temperature (^{0}C) with the solar radiation (Wm^{-2}) during the drying operation. When the ambient temperature increases, then the solar radiation increase rapidly. The similar result are reported on experimental analysis on corn drying of a sustainable solar dryer (Gisele *et al.,* 2020). Drying operation was conducted at 12.30 pm when solar radiation reaches maximum. The solar radiations were entering by the UV-resistant, water proof and transparent cover film into the drying chamber. At the time of entering the solar radiation was short wave length and after entering into the drying chamber it became long wave length and finally it was trapped as like a green house. Paddy was heated up and moisture was vaporized and cooled moisture was passed out by outlet. First one hour the solar radiation was maximum and fluctuated because of foggy and cloudy weather. Solar radiation intensity was achieved maximum at 2.00 to 4.00 pm about 750 Wm^{-2} at the 3rd trial of 3rd day. After 19 hrs later the intensity of solar radiation was decreased to 400 Wm^{-2} at the 3rd trial of 4th day. The drying operation was stopped at 2nd day of 3rd trial due to foggy weather.

Temperature distribution inside and outside of SBD dryer

The temperature inside the drying chamber was more or less similar with the ambient temperature (Fig. 4). Solar radiation intensity maximum was 1 to 3 hrs and

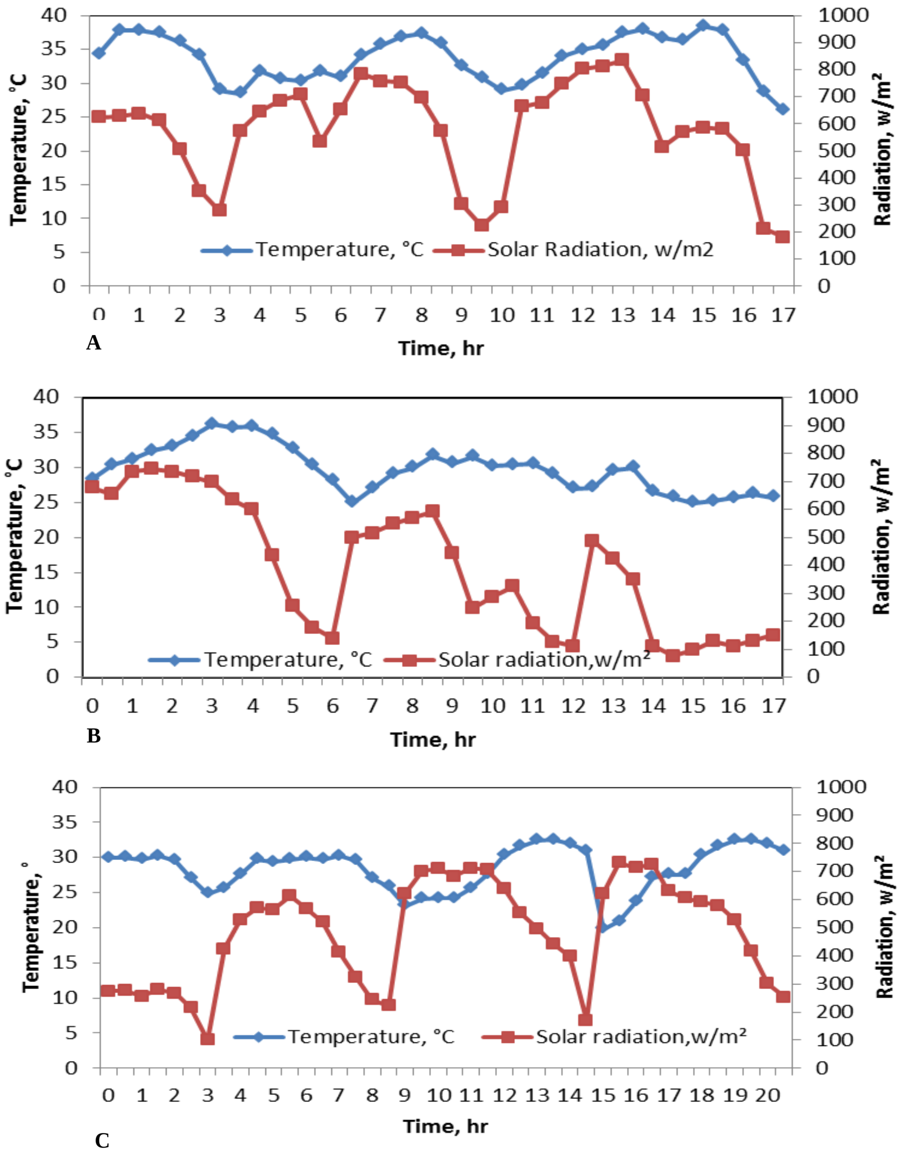

Fig. 3. Relation between ambient temperature and solar radiation during drying operation- (A) Trial 1, (B) Trial 2 and (C) Trial 3

temperature variation occurred at that time. Consequently the drying air temperature inside the drying chamber was maximum and drying rate of paddy was increased. Hossain *et al.*, (2012) reported the similar results for rough rice seed drying in the hybrid dryer. Due to unpredictable weather condition its normal working procedure hampered. There were three trials and 1st and 2nd trial was taken 3 days almost same. But 3rd trial was taken 5 days as a result it takes more time than those others because of 2nd day sun were invisible and there was foggy and cloudy weather. Drying operation of 2nd day of 3rd trial was totally closed.

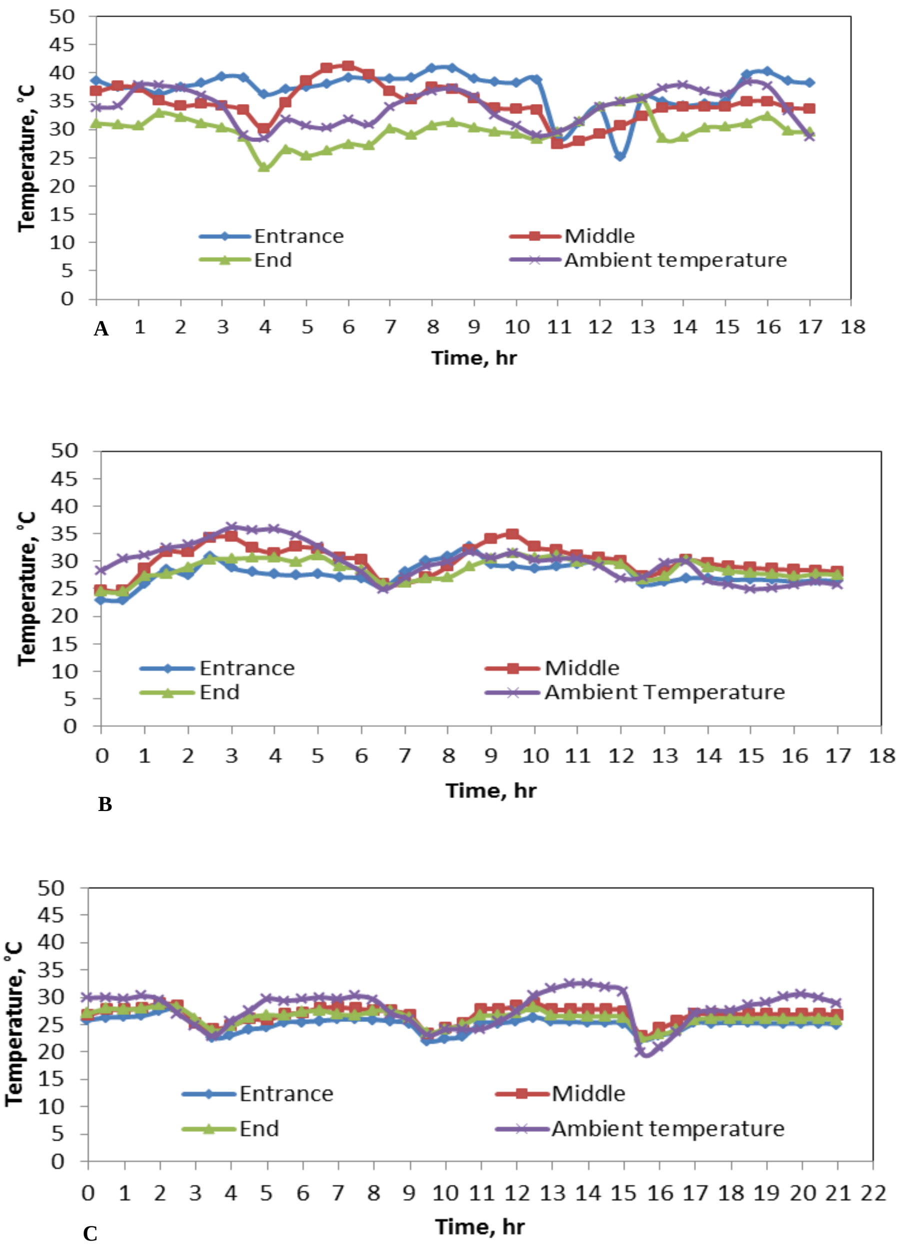

Fig. 4. Variation of temperature at different point of the SBD dryer in (A)Trial 1, (B) Trial 2 and (C) Trial 3

Moisture removal rate in different trials of SBD

Moisture removal profile with time is shown in Fig. 5. It shows that moisture content of paddy of inlet, middle and outlet portion on SBD dryer was decreased gradually with the time passed on all trials. The variation of moisture content among the inlet, middle and outlet locations were very much low during drying. The paddy sample in all locations inside the SBD was dried uniformly with time and finally the moisture content of paddy was achieved about same moisture value. Alam *et al.,* (2016) reported that the similar result for grain drying in all part of the BAU-STR dryer within 3 to 5 hours.

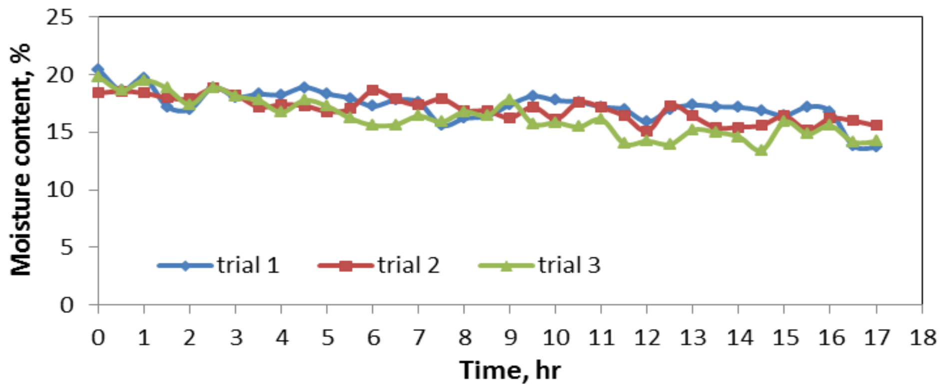

Fig. 5. Variation of moisture content at the middle point of SBD dryer in Trial 1, Trial 2 and Trial 3

The variation of moisture removal rate measured by moisture meter and oven dry method is shown in Fig. 6. Moisture content of paddy both in manual and oven dry method was determined from the collected paddy half an hour interval. Moisture profile shows the smooth curve which is gradually decreases with time both in manual and oven dry method.

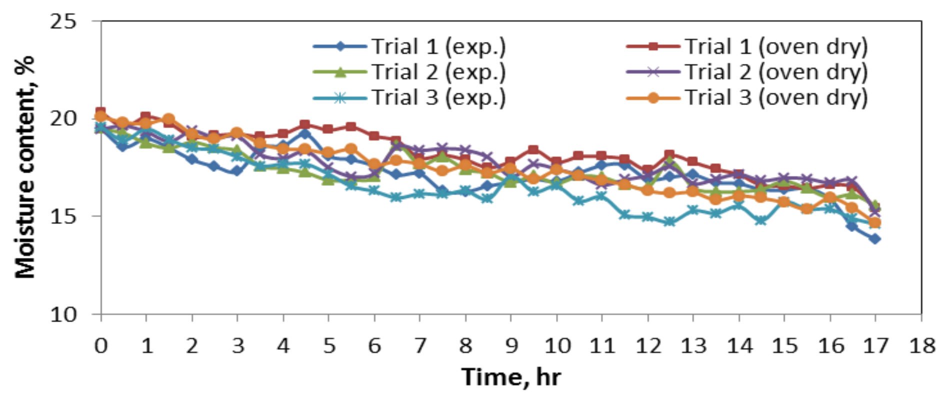

Fig. 6. Comparison of moisture content between experimental (manually moisture meter) and oven dried in Trial 1, Trial 2 and Trial 3

The moisture content of paddy builds up in every next day morning 1-2% compared with end time of last day because of entering moist air in SBD through the ventilators. 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). At the end of drying operation (3 to 5 days), the moisture content of paddy remains stable at about 14% due to equilibrium moisture content mechanism. The desired moisture content of paddy was 12% but actually achieved about 14%. The experiment trial 1 and trial 2 taken 3 days and trial 3 taken 5 days because of the foggy and dense weather. At day time moisture content of paddy was reduced but at night time the paddy gained moisture from the inlet portion because backup battery run the fan of inlet portion and cold air entered into the drying chamber. The paddy regained moisture and increased the moisture content by about 1-2% during the nighttime.

Technical performance of SBD dryer

Drying capacity, drying efficiency, moisture removal rate was measured to determine the technical performance of the dryer. Paddy was dried from average initial moisture content 20.1% to final moisture content 14%. Drying performance and fundamental parameter of paddy of the dryer are shown in Table 2. The drying rate, drying capacity, drying efficiency were varied with the variation of solar radiation, ambient air temperature and relative humidity. Aghbashlo *et al.,* (2015) explained that the drying rate becomes better while the drying air temperature supplied through the sun collector becomes excessive is because of extensive warmness and mass transfer observed through an excessive rate of water evaporation. The average drying rate, drying capacity and drying efficiency were 3.9 kg hr^{-1}, 60.2 kg hr^{-1} and 12.3%.

Table 2. Technical performance measurement of the Dryer

Trial	Max. temp.	Min. temp.	Initial MC (%)	Final MC (%)	Initial weight of paddy (kg)	Final weight of paddy (kg)	Moisture removed (kg)	Drying time (hr)	Drying rate (kg hr^{-1})	Drying efficiency (%)
1	41.2	23.2	19.5	14.0	1000	931.2	64.5	16.0	4.0	10.3
2	34.8	23.0	20.6	15.6	1000	937.7	59.5	16.0	3.7	14.0
3	28.9	22.1	20.3	14.0	1000	920.5	73.7	18.0	4.1	12.6

Seed germination rate of SBD dried paddy

Seed germination test in terms of counting the number of seedlings germinated. Seed sample was taken from SBD dried paddy and sun dried paddy. The germinate rate in SBD dryer and sun dried paddy is shown in Table 3. The average germination rate in SBD dried paddy is 89.66% (average of 3 trials) is more than the sun dried paddy (84%).

Rice quality assessment of SBD dryer

Milling test was determined from SBD dried paddy and sun dried paddy. Milling recovery, broken rice, hardness for SBD dried paddy and sundried paddy are shown in Table 4. Head rice yield depends on grain moisture content and temperature. Milling recovery of SBD dried paddy in average 71% and sundried paddy is 72.4 %. The percent of broken rice in SBD dried paddy sample is more than that of sundried sample because of high moisture content (14.5%) and less hardness.

Table 3. Germination rate of SBD and sun dried sample

Treatments	Sprouted seed	Dead seed	Abnormal seedlings	Normal seedlings
Trial 1	0	1	8	91
Trial 2	3	1	6	90
Trial 3	1	2	9	88
Sundry	5	3	8	84

Table 4. Milling recovery of dried paddy in SBD Dryer and sundry method

Treatments	Milling recovery, %	Broken rice, %	Unbroken rice, %	Hardness, N
SBD-1	70.5±0.8	40.7	59.3	21.6
SBD-2	70.9±1.1	27.7	72.3	18.3
SBD-3	73.1±1.0	6.6	93.4	27.8
Sundry	72.4±1.7	11.6	88.4	23.2

Drying loss in SB dryer during Aman season

Drying loss of paddy in SBD during Aman season at laboratory is shown in Fig. 7. The drying loss was between 0.40 to 0.93% during Aman season. It was revealed that the drying loss of SB dryer less than 1.0% in Aman season whereas it was found in open sun drying (field) at different locations in the range of 2.41 to 3.95% (Alam *et al.*, 2019).

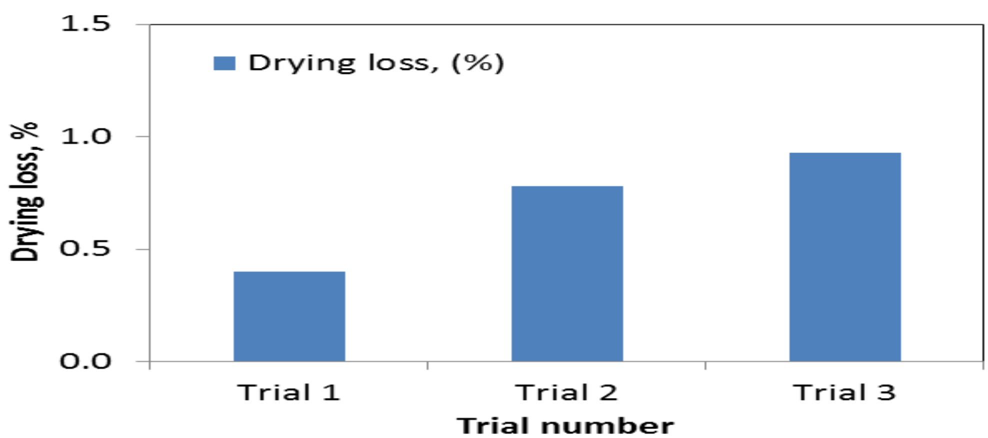

Fig. 7. Drying losses of paddy in SB dryer at laboratory

Economic analysis

Economic analysis for SBD dryer is given in Table 5. The purchase price of SBD dryer was Tk. 183000 with economic service life 10 years. The operating cost of paddy drying was found Tk. 1410.9 per ton in SBD dryer whereas in traditional sun drying methods the operating cost was Tk.1047.3 per ton. Ashfaq *et al.*, (2015) indicated that the operating cost of solar assisted rough rice dryer was obtained Tk. 900 per ton while the operating cost of drying by using open sun drying method ranged from Tk. 1500 to 2000 per ton. Though the dryer is not profitable over traditional drying, it is suitable to save harvested paddy from unpredictable weather.

Table 5. Economic analysis of SBD dryers

Description	Traditional drying	SBD
Drying capacity, kg hr^{-1}	38.2	60.2
Operating hour, hr yr^{-1}	-	900
Operating cost, Tk. ton^{-1}	1047.3	1410.9
Benefit cost ratio	-	0.7
Save over traditional, Tk. ton^{-1}	-	-363.6

Break-even point analysis

The break–even theory is based on the fact that there is a minimum cost level at which a Venture neither makes profit nor loss. The Fig.8 shows that the initial stage the drying cost is high for 5 ton paddy are dried per year. The traditional drying will be more profitable than the SBD dryer. The desired point is 120 ton annual used of paddy where no profit or no loss.

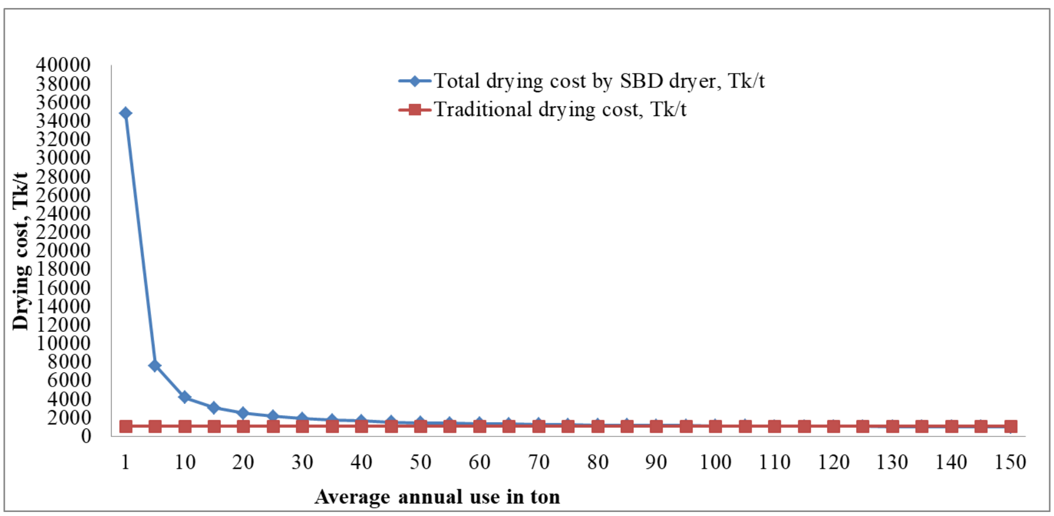

Fig. 8. Break-even point analysis of SBD dryer

Sun drying method

Paddy was dried in open sun shine using same variety BRRI dhan49. The initial moisture content was similar with SBD trial 1, 2 and 3. Paddy was dried from 19.5 to 13.9%, 20.6 to 14.3% and 20.3 to 12% with same duration of SBD drying in trial 1, 2 and 3, respectively. The moisture removal rate in open sun drying was more or less similar to

SBD drying. Drying cost of paddy in sundry method was lower than that of SBD drying operation due to high initial cost of SBD dryer (Table 5).

Conclusion

The temperature distribution and moisture removal rate was uniform in all locations of SBD dryer during drying operation. The required drying time was more or less similar with traditional sun drying method (3 to 5 days), however it was so difficult to achieved desired moisture content (below 12%) due to humid and foggy weather condition. It is difficult to protect moisture condensation in the black sheet of drying floor stirring with rake and tube mixer. Considering the technical performance and economic analysis, the SBD is applicable to protect qualitative and quantitative loss of fresh harvested paddy though it is not profitable for the weather condition in Bangladesh. Improved stirring mechanism and perforated screen might be incorporated for refining the performance of the dryer.

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Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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