Journal of Scientific Research and Reports

Volume 30, Issue 12, Page 159-166, 2024; Article no.JSRR.127857
ISSN: 2320-0227

Impact of Solar Bubble Drying on Milling Quality of Large-scale Paddy

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jsrr/2024/v30i122660

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/127857

Original Research Article

Received: 01/10/2024
Accepted: 04/12/2024
Published: 07/12/2024

ABSTRACT

Rice is the staple food for a large part of human population, in particular for the hundreds of millions of Asians, Africans, and Latin Americans living in the tropics and subtropics should be "About 65% of the population in India. For the offseason utilization of paddy, drying is critical for long-term storage. To address the challenge of low-cost drying methods in rural areas, the drying performance of the solar bubble dryer (SBD), developed by IRRI, was compared against open sun drying (SD) and solar tunnel drying (STD) under the climatic conditions of Odisha. SBD provides a more consistent and controlled temperature, which helps preserve the quality of the paddy. SBD can handle larger quantities of paddy than traditional solar dryers which reduces operational cost. After drying process milling properties of raw paddy rice were evaluated and found that total rice yield was 68.70±1.21 % for solar bubble dryer, 67.44±1.39% for solar tunnel dryer and 66.63±1.71% for solar drying. The head rice yield was higher (56.24±0.80%) for paddy dried using

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***Cite as:** Jyoti, Yogendra Kumar, Nikita Mishra, and Sanjaya K Dash. 2024. "Impact of Solar Bubble Drying on Milling Quality of Large-Scale Paddy". Journal of Scientific Research and Reports 30 (12):159-66. https://doi.org/10.9734/jsrr/2024/v30i122660.*

SBD compared to sun drying method (52.46±1.09%) and solar tunnel drying method (54.35±0.19%). Based on the statistical analysis, we reject the null hypothesis and conclude that SBD is statistically significant compared to STD and SD in terms of drying efficiency. The results suggest that SBD can effectively reduce the moisture content of paddy, making it a more efficient drying method. In conclusion, this study provides strong evidence that solar bubble drying is an effective method for improving the milling quality of large-scale paddy, resulting in higher quality rice, reduced energy consumption, and increased economic benefits for rural farmers and processors.

Keywords: Solar Bubble Dryer (SBD); Solar Tunnel Dryer (STD); SOLAR Drying (SD); milling recovery; head rice yield.

1. INTRODUCTION

In terms of cultivated area, rice (*Oryza sativa L.*) is the second most important agricultural product in the world, after wheat. Around 3.5 billion people rely primarily on rice for their diet (Anonymous, 2023b). Global rice production reached 513.36 million tons in 2022, up 0.64 percent from the previous ten years, according to USDA's Foreign Agricultural Service statistics (Anonymous, 2023a). The Food and Agriculture Organization (FAO) reports that India produced 177.6 million MT of rice in 2019. With about 11.0% of the global production share, India is the second-largest rice producer in the world after China thanks to the cultivation of high-yielding rice varieties like IR 64, CR 2301. The last 60 years have seen a 3.5-fold increase in the nation's rice output. The Rice Exporters Association of India reports that in 2021, rice exports totaled 20 million tons, of which 16 million tons were non-Basmati rice. Since rice is so necessary, no nation has put import restrictions on it. There was sufficient general production to sustain exports of about 16 million tons of non-Basmati rice (Madhu et al., 2023). Due to the limited number of rice mill factories and the rapid harvesting by combine harvesters, a significant amount of paddy accumulates during the harvest season. Prior to processing and storage, paddy drying is a crucial post-harvest procedure (Chukwuemeka et al., 2015). Absorption of moisture, uneven distribution of moisture throughout the grain mass, very rapid drying rates and incomplete drying can all be caused by inadequate or defective drying equipment or improper drying procedures. Poor drying leads to high milling losses, low efficiency, high costs and storage losses, and poor quality rice that have been milled. When stored with high grain moisture content or exposed to high relative humidity or moisture, paddy deterioration is accelerated (Juliano, 1985). Pre-milling and milling losses are likely to happen if grain isn't dried and stored properly right away after harvest (Chayan Kumer and Alam, 2022). If the moisture content of the paddy is between 11 and 15 percent, it can be stored for up to 12 months without developing mold (w.b). Furthermore, rice quality can be raised by drying paddy at a temperature of 40 to 60ºC (Müller et al., 2022; Mohapatra & Bal, 2006).

Studies have shown that SBD improves the milling recovery of paddy, with some reviews reporting a milling recovery of 71% for SBD-dried paddy. This is comparable to sun drying, which reported a milling recovery of 72.4%. In terms of broken rice, SBD-dried paddy has been found to have a slightly higher percentage of broken rice compared to sun-dried paddy (Verma et al., 2015). However, this can be mitigated by adjusting the drying parameters and conditions. The SBD technology has also been found to reduce drying losses, making it an attractive alternative to sun drying. Additionally, SBD has been shown to improve the overall quality of the dried paddy (Kumar and Sharma, 2020).

“Solar drying is the oldest method of preserving crops, and it is practiced worldwide. During natural or open sun drying, crops are laid out on compact earthen floors, mats, concrete, floors, and roads on sunny days. It is exposed to various contaminations such as dirt, pest infestation, and loss caused by birds and animals” (Janjai and Bala, 2012). For solution of these problems IRRI, Hohenheim University and GrainPro developed latest low-cost drying technology the solar bubble dryer (SBD). It basically constitutes a drying chamber which is made up of a black polythene sheet at the bottom and UV stabilized PE sheet as the glazing material (Imprasit & Noomhorn, 2001). The SBD is mobile and is completely independent from fuel or the power grid, and therefore has very low operating cost (Weerachat et al., 2010). Various works has been done on solar drying technology such as Aktar et al. (2016) studied on performance of STR dryer for paddy. They reported that drying temperature of STR dryer for paddy drying was in the range of 38°C to 42°C. The drying and the heat conveying efficiencies of the STR dryer were found about 31.2 % and 19.91 %, respectively. The overall dryer efficiency was found about 22.7 %, which satisfy the standard batch dryer performance.

Alam et al. (2019) studied on “experimental investigation of solar bubble dryer for rough rice drying in Bangladesh. They reported that 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 SB dryer can be applicable for drying rough rice at farm level in Bangladesh”. Dokurugu (2009) Studied on “two-stage drying of paddy and the effects on milled rice quality. They reported that head rice yield (HRY) of milled rice were 64.22%, 62.11% and 60.36% for fluidised bed drying at 60ºC (first stage drying), static bed drying at 45ºC (second stage drying) and subsequent storage for one, three and six months respectively. The samples dried at 80ºC and 45°C and subsequent storage for same months were 60.22%, 62.20% and 60.51% in head rice yield. Those dried at 100ºC and 45ºC were 59.54%, 62.37% and 57.35%. Complete sun drying had HRY of 62.27%, 63.55% and 61.91%. Those samples which were dried with the fluidised bed dryer and subsequently sun dried and stored for only one month had HRY of 63.29%, 60.06%, 58.37% and 64.25% for drying at 60ºC, 80ºC 100ºC and complete sun drying respectively”.

“An investigation was conducted to examine the drying characteristics of long-grain paddy (PR-118 variety) using an integrated dryer with multiple heating sources, including solar, biomass, and electricity. The study found that paddy drying occurred in the falling rate period, with drying times ranging from 5 to 9 hours, depending on the energy source used. To model the drying behaviour, six mathematical models were evaluated, and the Wang and Singh model was found to best describe the drying behaviour using solar, biomass, and combined heating sources. However, the Page model was more suitable for describing the drying behaviour using electrical heating” (Manikantan et al., 2014).

Danbaba et al. (2011) evaluated “the cooking and eating quality of rice. They showed that Ofada rice had high cooked rice volume with length and breadth increase of 152.54% and 87.85% respectively. Gelatinization temperature (GT) ratio ranged from 1.24-1.75 with Ofada10 having the lowest value and *Ofada*11 was having the highest value. The highest length/breadth ratio of cooked rice (3.68) was recorded by Ofada8, while *Ofada*3 had the lowest (2.49) and grain elongation (GE) index ranged from 0.99-1.44 with *Ofada*10 having the lowest value and Ofada11 was having the highest value. Water uptake (WU) ratio, cooking time (CT), cooking gruel (SCW) and amylose content (AC) of *Ofada* rice samples ranged from 174.0-211.0, 17-24 min, 0.8-2.1%, and 19.77-24.13% respectively. It is noticed from the earlier investigation that very few studies have been sought out on raw paddy drying by SBD, STD and SD drying technique concerning to cooking quality. Thus, the present study was focused on quality aspects of raw paddy by three drying methods as a comparative study”.

2. MATERIALS AND METHODS

2.1 Sample Collection

“For comparison of the drying methods, the SBD, STD and SD systems were installed in Krishi Vigan Kendra, ICAR- Central Institute of Fresh Water Aquaculture (CIFA) in Khorda district, Odisha. All the three systems were installed in the same place (with adequate distance in between them) so as to get uniform surrounding conditions” (Jyoti et al., 2023).

2.2 Experimental Setup

The solar bubble dryer was compared with solar tunnel dryer and sun drying to assess its performance for drying of paddy in terms of drying characteristics as well as quality of end product. The investigation was carried out in Department of Agricultural Processing and Food Engineering, College of Agricultural Engineering and Technology, Odisha University of Agriculture and Technology, Bhubaneswar and ICAR-CIFA, Bhubaneswar. The drying experiments were started in the morning and the freshly harvested grains of the previous day were put in the dryers. The ventilators in the SBD were allowed to operate during the whole time of each experimental trial.

2.2.1 Solar bubble dryer

The solar bubble dryer (SBD) is the latest low-cost drying technology developed by IRRI, Hohenheim University and GrainPro. It basically constitutes a drying chamber which is made up of a black polythene sheet at the bottom and UV stabilized PE sheet as the glazing material. A zipper is used to seam the glazing materials from both sides after spread of the materials. The ventilators are set up with the help of a collapsible aluminium bar frame. Solar panels (100 W) are fitted on an aluminium frame to get maximum sun light collection, in Indian situation it would be in the north-south direction at 45° angle. A solar battery (12V, 70Ah deep cycle battery) is connected to the 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. The ventilators are started to make the dome like shape of the polythene plastic roof and drying operation. It comes in different sizes, with current model having 0.5 and 1 tonne per batch capacity.

The SBD is mobile and is completely independent from fuel or the power grid, and therefore has very low operating cost. The SBD uses energy from the sun in two ways. First the drying tunnel serves as a solar collector to convert the energy contained in the sun rays entering the transparent top of the drying tunnel to heat, which increases the temperature of the drying air for faster drying. The solar panel, a deep cycle rechargeable battery and a controller generate electricity that drives a small blower to move air through the drying tunnel, inflate the tunnel, and remove the water evaporated from the grains placed inside the tunnel. A simple roller dragged on ropes attached to the ends underneath the tunnel is used for mixing the grains without the need to open the tunnel. A rake for internal mixing is also available. The SBD can be used on any reasonably plane surface like a pavement, on a lawn or even in a harvested rice field with short stubbles. The SBD should be exposed to the sun throughout the day, so it needs to be set-up clear of buildings, trees or other structures that might provide shade at some time during the day.

As per the recommendations for installation of the solar bubble dryer, the following steps were adopted for best results:

- The location was selected so that it was exposed to the sun throughout the day, in 90° angle towards the path of the sun.
- Before spreading the drying tunnel, the ground was checked and any pointed objects that might damage the plastic were removed. The ground was levelled in uneven areas.
- The tunnel was levelled, pulled at the ends to make sure it did not have any folds, which would get the mixing roller stuck.
- The photovoltaic system was assembled and the battery, solar panels and blower to the controller were connected, as indicated in the manual.
- The solar panel was positioned so that it faced the sun (adjust it during the day).
- The drying tunnel was loaded leaving one meter after the blower free of grains, the grain was spread evenly up to the sides of the tunnel. The roller was used for mixing the grains.

The different components of solar bubble dryer are shown in the Fig. 2. The experimental lay out of the solar bubble dryer is shown in Fig. 3. The observations on the air parameters were taken with the help of a data logger, which were later transferred to computer for the analysis.

Fig. 1. Solar bubble dryer

Fig. 2. Components of solar bubble dryer

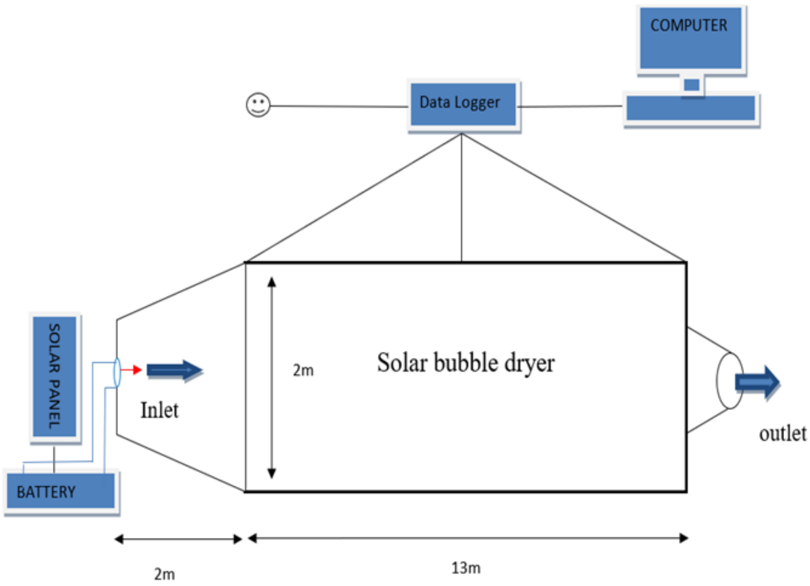

Fig. 3. Layout of solar bubble dryer experimental set up

For the present experiments, after taking the initial moisture content and weight of paddy, the grain was spread uniformly on the base, i.e. the black sheet of the solar bubble dryer (SBD). Three data loggers were fitted at different locations for recording of temperatures. Thereafter, the cover was stretched and zipped and drying operation was started. After the drying operation, the data from the data loggers was transferred to a computer. The continuous temperature reading at one-minute interval during drying operation was thus obtained.

2.3 Sample Preparation

The grains were spread in the solar tunnel dryer and were kept for open sun drying at the same location of the solar bubble dryer taking proper care that there was no shade on the tunnel. The observations on the ambient temperature, relative humidity was also taken on hourly intervals with the help of a data logger. The sun drying was done with 150 kg grain.

2.4 Assessment of Milling Performance

100 g paddy sample was taken and de-husked using a laboratory rice dehusker (Make: SATAKE, model: TMU35B) and milled in a single pass with proper gap between rollers adjusted for the grain variety. Thereafter the brown rice was milled in testing mill (Make: SATAKE, model: JM05C) and the bran and rice were collected in two different outlets. An indented cylinder separator used to separate the head rice and the broken rice. The head rice yield and total yield were determined by using the following formulae as per Saleh & Meullenet (2007).

The total rice yield and head rice yield were found out as follows.

$$\text{Total yield (\%)} = \frac{\text{Weight of the white rice}}{\text{weight of paddy}} \text{ X } 100 \qquad (1)$$

$$\text{Head rice yield (\%)} = \frac{\text{Weight of the head rice}}{\text{weight of total rice}} \text{X } 100 \qquad (2)$$

2.5 Statistical Analyses

In order to conduct the experiment in a systematic an efficient manner, the experiments were planned on two factorials completely randomized design (CRD). The effect of drying air temperature and mode of air flow on moisture content, drying rate, total rice yield, head rice yield, water uptake, solid loss, elongation ratio and volume expansion were analysed statistically through two-way analysis of variance (ANOVA).

3. RESULTS AND DISCUSSION

3.1 Quality Evaluation of Dried Paddy

3.1.1 Effect of drying method on milling quality

3.1.1.1 Total rice yield

Total rice yield is the most important criteria in assessing the quality of paddy, which is greatly influenced by drying. Total yield for paddy dried in different drying methods is shown in Fig. 4. The total yield of rice obtained was 68.70±1.21% for solar bubble dryer, 67.44±1.39% for solar tunnel dryer and 66.63±1.71% for solar drying.

Earlier, Meas et al. (2011) have reported that "head rice yield reached 57.70 % after shade drying in the rainy season, but it was only 46.50% during the dry season. This difference was attributed to the different varieties, growing and harvesting conditions. Although considerable over-drying occurred in inflatable solar bubble and sun drying during the dry season, no significant difference in head rice yield was found".

The statistical analysis for the effect of drying methods on milling recovery indicated that there was no significant difference ($CD_{0.05}$ = 1.84) in the total yields obtained from paddy dried by different methods.

3.1.1.2 Head rice yield

The head rice yield was 56.24±0.80% for solar bubble dryer. For the solar tunnel dryer, the value was 54.35±0.19 % and for solar drying it was 52.46±1.09 %. It was observed that head rice was maximum for solar bubble dryer as shown in the Fig. 5. Prakash (2019) also observed complete sun drying had head rice yield of 62.27%, 63.55% and 61.91%. Those samples which were dried with the fluidised bed dryer had head yield of 63.29%, 60.06% and 58.37%.

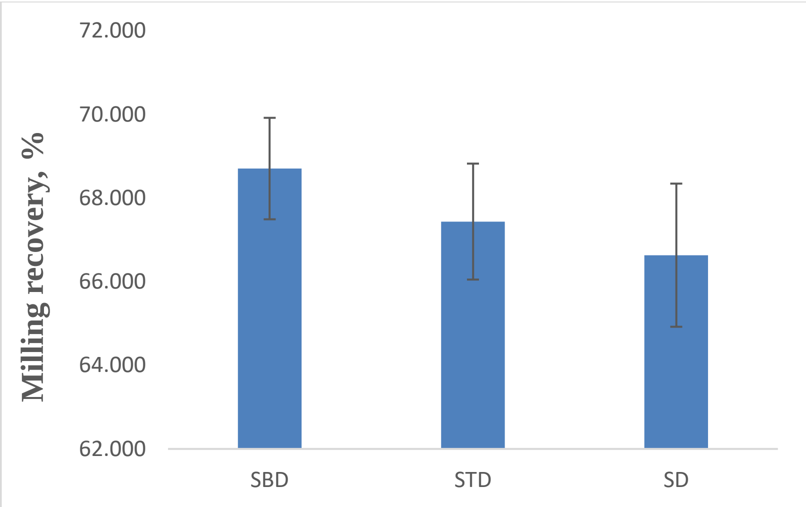

Fig. 4. Variation of milling recovery (Total yield) with different drying methods

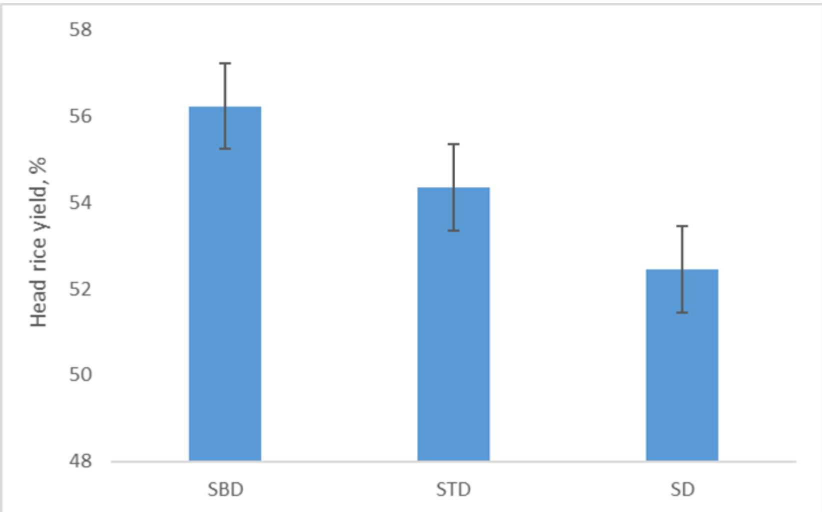

Fig. 5. Variation of head rice yield with different drying methods

The statistical analysis indicated that there was significant variation ($CD_{0.05}$ = 1.31) in the head rice yield for the three drying methods. In case of solar bubble drying the higher head rice yield is attributed to low local temperature on the grain surface which was due to the higher rate of air flow around the grain.

As far as the milling quality is concerned, there was no significant difference in between the drying methods; but there were significant differences in the cooking qualities as water uptake, elongation ratio, volume expansion and solid loss, and the solar bubble dryer gave the most acceptable product in terms of these quality parameters.

4. CONCLUSION

The solar bubble dryer (SBD), developed by IRRI, Hohenheim University, and GrainPro, offers a cost-effective and efficient alternative to traditional drying methods, particularly for rural areas lacking access to modern infrastructure. In this study, SBD demonstrated promising results for drying paddy compared to STD and SD. Total rice yields were 68.70±1.21% for SBD, 67.44±1.39% for STD, and 66.63±1.71% for SD, with no statistically significant differences among the methods. However, SBD achieved the highest head rice yield (56.24±0.80%), surpassing STD (54.35±0.19%) and SD (52.46±1.09%), indicating better preservation of grain integrity. Beyond milling performance, SBD excelled in maintaining superior cooking quality parameters, including water uptake, elongation ratio, volume expansion, and reduced solid loss, offering a more consumer-acceptable product. These findings highlight SBD's potential as a sustainable and scalable solution for paddy drying, particularly in resource-constrained settings, providing significant advantages in reducing post-harvest losses, improving rice quality, and enhancing rural livelihoods. Future research should explore long-term storage implications and cost-benefit analysis to validate SBD's adoption on a larger scale.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

ACKNOWLEDGEMENT

The authors are thankful for the technical assistance provided by the College of Engineering and Technology at OUAT, Bhubaneswar. They also express gratitude to the reviewers whose identities were concealed for their helpful comments that led to a significantly modified text. The authors are grateful to Krishi Vigan Kendra, ICAR- Central Institute of Fresh Water Aquaculture (CIFA) in Khorda district, Odisha.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/127857