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Recent advances in solar bubble drying of paddy: A comprehensive review on technical applications

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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. About 65% population of India consumes rice. Drying is the one of the most important post-harvest processes to improve yield in rice production. Farmers mostly perform drying of rice traditionally by sun drying. Sun drying has many disadvantages such as: over-drying, animals feeding on the grains, spillage and nonuniform drying. The (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 aluminum bar frame. 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. Several types of materials can be used for the glazing of STD. The criteria for selection of glazing material would depend on the transmission of solar radiation, strength, resistance to weathering, surface condensation properties, availability and cost. Ultra-violet stabilized polythene sheet is thus considered the best glazing material among commonly available materials. Therefore, various researchers concluded that Solar Bubble Dryer can be one of the best options for drying of rough rice.

Keywords: Solar drying, rough rice, drying rate, solar bubble dryer, total rice yield

Introduction
Traditional/open sun drying after the maturity stage of the plant causes a significant percentage of postharvest loss of grains in underdeveloped nations. After harvesting, solar drying is a fantastic choice for reducing loss and producing high-quality grains. For freshly harvested paddy grain, the performance of a newly developed solar bubble dryer and a thin-layer drying mathematical modeling are described. This research will benefit not just small-scale farmers, but also all agricultural cooperatives by providing a low-cost and sustainable grain drying system. Producing safe grain products for consumers and many food businesses will be critical. It can also be used to aid in the design, modeling, and performance evaluation of solar dryers.

Before or after harvesting, one of the most often used ways for preserving cereal crops is drying, which involves removing moisture from the crops and reducing it to a safe storage level. Sun-drying or on-field drying is still the most common method for preserving cereals and other agricultural goods before and after harvesting in most tropical and subtropical regions. However, this approach has a number of drawbacks, including contamination in outdoor environments, product degradation owing to microbiological or biochemical reactions, insect pest losses, high labour expenses, harsh temperature conditions, and so on (Mujumdar, 2007) [12]. The amount of time necessary to dry an agricultural commodity in the open sun can be rather long, resulting in postharvest losses of up to 30% (Hii, Jangam, Ong and & Mujumdar, 2012) [6].

Paddy grain is dried in Ethiopia by keeping it on the field for long periods of time before harvesting; or by bending mature maize stalks; or by "doubling" the initial cob so that the tips point downwards. The crop can be left in the field for up to four months, during which time it is susceptible to losses from birds, moulds, and insects. Cutting the crop and stacking it in the field is another alternative; this stage might be considered a temporary drying/storage phase. Traditional drying techniques result in a loss of up to 16.6%. (Hodges, Buzby, & Bennett, 2011; Rembold *et al*., 2011) [7, 15].

When the grain is rewetted, such as during rapid rain showers during sun drying or when grains with substantially varying moisture contents are blended for drying, the most damage occurs. To reduce postharvest losses, maize grain should be collected around physiological maturity, at a moisture content of 22–25 percent (w.b.) (Thomison, 2010) [18], then artificially dried. Grain collected and dried in this manner is less susceptible to climate change because it remains on the field for a shorter period of time. It is also protected from insect attack and microbes, which would otherwise degrade its overall quality. Solar drying is a more environmentally friendly alternative to open-air drying.

Solar drying of cereal crops utilizing an enclosed and forced convection drying system is a viable way to avoid postharvest losses and limit quality degradation of dried products, which is typical in open sun-drying methods (Jain & Tiwari, 2003) [9]. As a result, correct solar dryer design should be addressed in order to meet the specific drying requirements of any agricultural product while also achieving reasonable energy efficiency. The drying rate of various crops under various situations must be determined before a solar dryer can be designed (Ismail & Ibn Idriss, 2013) [8]. Furthermore, thin-layer drying mathematical models are an essential tool for comprehending any commodity's drying characteristics. They are widely used to explain product drying kinetics, especially when the geometry of the product is complex.

There has been a recent advancement in the use of low-cost solar bubble dryers (SBD) for the drying of various grain products. SBD is a newly developed forced sun drier for large-scale production, capable of handling up to one tonne at a time. SBD is also a cutting-edge multicrop drying technology that reduces the impact of unpredictably bad weather on commodities throughout the drying process. Manufacturers initially evaluated the dryer's performance in the Philippines in 2016 for paddy rice drying (Salvatierra-rojas, Nagle, Gummert, De Bruin, & Müller, 2017) [16]. The SBD was recently compared to other dryers for paddy drying in four Southeast Asian nations, Vietnam, Cambodia, Myanmar, and the Philippines, in terms of cost-benefits, labour operation, and energy efficiency.

According to reports, the SBD uses less energy and emits fewer carbon gases than other techniques by more than half (Nguyen-Van-Hung, Meas, Tado, Kyaw, & Gummert, 2019) [13]. However, there is a scarcity of information regarding the SBD's maize drying performance. Furthermore, the application of thin layer drying kinetic models for grain drying utilising the SBD has yet to be determined. In order to explore the drying characteristics of freshly harvested maize grain in an SBD and to estimate the optimal thin layer drying kinetics model under warm and temperate climatic circumstances, such as those found in Bahir Dar, Ethiopia, this study was done.

This study used freshly harvested maize grains (Zea mays) of the BH-540 and BH-660 kinds collected from farmers in the communities of Merawi district, 35 kilometres from Bahir Dar, Ethiopia. With an estimated average annual temperature of 19.6 °C and rainfall of 1,419 mm, the climate is classed as warm and temperate. The highest average monthly temperature is around 29.7 °C in April, while the lowest average monthly temperature is around 23.3 °C in July and August. In January, the average monthly low temperature is 7.1 °C, while in May, it is 14.2 °C. The daily hours of sunshine range from 6 hours (in July and August) to 10 hours (in January and February) (Weldegerima, Zeleke, Birhanu, Zaitchik, & Fetene, 2010) [20]. To eliminate exposed surfaces for insects and mould during storage, the grain was harvested and threshed manually with great care and precision. It was transferred to the trial site in polyethylene bags and stored in a cold room (5 °C) until the drying procedures began

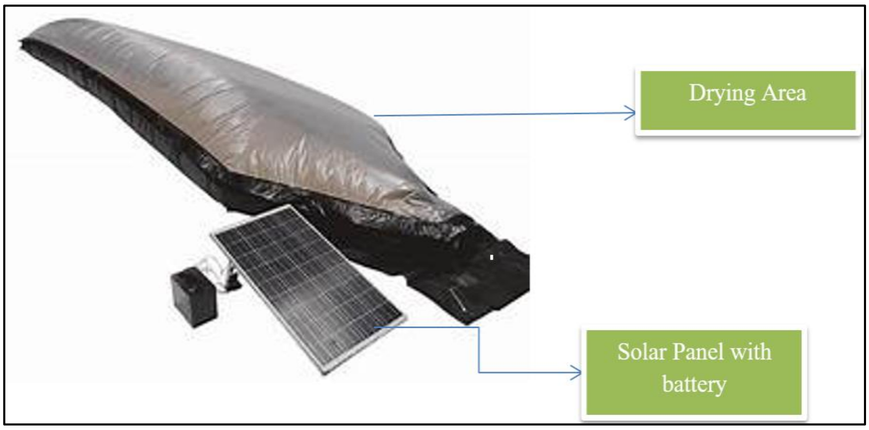

Fig 1: Schematic diagram of solar bubble dryer

Recent advances in solar bubble dryer for paddy

In Bangladesh, Alam *et al.* (2019) [3] investigated mechanical paddy drying using a BAU-STR dryer to reduce drying losses. They found that average paddy drying loss in BAU-STR dryers was 0.48 percent and 0.36 percent during Boro and Aman seasons in 2015 and 2016, respectively, while sun drying loss at farmer's field level was 3.95, 3.24, 2.98, 2.41, and 3.04 percent in Tangail, Mymensingh (Phulpur), Mymensingh (BAU), Netrokona, and Jessore districts, respectively.

Inflatable sun dryer (ISD) created by Rojas *et al.* (2017) for enhanced postharvest handling of paddy rice in humid areas. They stated that sun and shade drying were done simultaneously for a comparative study of drying, and that the product was examined for moisture content and quality in terms of milling recovery and head rice yield. Because to the reduced drying time, the ISD outperformed sun drying. Jibhakate *et al.* (2016) [10] used a taguchi lorthogonal array to evaluate the efficacy of a solar tunnel dryer for drying red chillies. They claimed that open sun drying resulted in a significant reduction in drying time and improved dried product quality.

Aktar *et al.* (2016) [2] investigated the performance of a STR paddy dryer. The drying temperature of the STR drier for paddy drying was reported to be in the range of 38 °C to 42 °C. The STR dryer's drying and heat conveyance efficiency were found to be around 31.2 percent and 19.91 percent, respectively. The overall dryer efficiency was determined to be at 22.7 percent, which is satisfactory for a batch dryer. Candia *et al*. (2015) [5] investigated an open-sun drying method for Ugandan marsh rice. They stated that the "Kaiso" variety should be dried for two days at a depth of 80 mm, then dried at a depth of 30 to 40 mm for further drying.

At Prathumtani, Thailand, Sookramoon *et al*. (2015) [17] evaluated the performance of a solar tunnel dryer for paddy drying. In under 6 hours, the moisture content dropped from 49.96 percent MC (wb) to 17.64 percent MC (wb). 67.75 °C was the average drying temperature. The heated air had a temperature of 344.47 W, whereas the solar tunnel dryer had a temperature of 1738.34 W. The average thermal efficiency of a solar tunnel drier was 22.72 percent.

Wankhade *et al*. (2014) [19] investigated the design and evaluation of a solar dryer. They discovered that the highest drying air temperatures inside the dryer cabinet were 57 °C. The drying cabinet's average drying air temperature was greater than the ambient temperature, ranging from 5 °C in the morning to 20-25 °C in the afternoon. The average temperature in the drying cabinet was found to be 2-5 °C higher than that of the air-heater, indicating that the extra heat absorbed from direct sun radiation via the transparent walls was justified. As the air velocity through the system increased, so did the dryer's efficiency.

Ahmad *et al*. (2014) [1] investigated the performance of cross-flow rice dryers. The gas-fired and rice husk-fired dryers' drying air temperatures were 54° and 66 °C, respectively. The average air flow rate of gas-fired and rice husk-fired cross-flow dryers, however, was 6.24 and 2.60 m3s-1, respectively. The gas-fired dryer had a drying rate of 2.0 percentage point h-1, while the rice husk-fired dryer had a drying rate of 1.0 percentage point h-1. Gas-fired and rice husk-fired dryers have drying costs of around Rs. 0.21 and 0.16kg-1, respectively. The gas-fired dryer's overall performance was satisfactory, but the rice husk-fired dryer's performance may be enhanced by including an appropriate heat exchanger.

Meas *et al*. (2011) [11] evaluated the effects of several solar drying methods on rice grain quality and drying time. The grain moisture content was monitored at regular intervals, they said. The drying time was influenced by the grain kinds employed, bed depths, grain churning, bulk tempering after drying, and drying pads. When the bed depth was reduced, the bed was periodically stirred but not shaded or covered, and the drying was done on a porous pad, the drying was faster. When the bed was thin, agitated, and shaded, as well as when the drying was delayed on pads with less air circulation, damage to the dried grain was reduced.

Bhandari and Gaese (2008) [4] worked on evaluation of box type paddy dryers in south Sumatra, Indonesia. They reported that Sun drying, whenever possible, is the cheapest option for the farmers if they want to sell their dry paddy. If the farmers sell rice, use of box dryer for drying their paddy makes more profit than using sun drying, provided a market for different quality rice exists.

Conclusion

To avoid the drawbacks of traditional sun drying methods, a solar bubble dryer is the finest solution. The solar bubble drier is specifically intended for drying agricultural products, particularly rice. Direct, indirect natural, and indirect forced convection drying are discussed in this work. It has been discovered that the time necessary for drying in a solar bubble dryer is less than that required in other types of dryers. SBD is a newly developed forced sun drier for large-scale production, capable of handling up to one tonne at a time. SBD is also a cutting-edge multicrop drying technology that reduces the impact of unpredictably bad weather on commodities throughout the drying process.

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