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RESEARCH ARTICLE

HOT-AIR BATCH DRYER FOR PADDY: EVALUATION OF PERFORMANCE AND QUALITY OF DRIED PADDY

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Abstract

This study aimed to assess the drying performance of an electric-powered hot-air batch dryer. Freshly harvested paddy (BG350) with initial moisture contents of 18.62 ± 1.75% and 21.91 ± 2.54% (wet basis) was dried at bed thicknesses of 0.10 m and 0.25 m, and evaluated for moisture content, germination rate, and head rice yield using two-way ANCOVA and non-linear regression. Performance evaluation was conducted according to ISO 11520-1:1997 standards. According to the results, the moisture content of paddy was lowered to 13.56±0.35% and 14.38±0.08% (wet basis) within 70 and 140 minutes of drying time for 0.10 m and 0.25 m bed thicknesses, respectively. The drying curves illustrated a falling-rate period. The drying rate constant (k) was 0.0059 for the 0.10 m bed and 0.0035 for the 0.25 m, confirming that drying was faster at the lower bed thickness, as indicated by the higher k value. Statistical analysis revealed that, after controlling for initial moisture content, both bed thickness and drying time had a significant effect ($p \leq 0.05$) on the final moisture content. Bed thickness also significantly affected ($p \leq 0.05$) germination rate, cracked grain percentage, and head rice yield. However, discoloration analysis indicated no significant effect of bed thickness or initial moisture content on grain color. In conclusion, the study demonstrated that the paddy bed thickness in the electric-powered hot-air batch dryer significantly impacts both drying efficiency and quality of dried paddy. These findings provide valuable insights for optimizing drying conditions to enhance paddy quality and dryer performance.

Keywords: Cracked grain percentage, Drying rate, Grain drying, Moisture content, Postharvest

INTRODUCTION

Rice (*Oryza sativa*) is the primary staple food in Sri Lanka and is deeply embedded in the nation's diet, culture, and agricultural economy. Paddy cultivation is crucial in ensuring national food security while providing a livelihood for a significant portion of the population. Approximately 25% of Sri Lanka's population is involved in agriculture, either directly or indirectly, and nearly 40% of the country's cultivable land is dedicated to paddy cultivation (ITA, 2024). Given the critical importance of paddy production, optimizing post-harvest processing techniques, including drying, is essential to minimize losses and maintain grain quality. In 2024, despite challenges such as fluctuating weather conditions, pest infestations, and variations in input costs, Sri Lanka's paddy production demonstrated resilience, achieving a total output of approximately 4.75 million metric tons, an increase of 5.2% compared to the previous year (DCS, 2025).

One of the significant post-harvest challenges in paddy production is managing high moisture content in freshly harvested grains. After harvesting, paddy grains are highly susceptible to deterioration when exposed to low temperatures and high relative humidity conditions that accelerate spoilage and negatively impact grain quality (Ashfaq *et al*., 2016). Inefficient drying processes exacerbate this issue, resulting in both qualitative and

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quantitative losses. Moist grains are highly susceptible to discoloration and mold development, which pose significant threats to food safety and marketability. Additionally, elevated moisture levels increase the risk of pest infestations, irrespective of the type of storage facility used. Beyond storage concerns, excessive moisture content also negatively affects the germination potential of rice seeds, compromising their viability and reducing overall productivity in subsequent planting cycles (Pan *et al*., 2008).

Rice grains are usually harvested with a moisture content ranging from 20% to 25% (wet basis), which needs to be lowered to around 14% or less to allow for safe storage and minimize the risk of spoilage (Islam *et al*., 2024). Drying is vital in post-harvest handling, involving heat and airflow to remove excess moisture through evaporation (Kumar *et al*., 2014). In many developing countries, conventional methods like sun drying and open -air ground drying are still commonly used because they are cost-effective and straightforward. However, these conventional approaches present several challenges and limitations. Since the grains are directly exposed to the environment, they are highly susceptible to spoilage due to adverse weather conditions, including unexpected rain, wind, high humidity, and contamination from dust. Additionally, losses from birds, insects, rodents, and other pests are common, significantly reducing both quantity and quality of the grain. The slow drying rate associated with traditional methods further exacerbates the risk of mold growth, which can cause grain deterioration and decomposition, ultimately diminishing its nutritional and economic value (Raju *et al*., 2013). Given these challenges, the adoption of mechanized drying systems, such as hot-air batch dryers, is critical for improving drying efficiency, minimizing losses, and maintaining the overall quality of paddy grains.

Artificial or mechanical drying methods offer significant advantages over traditional drying techniques by accelerating the drying process, minimizing handling losses, and preserving the overall quality of the grain. These methods provide better control over drying parameters, ensuring that paddy reaches the desired moisture content efficiently and uniformly, enhancing its suitability for safe storage, transportation, and subsequent processing (Masood *et al*., 2018). Among the various mechanical drying techniques, hot-air dryers are particularly favored due to their ability to operate year-round, achieve faster drying rates compared to sun drying, and maintain precise control of grain quality. Mechanical drying of maize has been reported to yield equal or superior nutritional quality compared to sun drying, with lower ΔE values indicating minimal color changes. Moreover, drying maize at 60-80 °C in mechanical dryers requires only 8-10 h, whereas sun drying at about 35 °C takes about 16.14 h (Alam *et al*., 2023).

Innovative drying technologies have enhanced both the quality of paddy and the efficiency of the drying process by shortening drying time, minimizing energy usage, and preserving the grain's microstructure and nutritional content. Despite recent advancements in alternative methods, such as infrared (Wang *et al*., 2025) and microwave (Fan *et al*., 2024), hot air drying remains the most extensively studied and widely applied technique in many countries (Mahmood *et al*., 2024).

Although hot-air batch dryers are widely used for paddy processing in Sri Lanka and other rice-producing regions, their performance under local operating conditions has rarely been systematically evaluated. Limited information on drying kinetics, energy efficiency, and quality outcomes restricts the ability to optimize process parameters, which can lead to energy inefficiencies and reduced grain quality. To fill this gap, the current study systematically assesses the performance of a hot-air batch dryer at the Faculty of Agriculture, Rajarata University of Sri Lanka, focusing on drying kinetics, energy efficiency, and the quality of dried paddy. The results aim to offer practical insights for dryer operators and researchers, assisting in optimizing operating conditions to improve drying efficiency, boost grain quality, and decrease postharvest losses.

MATERIALS AND METHODS

Freshly harvested paddy (*Oryza sativa*) (variety BG350 available at the faculty farm) was obtained from the agricultural research fields of the Faculty of Agriculture, Rajarata University of Sri Lanka, in Anuradhapura.

Hot-air batch dryer used for the experiment

The electric-powered hot air dryer used for performance evaluation was specifically designed for drying paddy in batch mode. The drying system consisted of two primary components: the air heating unit and the drying chamber. The heating unit was responsible for generating and delivering heated air to facilitate the drying process. It comprised a centrifugal fan, which supplied the necessary airflow to the system; an electric heater to raise the air temperature; an air transfer motor; an exhaust fan; and a conveying pipeline to distribute hot air. The heated air was introduced at the base of the drying chamber and allowed to flow upward through the paddy bed, promoting uniform moisture removal.

The drying chamber was a horizontally oriented cuboid structure with internal dimensions of 1.82 m × 0.60 m × 0.73 m. The chamber's four lateral sides were constructed using 3 mm thick wooden sheets, providing insulation and structural integrity. The paddy was placed on a metal perforated floor inside the drying chamber, allowing even air distribution through the grain layers.

Additionally, the system featured an automatic on-off mechanism for the air transfer motor, which regulated the airflow to prevent overheating and optimize energy consumption. The motor operated on a five-minute cycle, switching on for five minutes and off for the next five minutes. This intermittent airflow control helped maintain a balanced drying environment while optimizing energy consumption.

Experimental Procedure

The dryer was loaded with freshly harvested paddy samples of two different heights of bed thickness (0.1 m and 0.25 m), and the samples were dried to a target moisture level of 12 – 14% (wet basis). During the drying process, variations in temperature within the drying chamber and changes in moisture content were measured at ten-minute intervals. Five K -type thermocouples were installed inside the drying chamber, and data were recorded using a data logger (Omega 2400, USA). One thermocouple was placed at the center of the bin, while the remaining four were positioned along a diagonal line, each 0.24 m away from the cuboid corners.

Physical and quality characteristics of dried paddy

Paddy moisture content

During the testing period, the moisture content of the paddy was determined at ten-minute intervals using the oven dry method. Approximately twenty grams of paddy were placed in a porcelain cup and dried in an oven maintained at 103 °C for 24 hours.

Moisture measurement samples of paddy were collected from locations where thermocouples had been inserted. The samples were immediately sealed in polyethylene bags to avoid moisture loss before oven drying. The wet basis moisture content was subsequently determined using Equation 1.

$$MC_{wb} = \frac{(W_w - W_d)}{(W_w)} \qquad \text{(Eq. 1)}$$

Where; MC_{wb}: Moisture content (wet basis), W_w: Weight of the wet grains (g), and W_d: Weight of the dry grains (g)

The weight of the paddy samples was analyzed using a lab-scale digital analytical electronic balance (accuracy ±0.001g). The dry basis moisture content (MC_{db}) was calculated using Equation 2:

$$MC_{db} = \frac{(W_w - W_d)}{(W_d)} \qquad \text{(Eq. 2)}$$

Where; MC_{db}: Moisture content (dry basis), W_w: Weight of the wet grains (g), and W_d: Weight of the dry grains (g)

The simplified form (Eq. 3) of the Newton model (Lewis, 1921), obtained by assuming the equilibrium moisture content is approximately zero, was applied to estimate the drying rate.

$$M_t = M_0 e^{(-kt)} \quad \text{(Eq. 3)}$$

Where; M_t: moisture content at time t (%, db), M_0: initial moisture content (%, db), k: drying constant (min^-1) , and t: drying time (minutes).

Germination percentage of paddy

The germination percentage of paddy was measured after the drying trials. For the germination test, water-absorbent material was placed inside the water-resistant tray. One hundred seeds of paddy in each experiment were randomly selected and placed on carefully saturated absorbent material for ten days; the absorbent cloth was checked to ensure it remained moist, and the number of germinated seeds was counted. The germination test was done after five days, and every other test after ten days (IRRI, 2019).

The germination rate represented the average number of seeds that successfully germinated during 5- and 10-day intervals (Onofri *et al.*, 2018). The germination percentage was calculated using Equation 4.

$$\text{Germination percentage} = \frac{N_g}{N_t} \times 100 \quad \text{(Eq. 4)}$$

Where; N_g: Number of germinated seeds, and N_t: Total number of tested seeds

Cracked grain percentage

Approximately 150 g of dried paddy samples were dehulled using a Satake rubber roll huller (Model THU-35A, Japan). The resulting brown rice was then polished using an abrasive-type rice polisher. A small representative sample of a known weight was taken from the milled rice to determine the percentage of broken, cracked, and discolored grains. Cracked grains was identified through the visual inspection method (Crostack *et al.*, 2012). Equation 5 was used to calculate the cracked grain percentage.

$$\text{Cracked grain (\%)} = \frac{W_{cg}}{W_s} \times 100\% \quad \text{(Eq. 5)}$$

Where; W_{cg}: Cracked grain weight, and W_s: Sample weight

Head rice percentage

Head rice refers to milled kernels that remain intact after milling, with a length of at least three-fourths of the original kernel, and are not broken (U.S. Department of Agriculture [USDA], 2009). The head rice was measured through visual inspection. It includes broken kernels, 75-80% of the whole kernel. The head rice percentage was calculated using Equation 6 (Wazed *et al.*, 2022).

$$\text{Head rice (\%)} = \frac{W_h}{W_s} \times 100\% \quad \text{(Eq. 6)}$$

Where; W_h: Weight of Head Rice, and W_s: Weight of Total Sample

Discolored grain percentage

The discolored grain percentage and the milled rice color were determined using a Konica CR-10 Plus color reader (USA), and calculated using Equation 7 (Raghu *et al.*, 2020).

$$\text{Discolored grains (\%)} = \frac{N_d}{N_t} \times 100 \quad \text{(Eq. 7)}$$

Where; N_d: Number of discolored grains, and N_t: Total number of grains

Testing the dryer performance

Performance evaluation of dryer was carried out according to ISO 11520-1:1997 Standards. The drying process parameters that provided the highest quality dried paddy were selected for the performance testing. The ambient air temperature was recorded using the data logger (Amprobe TMD 56, USA) and K-type thermocouples. Ambient relative humidity was estimated by using wet and dry bulb temperatures and a psychometric chart. Barometric pressure was measured using an Android-based barometer (Weems RS15700, USA). The electrical current was measured by a clip-on ammeter (Fluke 362, India).

The filling, drying, cooling, and emptying times of paddy were measured using a stopwatch. The electrical energy consumption during the drying process was calculated using Equation 8.

$$W_e = (P_{ed} \times t_d + P_{ec} \times t_c) \quad \text{(Eq. 8)}$$

Where; W_e: electrical energy consumption (kWh), P_{ed}: power of electrical drying (W), P_{ec}: power of electrical cooling (W), t_d: total test drying time (h), and t_c: cooling time (h).

The parameters for Equation 8 were calculated using Equation 9.

$$P = I \times V \quad \text{(Eq. 9)}$$

Where; P :either P_{ed} or P_{ec}, V: voltage (V), and I: current (A).

The total operational time was estimated using Equation 10.

$$t_d + t_c = t \quad \text{(Eq. 10)}$$

Where; t_d: drying period (h), and t_c: cooling time (h).

The thermal power required for drying was calculated using Equation 11.

$$P_t = F \times H \quad \text{(Eq. 11)}$$

Where; P_t: thermal power (W), F: fuel consumption (kg/h), H, and Net calorific value of electricity- 860 kcal/kWh.

The total mass of evaporated moisture was estimated by using Equation 12.

$$E = m_f \frac{(M_i - M_f)}{(100 - M_i)} \quad \text{(Eq. 12)}$$

Where, m_f: mass of final grain at the drier exit (kg), M_i: grain moisture content (%, wb) at the drier inlet, and M_f: grain moisture content (%, wb) at the drier exit.

The mean evaporation rate was calculated using Equation 13.

$$E' = \frac{E}{t_d} \quad \text{(Eq. 13)}$$

Where; E': mean evaporation rate, and t_d: time duration of the test period of drying.

Equation 14 gives the electrical power required for moisture evaporation.

$$P_e = U \times I \times \cos\theta \times \sqrt{3} \quad \text{(Eq. 14)}$$

Where; P_e: electrical power (W), U: electrical voltage (230 V), and I: electrical current (A).

$\cos\theta$ = Power factor- 0.8

The specific thermal energy consumption of the dryer was determined using Equation 15.

$$Q = \frac{W_t}{E} \quad \text{(Eq. 15)}$$

Where; Q: specific thermal energy consumption (kWh/kg), W_t : thermal energy consumption (kWh), and E: evaporation mass (kg).

The thermal energy consumption of the dryer was calculated using Equation 16.

$$W_t = P_t \times t_d \quad \text{(Eq. 16)}$$

Where; P_t: thermal power (kW), t_d: the time duration of the test period of drying (h).

The specific total energy consumption (both electrical and thermal) per unit evaporated moisture was calculated by Equation 17.

$$S = \frac{(W_e + W_t)}{E} \quad \text{(Eq. 17)}$$

Where; S: specific heat consumption (kWh/kg), W_e: electrical energy consumption, W_t: thermal energy consumption (kWh), and E: evaporation mass (kg).

Statistical Analysis

Data were analyzed using Analysis of Covariance (ANCOVA) to evaluate the impact of drying bed height and drying time on final moisture content, germination rate, cracked grain percentage, head rice percentage, and grain discoloration, controlling for initial moisture content. The ANCOVA model for final moisture content included bed height and drying time as fixed factors, with initial moisture content as a covariate. For the other variables, germination rate, cracked grain percentage, head rice percentage, and grain discoloration, the model incorporated bed height as a fixed factor, again controlling for initial moisture content. Statistical significance was set at $p < 0.05$, ensuring robust findings throughout the analysis. Newton's drying model was applied using non-linear regression analysis to fit the drying data. The drying constant (k) and the coefficient of determination (R^2) were computed.

RESULTS & DISCUSSION

The performance evaluation of the batch dryer utilized in this study was conducted using a horizontal cuboid dryer with a volume capacity of 0.797 m^3. The dryer featured a length of 1.82 m, a height of 0.73 m, and a grain column thickness of 0.10 m. Air was introduced into the dryer through a perforated metal base, facilitating effective hot air transfer to the grain. The drying process was supported by two in-line centrifugal fans, each powered by a 1.1 kW motor, operating at a rotational speed of 96.66 rpm. These fans generated an airflow of 145.454 m^3/min and a pressure of 446.098 Pa, effectively enhancing the drying efficiency. The heating system, comprising a direct coil-type electric heater with an on/off control mechanism, maintained the temperature at 41.1 ºC, ensuring optimal conditions for drying. However, it is noteworthy that the dryer did not incorporate temperature and moisture probes, pressure indicators, or automated moisture discharge controls, relying instead on manual operations for both the air transfer motor and heater. The grain subjected to drying was identified as BG350 paddy with a bulk density of 1.176 g/cm^3 at 15% moisture content and a purity of 87%, which may impact the overall efficiency and quality of the drying process.

The drying performance of the electric-powered hot-air batch dryer for paddy was evaluated at two different paddy bed heights: 0.10 m and 0.25 m. The ambient temperature during this experiment was 32±0.01 ºC. The temperature distribution within the drying chamber was monitored and is shown in Figures 1a and 1b, corresponding to the 0.10 m and 0.25 m bed heights, respectively.

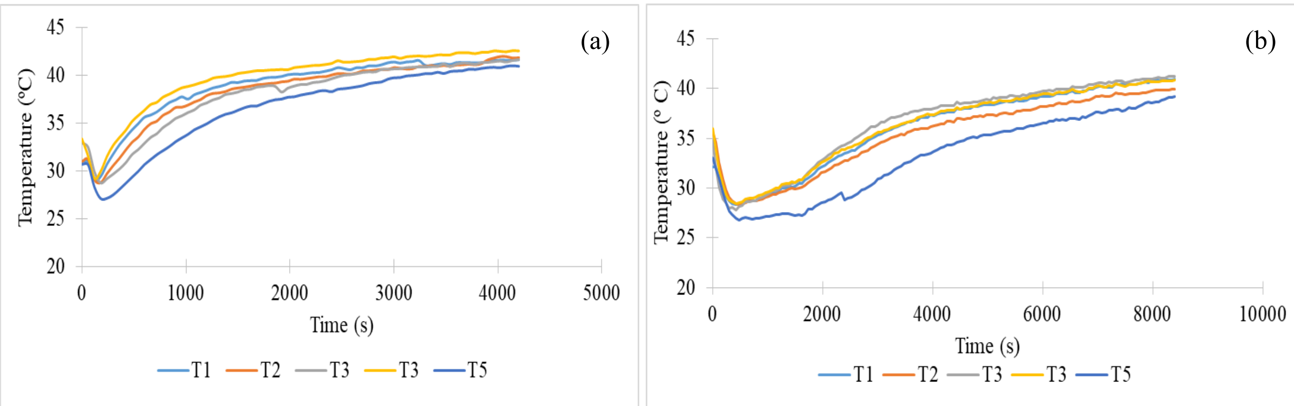

Figure 1(a): The paddy bed temperature at a height of 0.10 m, Figure 1(b): The paddy bed temperature at a height at a height of 0.25 m in the paddy

The experimental results suggest that the surface temperature of the drying bed is influenced by its thickness. The thinner bed (0.10 m) reached a higher temperature (38.27 ± 3.63 °C) compared to the thicker bed (0.25 m), which recorded a lower temperature (35.51 ± 2.02 °C). This suggests that reducing the bed thickness enhances heat transfer efficiency, leading to higher surface temperatures, which could be beneficial for optimizing drying processes.

Dried paddy moisture content

The drying duration was influenced by factors such as the initial moisture content and the thickness of the paddy bed. As shown in Figure 2, moisture content changes over time for each bed height.

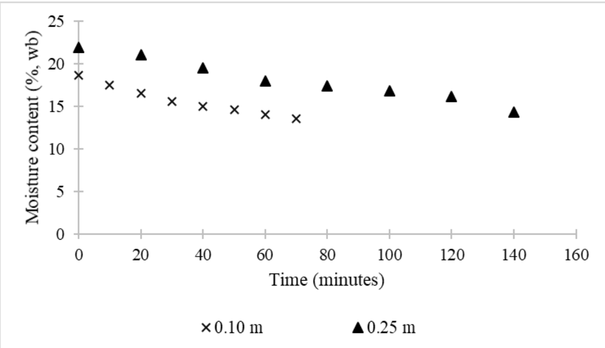

Figure 2: Moisture content variation with time for each paddy bed height

The drying rate constants (k) were 0.0059 for the 0.10 m bed and 0.0035 for the 0.25 m bed, indicating a faster drying rate at the thinner bed height. The exponential drying model equations were

for 0.10 m: $M_t=18.6149e^{-0.0059t}$,

for 0.25 m: $M_t=21.9113e^{-0.0035t}$.

The coefficient of determination (R^2) was 0.9798 for 0.10 m, and 0.9814 for 0.25 m, demonstrating a strong fit for both models. At 0.25 m bed height, the paddy moisture content decreased from 21.91% to 14.38% (wet basis) over an extended drying period, reflecting the increased resistance to airflow due to the thicker bed layer.

The ANCOVA results ($F(1,12) = 12.14$, $p = 0.0045$) indicated that height (0.1 m vs. 0.25 m) had a statistically significant effect ($p < 0.05$) on the final moisture content after controlling for initial moisture content. This suggests that drying height significantly influences moisture content. Thicker layers facilitate faster moisture reduction, while deeper layers prolong the drying time due to limited air penetration and moisture diffusion. Understanding these drying kinetics is crucial for optimizing batch dryer operation, ensuring uniform drying, and minimizing post-harvest losses. Srivastava and John (2002) examined thin-layer semi-empirical equations for predicting air humidity, air temperature, and grain temperature with varying heights of a fixed bed of grains under unsteady-state conditions. However, they did not investigate the variation in moisture content with paddy bed height.

The moisture content gradient within the paddy grains varied across different bed thicknesses throughout the drying process (Figure 2). The results indicated that the moisture reduction rate was steeper at the beginning of drying, particularly as the bed thickness increased. This initial rapid moisture loss can be attributed to the availability of free moisture on the grain surface, which evaporates more quickly when exposed to heated air. As drying progressed, the moisture content continued to decline, albeit at a slower rate.

Further, the drying process occurred entirely within the drying curve falling rate period without indicating a constant rate period. This suggests that moisture removal was primarily caused by internal diffusion rather than surface evaporation. Similar findings were reported by Manikantan *et al*. (2014), who also observed a non-evident constant rate period during paddy drying. The prevalence of the falling rate period suggests that the movement of moisture from within the grain to its surface became the primary limitation in the drying process, indicating the necessity of adequate time and controlled conditions to ensure even moisture removal.

For the 0.10 m paddy bed height, the drying process effectively reduced the grain moisture content from 18.62% to 13.57% (wb) within the recorded drying duration. The effect of time on final moisture content was highly significant, as indicated by $F(1,12) = 84.05$, $p = 9.08e\text{-}07$. The extremely small p-value confirms that grain moisture content decreases significantly as drying time increases. The effect of initial moisture content (Covariate) indicates $F(1,12) = 1453.84$, $p = 6.81e\text{-}14$. The covariate (initial moisture content) has a very strong influence on the final moisture content, which is expected since the drying process depends on the initial physical characteristics of paddy. According to Hemhirun and Bunyawanichakul (2020), higher initial moisture content led to a higher final moisture content in rough rice when dried for the same duration.

The residual sum of squares was 6.08 with 12 degrees of freedom, indicating a relatively small residual variance and suggesting a good model fit. Since the ANCOVA results showed significant p-values for height, time, and initial moisture content, we reject all three null hypotheses (H_{01}, H_{02}, H_{03}). This concludes that both drying height and time significantly affect the final moisture content after controlling for initial moisture content. Drying height affects moisture loss, potentially due to variations in air circulation at different heights. As expected, drying time was a significant factor, with longer durations resulting in greater moisture reduction.
The drying behavior observed in this study aligns with earlier findings on paddy drying characteristics. The results are consistent with those reported by Ng *et al.* (2005) in their research on the drying characteristics of Malaysian paddy at 60 ºC and 80 ºC, who reported that the drying rate decreased continuously, illustrating only a falling-rate period, confirming that moisture removal primarily occurred due to internal diffusion rather than surface evaporation.

The findings of this study further support that internal diffusion is the primary physical mechanism causing moisture movement within paddy grains during hot-air batch drying. Similar drying behaviors have been reported in other agricultural commodities, such as mushrooms (Arumuganathan *et al.*, 2009) and soybeans (Rafiee *et al.*, 2009), where moisture migration occurs predominantly through internal diffusion. The absence of a constant-rate period emphasizes the need for precise drying control to prevent excessive stress within the grain, which can lead to quality deterioration, such as formation of cracks or structural damage.

Quality characteristics of paddy
Germination rate
In this study, the average germination rates for paddy dried at 0.10 m and 0.25 m bed heights were 15% and 31.67%, respectively, with the highest germination percentage observed at 0.25 m bed height. Statistical analysis revealed a significant difference in germination rates between the two drying heights ($F = 568.3$, $p = 0.000$). As a result, the null hypothesis (H_0) was rejected, confirming that drying bed height significantly affects germination rate. Accordingly, the higher drying bed height (2.5 m) resulted in a significantly greater germination rate than the lower bed height (0.1 m). A reduction in bed height leads to a rapid increase in bed temperature, causing prolonged exposure of seeds to equilibrium temperature. This thermal stress negatively impacts seed viability, leading to a decline in germination rate. The lower bed height accelerates temperature rise, subjecting seeds to prolonged thermal exposure, ultimately reducing their viability and germination rate. Chaji and Hedayatizadeh (2017) observed that air temperature influences the germination quality of paddy in their study on the drying behavior and quality of watermelon seeds. Elevated drying temperatures (50 ºC to 120 ºC) can negatively impact germination potential by inhibiting the catabolic processes in the endosperm essential for maintaining seed vigor and successful germination (Bajus *et al.*, 2019).

Cracked grain percentage
The percentage of cracked grains varied with paddy bed thickness during drying, with values of 9 ± 0.32% for the 0.10 m bed and 10.9 ± 0.56% for the 0.25 m bed. The statistical analysis revealed a significant

difference between the two treatments (F = 18.28, p = 0.0209), indicating that bed thickness significantly affects the cracked grain percentage. Consequently, the null hypothesis (H_0) was rejected.

The higher cracked grain percentage associated with the thicker paddy bed (0.25 m) may be attributed to prolonged exposure to higher temperatures. Stress cracking is commonly used as an indicator of quality to evaluate the extent of damage caused by the drying process, and such breakage significantly contributes to reduced grain quality and postharvest losses (Mwaro *et al*., 2014). A high stress-cracking index is associated with greater susceptibility to grain breakage. Leilayi *et al*. (2023) indicated a higher stress cracking index of 11 for paddy samples with an initial moisture of 16% at a temperature between 43 °C and 46 °C.

The 0.25 m thick paddy bed showed a higher initial moisture content, which, according to Baidhe and Clementson (2024), increases susceptibility to stress cracking and breakage during high-temperature drying. During drying, breaking hydrogen bonds between water molecules causes grain shrinkage. When the initial moisture content is high, this shrinkage is more severe, creating greater tensile stress that can cause breakage. Additionally, the brittleness of structures like the endosperm height makes the grain more prone to damage. At higher temperatures, rapid moisture loss boosts these stresses, further raising the risk of cracking. Moisture content has therefore been identified as a key factor in crack formation in rough rice after drying (Jin *et al*., 2019). Further, Leilayi *et al*. (2023) also confirmed that higher initial moisture contents increase the stress crack index.

Head rice percentage

The head rice percentage was significantly affected by drying bed height, with a statistically significant difference observed between treatments (F = 530.1, p = 0.000). Consequently, the null hypothesis (H_0) was rejected, confirming that bed height significantly influences head rice yield. The head rice percentages at 0.10 m and 0.25 m bed thicknesses were 79.0 ± 0.05% and 71.83 ± 0.3%, respectively. The less thickened paddy bed (0.10 m) with higher temperatures of 38.27 ± 3.63 °C showed a higher head rice percentage.

Although previous studies by Akowuah *et al*. (2012) and Inprasit and Noomhorm (2001) reported that elevated drying temperatures tend to reduce head rice yield due to increased thermal and moisture stresses, the present result can be explained by the combined effects of shorter drying duration and more uniform moisture removal in the thinner bed. These conditions likely minimized internal moisture gradients and stress buildup, thereby reducing fissuring despite the higher temperature. In contrast, the thicker bed experienced slower, less uniform drying, leading to greater moisture differentials within the grain mass and consequently more cracking.

Grain discoloration

The analysis of grain discoloration during drying at different bed heights indicated no significant effect of bed height or initial moisture content on rice color (F-statistic = 0.2182, p = 0.816). This confirmed that bed height does not significantly impact grain discoloration after controlling for initial moisture content.

The yellowness (b* value) of milled rice for 0.10 m and 0.25 m bed thicknesses was 13.36 ± 0.3 and 13.50 ± 0.2, respectively. The 0.25 m bed thickness sample, which was dried for 140 minutes, had a higher b* value than that of the 0.10 m bed thickness sample. These observations align with those of Inprasit and Noomhorm (2001), who suggested that chemical and physical alterations prompted by heating, such as the Maillard reaction and the color compounds, which migrate from the husk and bran layers to the endosperm, are key contributors to grain discoloration. Additionally, Bai *et al*. (2018) (tested power levels: 200, 280, 460, and 640 W) and Mondal *et al*. (2022) (drying temperature: 60, 70, and 80 °C) and air velocity (3.0, 6.0, and 9.0 m/s) observed that prolonged drying time led to a decline in grain color quality, with seeds appearing darker due to decreased lightness values in Ginkgo biloba seeds and maize, respectively.

Performance evaluation of dryer according to ISO standard

The 0.10 m bed thickness of the paddy was selected for the dryer's performance assessment. The ISO standard was applied for this thickness, and the data are represented in Table 1.

Table 1: Test value of 0.10 m bed thickness according to ISO 11520-1:1997

Criteria	Test value
Ambient conditions	
Ambient temperature, (°C)	32.10
Ambient relative humidity, (%)	96
Barometric pressure, (Pa)	101325
Grain	
Input grain moisture content, (%, wb)	18.62±0.40
Output grain moisture content, (%, wb)	13.57±0.35
Mass of dried grain, (t)	0.0797
Germination of input grain, (%)	30.18
Germination of output grain, (%)	15
Input grain temperature, (°C)	31.8±1.70
Output grain temperature, (°C)	41.3±0.685
Drier temperature, drying time, fuel consumption and evaporation	
Drying air temperature, (°C)	41.8±4.02
Filling time, (h)	0.0113
Drying time, (h)	1.22
Cooling time, (h)	0.425
Emptying time, (h)	0.252
Fuel consumption, (kg/h)	28078.319
Thermal power, (W)	47.228
Evaporation rate, (kg/h)	3.675
Electrical power, (W)	78.7
Specific thermal energy consumption, (J/kg)	0.929×10^5
Specific total energy consumption, (J/kg)	1.67773×10^5
Results corrected to specified grain and standard ambient condition	
Input grain moisture content, (%, wb)	19
Output grain moisture content, (%, wb)	13.57
Drying air temperature, (°C)	42.5
Ambient air temperature, (°C)	27
Ambient air humidity, (%, RH)	80
Drying time, (h)	1.29
Evaporation rate, (kg/h)	3.75
Electrical power, (W)	78.7
Thermal power, (W)	47.573
Specific thermal energy consumption, (J/kg)	1.011×10^5
Specific total energy consumption, (J/kg)	1.467×10^5

CONCLUSION

This study evaluated the performance of an electric-powered hot-air batch dryer for paddy (BG350). The results confirmed that thinner bed layers (0.10 m) achieved faster drying rates than thicker layers (0.25 m), significantly impacting final moisture content, germination rate, cracked grain percentage, and head rice yield. However, grain discoloration was not significantly influenced by bed height or initial moisture content. Further, the ISO test reports of the dryer indicated that standardized performance helps assess the efficiency, effectiveness, and quality outcomes of the drying process. These findings support the effective use of hot-air batch driers to maintain paddy quality. These insights contribute to improving postharvest drying strategies, ensuring better grain preservation and processing efficiency. Variations in initial moisture content and the evaluation of only two paddy bed heights were key limitations. Future studies should examine a broader range of bed heights while maintaining consistent initial moisture content to optimize drying performance and enhance product quality.

AUTHOR CONTRIBUTION

FAJ Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Methodology, Project Administration, Resources, Supervision, Validation, Visualization, Writing Original Draft, Writing Review and Editing, WTPM Data Curation, Formal Analysis, Investigation, Validation, Visualization, Software, WGVTV Project Administration, Resources, Editing, and BDMSP Project Administration, Resources, Editing

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