Drying and tempering effect on milling process of paddy in unparboiled condition

Anamica Chowdhury Keya[1,3], Md. Anwar Hossen[4], Muhammad Rashed Al Mamun[2,3*], Mst. Sabina Alim[1,3], Billal Hossain[3], Joyshankar Baidya[5]

(1. Department of Farm Power and Machinery, Khulna Agricultural University, Khulna -9100, Bangladesh;
2. Faculty of Agriculture, Kyushu University, Fukuoka 819-0395, Japan;
3. Department of Farm Power and Machinery, Sylhet Agricultural University, Sylhet-3100, Bangladesh;
4. Principal Scientific Officer, FMPHT Division, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh;
5. Department of Farm Structure and Environmental Engineering, Khulna Agricultural University, Khulna-9100, Bangladesh)

Abstract: This research was conducted during the Aman season to assess the impact of drying and tempering on the milling performance of unparboiled rice (BRRI dhan49). The paddy temperature recorded during the drying process ranged from 24.1°C to 42.7°C for the five treatments. Drying over three days at different time intervals led to reduced moisture content (from 23.42% to 9.24%), resulting in increased kernel hardness for reduced breakage during milling. The strongest kernel strength recorded was 34.933 N m^{-1}. Varying conditions like relative humidity, temperature, air flow, and solar radiation influenced the drying process. Treatment T4 (5 hours sun drying with 1-hour drying and 1-hour tempering) and T1 (4 hours drying with 1-hour drying and ½-hour tempering) exhibited the highest milling yield (19.03 kg) and head rice recovery (17.05 kg) respectively, with T1 having the minimum loss (1.9 kg). These treatments increased milling yield, head rice recovery, and reduced losses, proving their effectiveness in maximizing rice output.

Keywords: unparboiled rice, drying, tempering, milling yield

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1 Introduction

Rice (*Oryza sativa* L.) is one of the most important staple foods in the world, and its significance extends beyond just being a dietary staple. Bangladesh is producing 35.3 million metric ton of white rice (WAP, 2022) to feed about 167 million people (Worldometer, 2022). The population of Bangladesh will be increased to about 215.4 million in 2050 and to feed the estimated people around 44.6 million metric ton of white rice will be required (Kabir et al., 2015).

Rice is one of the grains that is treated for consumption or commercial purposes and consumed whole. The estimated postharvest losses from harvest to storage in Bangladesh were approximately 14% (threshing loss: 3.09% to 3.23%, drying loss: 2.86% to 3.14%, parboiling loss: 1.93%-2.75% and milling loss: 3.28% and 4.54%, storage loss: 3.45%-4.14%, transportation loss: 0.87%-1.13%) in three rice growing seasons Aus, Aman and Boro (Bala, 2009; Schmidley at el., 2015; Nath at el., 2016). In

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***Corresponding author: Muhammad Rashed Al Mamun,** Ph.D. Specially Appointed Professor, Faculty of Agriculture, Kyushu University, Fukuoka, Japan; Professor, Department of Farm Power and Machinery, Sylhet Agricultural University, Sylhet, Bangladesh. Tel: +81-070-9116-2903, +88-01913-323845. Email: rashed.fpm@sau.ac.bd.

unparboiled rice, since no boiling takes place, the loss that occurs during the parboiling process is minimized.

The storage loss of rice is (3.45%-4.14%) and it is followed by drying (2.19%-2.37%), harvesting (1.60%-1.91%), threshing (1.10%-1.79%) and transportation (0.87%-1.13%). The estimated total post-harvest losses of rice at processor level in Bangladesh were 1.30%, 1.30% and 1.13% for Aman, Boro and Aus, respectively. These were 0.17, 0.18 and 0.19 percent for Aman, Boro and Aus, at wholesale level. At retail level, these losses were estimated as 0.27, 0.31 and 0.28 percent for Aman, Boro and Aus, respectively (Bala et al., 2010).

Unparboiled rice is a variety of milled rice which has gone through a process of removing the husk, bran and germ. When opposed to parboiled rice undergoes soaking, steaming, and drying before milling, making it firmer and more nutrient-rich due to the steaming process. White rice, in contrast, has the husk, bran, and germ removed without any parboiling, resulting in a softer texture but fewer nutrients. Unparboiled rice, also known as raw rice, skips the boiling process entirely and is dried directly after harvesting. It retains natural flavor-enhancing compounds like monosodium glutamate, which is why some individuals prefer its taste.

Drying and tempering processes had significant effects on the moisture gradient and rice fissuring. Drying is the removal of moisture from grains and an essential step for grain storage to prevent respiration, germination, and mold damage (Nguyen et al., 2016). Rice should be dried promptly in bins to a moisture level of about 12.5% to avoid quality damage, prevent respiration, germination, and mold damage (Atungulu and Sadaka, 2019). In Bangladesh, sun drying is a common method for drying paddy where paddy is exposed to sun or wind in the yard or field (Alam et al., 2019). Head rice recovery decreased at high moisture level particularly for long grain variety (Firouzi, 2014). Kernel fissuring mostly depends on variety and drying time. Proper drying helps to achieve optimal kernel strength and prevents the rice from becoming too brittle in unparboiled condition. Tempering, the process where dried rice is conditioned by exposing it to a specific level of moisture for a certain period and is typically performed after drying. When compared to tempering at 20°C, tempering at 50°C reduced fissuring incidence by 32% to 50% (Omar and Yamashita, 1987). The storage and drying losses can also be reduced by creating awareness about the importance of drying and storage practices, proper management, ensuring the use of improved drying systems and storage structures.

On the other hand, rice quality also depends on different milling parameters. Rice milling is a major stage in the post-harvest process where removal of husk and bran takes place making the rice edible and free of contaminants. During the process of milling paddy, various components are derived, including rice fractions and by-products. These include rough rice, milled rice, rice germ, rice brokens, as well as a combination of bran and husk. Rice kernels are composed of 20% rice husk, 11% rice bran, and 69% starchy endosperm (milled rice) (Islam et al., 2003). The rice should have as few broken kernels as feasible (usually 12–15 percent) depending on the customer's needs (Siebenmorgen et al., 2011). Milling yield significantly vary with drying and tempering. Significant milling yield can be obtained by maintaining proper drying and tempering processes. If this operation can be practiced in farmer's level, it is possible to increase milling recovery and reduce losses. The present study aimed to investigate how drying and tempering impact the milling performance of unparboiled rice, with the goal of enhancing milling recovery. Additionally, the study sought to compare the drying, tempering, and milling methods with traditional farmer practices.

2 Materials and Methods

2.1 Study area

The experiment was conducted in Bijoynagor upazilla of Brahmanbaria district in the division of

Chittagong, Bangladesh and the Bangladesh Rice Research Institute (BRRI), Gazipur in the division of Dhaka. The latitude and longitude of the locations are 24 1.3'N and 91 16.8'E, and 23.9903° N, and 90.3996° E respectively (Figure 1). The experiment was done during the local cropping season known as Aman (July to November).

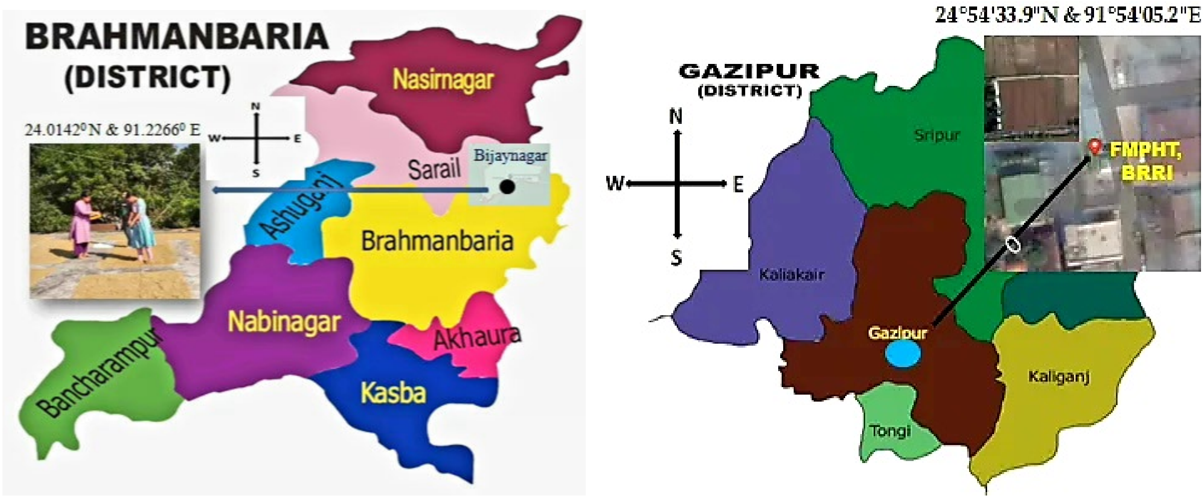


Figure 1 Map of the study area

2.2 Variety

Freshly harvested paddy BRRI dhan49 was collected from farmer's field in Bijoynagor, Brahmanbaria and used for five different treatments where each treatment contains a total of 36 kg paddy. Then the paddy was cleaned by electrical fan. The Length to breadth ratio of BRRI dhan49 was 3.69 and thousand grain mass (TGM) was 20 gm.

2.3 Scientific equipment used in the study

In this experiment Digital Anemometer (AR836), Digital Lux Meter (AS813), Grain moisture meter (AR991), Digital slide caliper, Digital thermometer (DM6801A TYPE K), Digital weight balance, Kernel strength measuring meter (FGN-20B SHIMPO), locally available bamboo made sieve was used to measure the wind speed, the brightness of sun, grain moisture, length, breadth and thickness, paddy grain temperature, paddy grain weight to distribute equal amount of paddy for each treatment, the strength of paddy grain and for separating head rice and broken rice respectively. The day temperature and relative humidity data were collected from the local weather stations.

2.4 Experimental design

Treatments were set as follows with three replications:

T_1= Daily 4 hours drying maintaining the procedure of 1 hour drying and ½ hour tempering until moisture content (MC) reduce to 10% (wet basis);

T_2= Daily 5 hours drying maintaining the procedure of 1 hour drying and ½ hour tempering until moisture content reduce to 10% (wet basis);

T_3= Daily 4 hours drying maintaining the procedure of 1 hour drying and 1 hour tempering until moisture content reduce to 10% (wet basis);

T_4= Daily 5 hours drying maintaining the procedure of 1 hour drying and 1 hour tempering until moisture content reduce to 10% (wet basis);

T_5= Farmer's practice (followed by traditional drying methods without tempering).

2.5 Collected data

Data were systematically collected throughout the drying, tempering, and milling processes. During the drying and tempering stages, the following parameters were recorded: day temperature, relative humidity (RH), solar radiation, air velocity, moisture content, paddy temperature, and kernel strength. These measurements provided insights into the environmental conditions and their influence on the rice's physical properties and drying efficiency. During the milling process, data on milling yield, head rice recovery, broken rice, small broken rice, and the percentages of husk and bran were collected to evaluate milling efficiency and rice quality. This extensive data collection allowed for a deeper understanding of the interaction between processing conditions and final rice quality, offering valuable insights into how each parameter affects the overall performance of the rice processing system.

2.6 Drying

After cleaning, paddy was spread on the concrete floor for sun drying maintaining 1.25 cm thickness for equal drying and stirring activity was done at every 20 minutes intervals. The paddy was dried up to the moisture content of 10% (wet basis). The drying process was conducted over three consecutive days, with T1 and T3 receiving 4 hours of drying each day from 1000 to 1400 hours, T2 and T4 having 5 hours from 1000 to 1500 hours, and T5 receiving 6 hours from 1000 to 1400 hours each day.

2.7 Tempering

Tempering is a process used to achieve uniform moisture distribution, which helps reduce breakage and increase the strength of the paddy. In this experiment, we applied the tempering method to treatments T1, T2, T3, and T4, adjusting the duration for each treatment to assess its effect on the rice quality.

2.8 Milling

After the drying and tempering was completed, the paddy was stored for 7 days. Then the milling was carried out on the same day for all treatments through Engle Berg mobile hullers. Milled rice is a combination of head rice and broken rice. The mixer of husk and bran was collected from one of the outlets of the Engle berg huller and the small broken rice from another outlet of the huller. The mixture of head rice and broken rice was then separated using a locally available sieve. Some losses were also detected during milling. Moisture content and temperature of paddy before and after milling were also calculated. Finally, all the materials are weighted and packaged.

2.9 Milling parameter

2.9.1 Milling yield (%)

The percentage of finished product obtained from the milling of a grain crop is known as milling yield. The amount of polished white rice recovered from rough rice is referred to as rice milling yield (Sangeetha et al., 2013).

Milling yield was calculated by the following equation (Sangeetha et al., 2013):

$$Milling\ yield(\%) = \frac{Total\ milled\ rice}{Total\ rough\ rice} \times 100 \qquad (1)$$

2.9.2 Head rice recovery (%) (Grain size >2/3, %)

The percentage of head rice (excluding broken) recovered from a paddy sample is known as head rice recovery (Sangeetha et al., 2013):

$$Head\ rice\ recovery(\%) = \frac{Total\ head\ rice}{Total\ rough\ rice} \times 100 \qquad (2)$$

2.9.3 Broken rice (%)

The broken rice percentage is calculated by dividing the total weight of broken rice by the total weight of milled rice (Belsnio, 1980):

$$Broken\ grain(\%) = \frac{weight\ of\ total\ broken\ rice}{weight\ of\ total\ milled\ rice} \times 100 \qquad (3)$$

2.9.4 Small broken rice (%)

The small broken rice percentage is calculated by dividing the weight of total small broken rice by the weight of total milled rice (Belsnio, 1980):

$$Small\ broken\ rice(\%) = \frac{weight\ of\ total\ small\ broken\ rice}{weight\ of\ total\ milled\ rice} \times 100 \qquad (4)$$

2.9.5 Husk and bran (%)

The husk and bran percentage are calculated by dividing the weight of total husk and bran by the weight of total milled rice (Belsnio, 1980):

$$Husk\ and\ bran(\%) = \frac{weight\ of\ total\ husk\ and\ bran}{weight\ of\ total\ milled\ rice} \times 100 \qquad (5)$$

2.10 Farmers practice

Farmer used traditional method for parboiling and drying of paddy. Where no tempering and no specific thickness was maintained. Farmers dried their paddy on courtyard for 3 days.

2.11 Statistical analysis

Data was analyzed as a single factorial design using the Statistix 10 tool (Statistix 10 software, 2013) according to Gomez, and Gomez (1984). The least significant difference (LSD) test was used to compare means. To investigate the relationship between machine performance and the results of a simple correlation analysis, Excel 2010 and MATLAB 2024b were used.

3 Results and discussion

3.1 Day temperature vs relative humidity, solar radiation and air velocity changing profile with time during the study period

Figure 2 illustrates that the temperature profile was in a continuous growing pattern (not more than 30°C) and the relative humidity profile was observed to be in a decreasing pattern with the increasing temperature throughout the experiment period. The day temperature and relative humidity of the study location on day 1 was ranging from (24°C -29°C) and (48%-78%) respectively. On day 2, the day temperature and relative humidity range were (24°C - 28°C) and (55%-69%) respectively whereas on day 3 temperature variation was the same as the previous day (24°C -28°C) and the relative humidity range was (55%-74%). The findings were compatible with those of Prasetyo et al., (2018) who found that the relative humidity decreased as the temperature of air increased, with relative humidity of 35.4%, 16.4% and 8.5% at temperatures of 40°C, 50°C, and 60°C, respectively. Jin et al. (2019) took the minimum crack percentage as the performance index, showing that the crack additional percentage could reach its lowest value of 1.090% when the drying medium temperature was 31.2°C and the relative humidity of the drying medium was about 62.5% which is more or less similar with the present study. It is clear that temperature and relative humidity is inversely proportional which is a good sign for the drying period and the lower relative humidity is effective for expelling moisture content from the paddy grain.

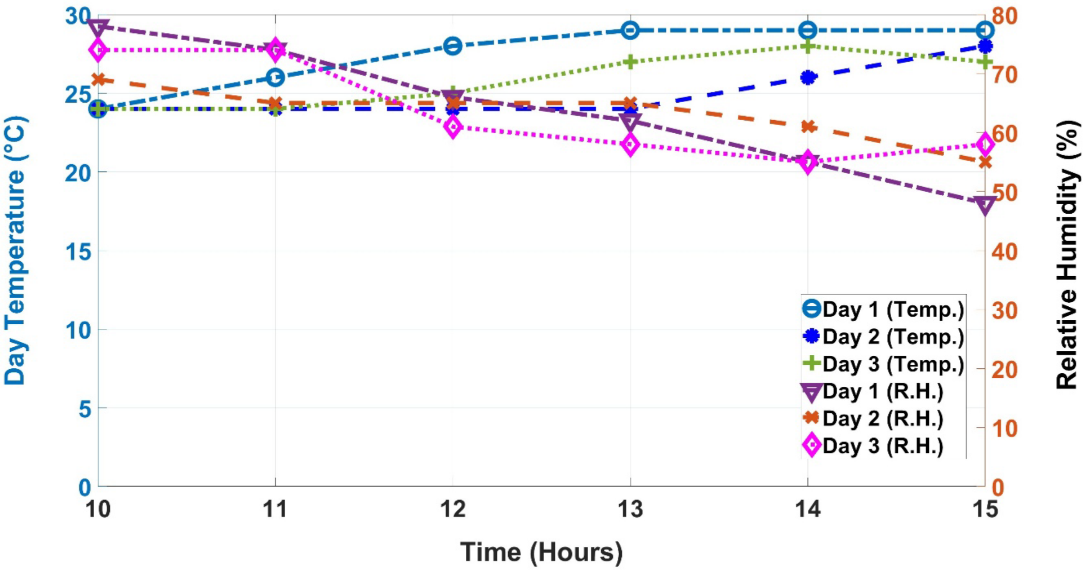


Figure 2 Day temperature *Vs* relative humidity on day 1, day 2, and day 3

Solar radiation throughout the study period was different due to location, wind velocity, and day temperature. On days 1, 2, and 3, the highest solar radiation was recorded at 1300 h, 1200 h and 1100 h respectively whereas the lowest radiation after all days was observed at 1500 h shown in Figure 3. Solar radiation was varied from 64450 to 108100 lux during the time of drying operation. Peng et al. (2004) showed the importance and the positive effect of solar radiation on rice grain yield. The present study indicates an increasing solar radiation pattern for most of the time which is compatible with the findings of others (Aghbashlo et al., 2015; Alam et al., 2020).

The air velocity profile shows the same type of variation throughout the study period due to location and day temperature. On days 1, 2, and 3, the average air velocities varied from 0.02 to 0.56 m s^{-1}, as shown in Figure 4 (Jin et al., 2019) identified the minimum crack percentage as a performance index, indicating that the additional crack percentage could be reduced to its lowest value of 1.090% when the airflow velocity reached 0.5 m s^{-1}. This finding corresponds with the results of the present study. The present study also showed that there is a relationship between drying performance and air velocity. The drying rate increased with air velocity. Moreover, the drying rate gradually decreased and tended to level off with air velocity.

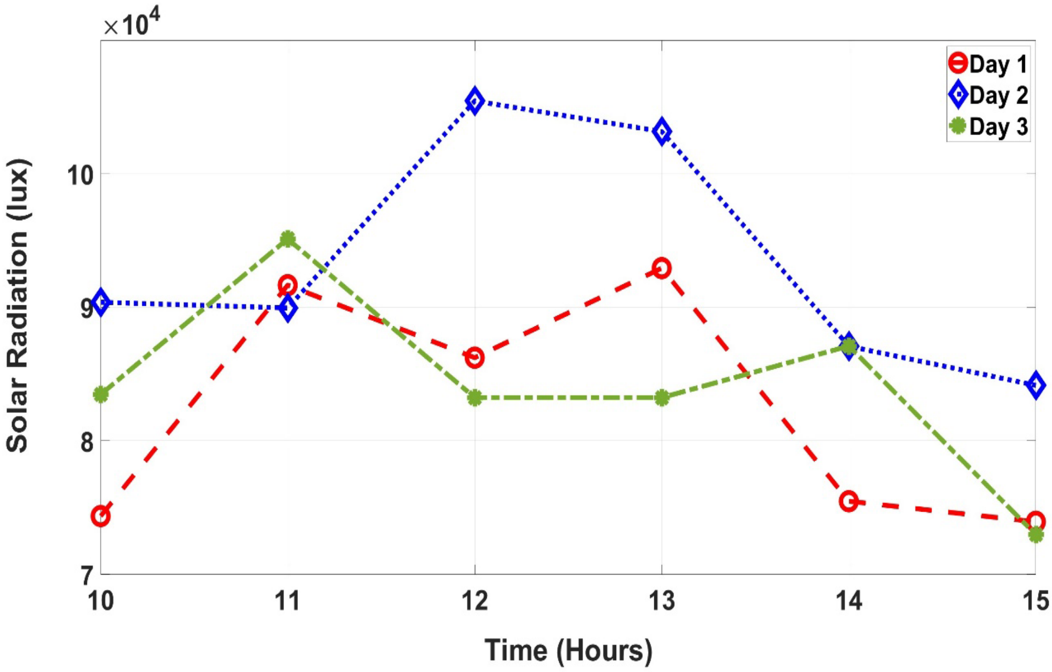


Figure 3 Solar radiation on day 1, day 2, and day 3

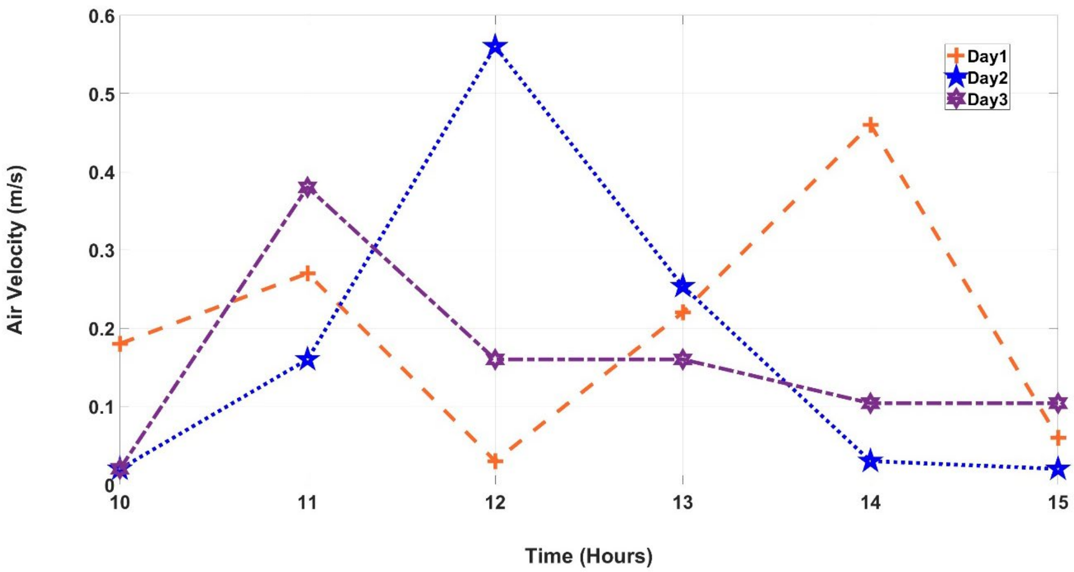
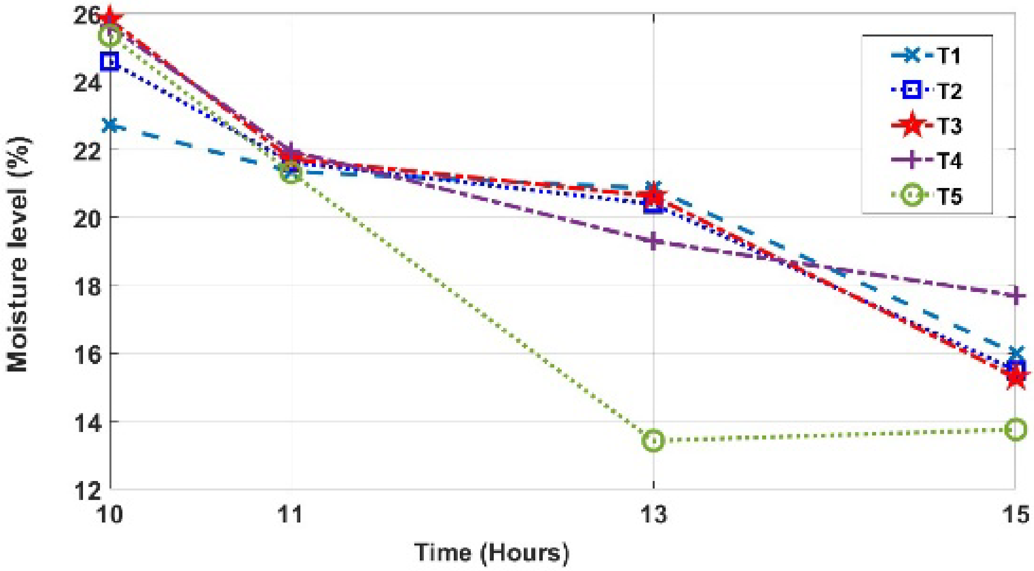


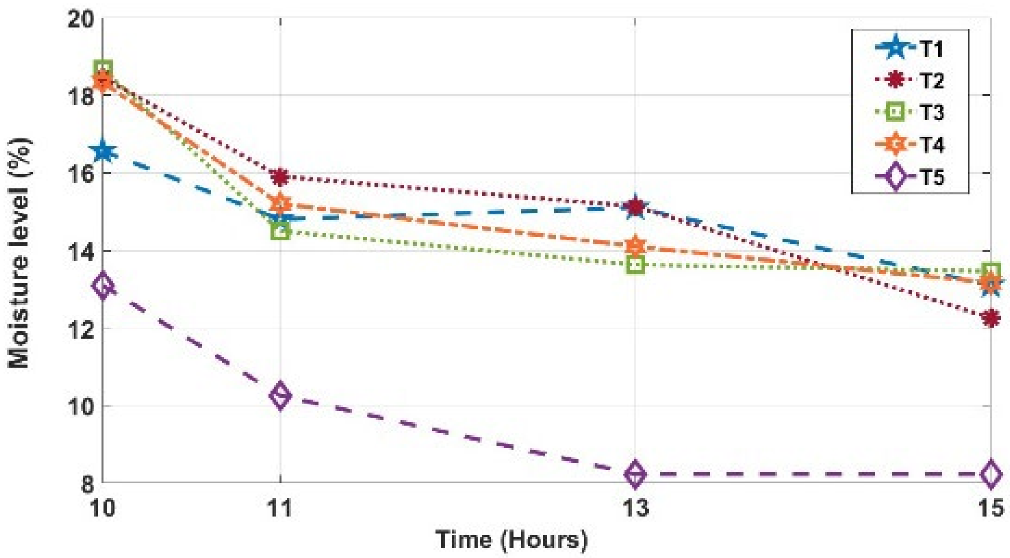
Figure 4 Air velocity on day 1, day 2, and day 3

3.2 Moisture content at different time during drying (before tempering)

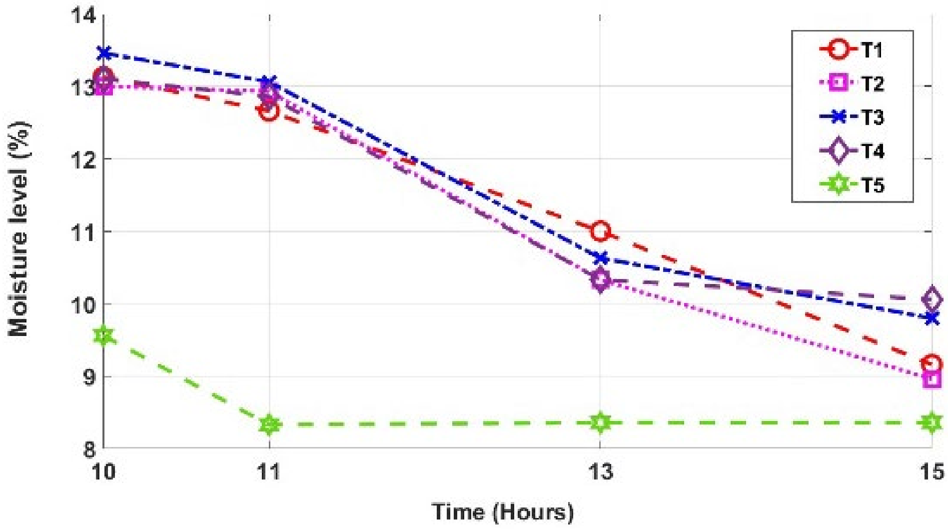
A series of experiments conducted over three days to observe moisture levels in different treatments (T1 to T5) during the drying process. Figure 5(a) shows on Day 1, T3 had the highest initial moisture level, while T5 had the lowest. Over time, moisture levels changed, and after 1 hour (1100 h), T1 had the highest moisture, while T5 remained the lowest. T3 and T4 consistently differed from T1 and T2. After 3 hours (1300 h), T1 still had the highest moisture, and T4 had the lowest. After 5 hours (1500 h), T1 remained the highest, while T3 and T4 had the lowest moisture levels. Additionally, T2 and T5 consistently showed significant differences from the other treatments throughout the experiment. On Day 2, T4 had the highest initial moisture level (1000 h) and after 5 hours of drying, T3 had the maximum moisture level whereas T5 had the lowest showed in Figure 5(b). On Day 3, T3 had the highest initial moisture level and T5 had the lowest showed in Figure 5(c). Moisture reduction followed a similar pattern to Day 2. T1 was significant with T3 and T4 before tempering. The study highlights the variations in moisture content due to different drying times and treatment designs. According to Yang et al. (2002), during drying, the kernel temperature will increase and moisture will diffuse from the kernel. A temperature and an MC gradient will develop from the surface to the center of the kernel. The temperature gradient will disappear within 2 min and it is generally agreed upon that temperature variations in the kernel can be neglected after a few minutes of drying. The MC gradient, however, plays a much more important role during and after drying which is consistent with the present findings. The observations indicate the influence of drying time, treatment design, and tempering on moisture content, as well as the significant relationships between certain treatments in terms of moisture levels.



(a) Moisture reduction before tempering on day 1



(a) Moisture reduction before tempering on day 2



(a) Moisture reduction before tempering on day 3

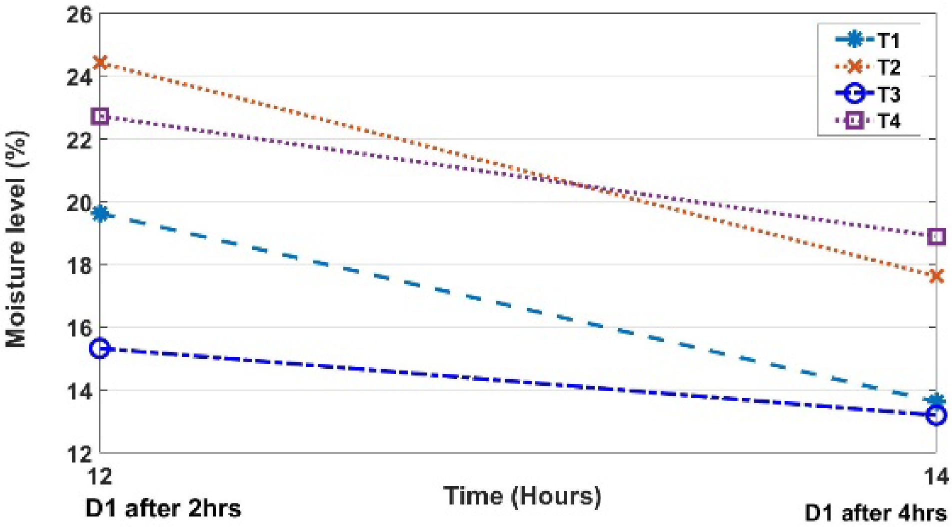
Figure 5 Moisture level before tempering on different days

3.3 Moisture content at different time during drying (immediately after tempering)

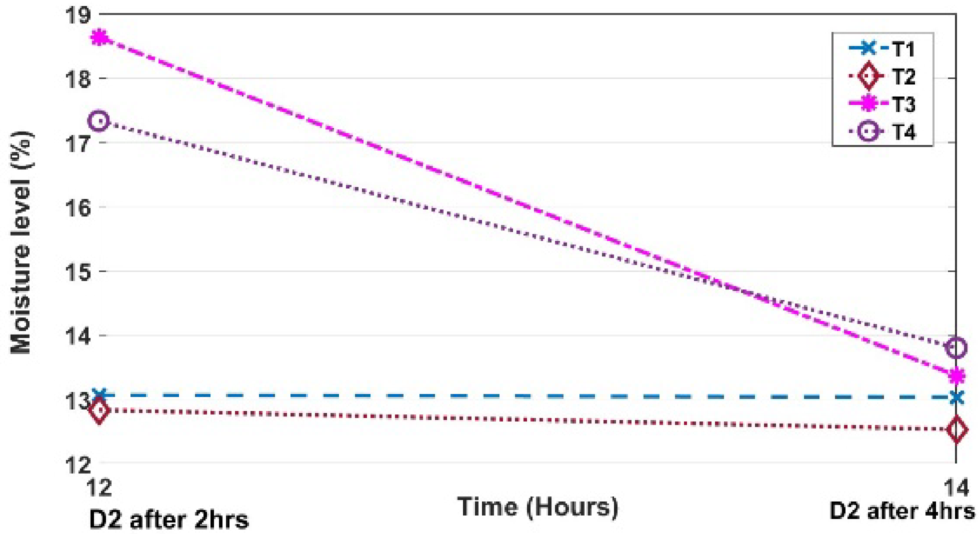
Figure 6 illustrates the moisture content changes during immediately after tempering, varying treatments were applied over three days (T1, T2, T3, T4). Notably, T2 exhibited the highest moisture after 1st tempering (after 2 hour), while T3 had the lowest on the first day. T1 consistently maintained relatively lower moisture content. Day 2 showed similar trends, with T3 having the highest moisture after 1st tempering (after 2 hour), and T2 the lowest. T4 consistently had higher moisture after 2nd tempering (after 4 hour). On the third day, T3 had the highest moisture after 1st tempering (after 2 hour), while T1 consistently displayed the lowest. T4 showed consistently higher moisture after 2nd tempering (after 4 hour). The interaction of drying and tempering times significantly influences moisture changes. Longer drying times decrease moisture, while longer tempering times increase it. Treatment variations led to distinct moisture patterns, emphasizing the importance of optimizing drying and tempering schedules for effective moisture management. Li et al. (1998) showed that intermittent drying with tempering periods between cycles has been shown to reduce the number of fissured kernels. The present study's emphasis on different drying and tempering treatments and their effects on moisture content and kernel strength relates to this observation. It demonstrates that the choice of drying and tempering processes can impact fissure occurrence and overall rice quality. Li et al. (1998) observed that a higher tempering/drying ratio resulted in a lower percentage of fissured kernels. The present study's examination of different tempering times and their influence on moisture content and kernel strength supports this finding. It suggests that longer tempering times might lead to better prevention of fissuring.

3.4 Paddy temperature at different time during drying (before tempering)

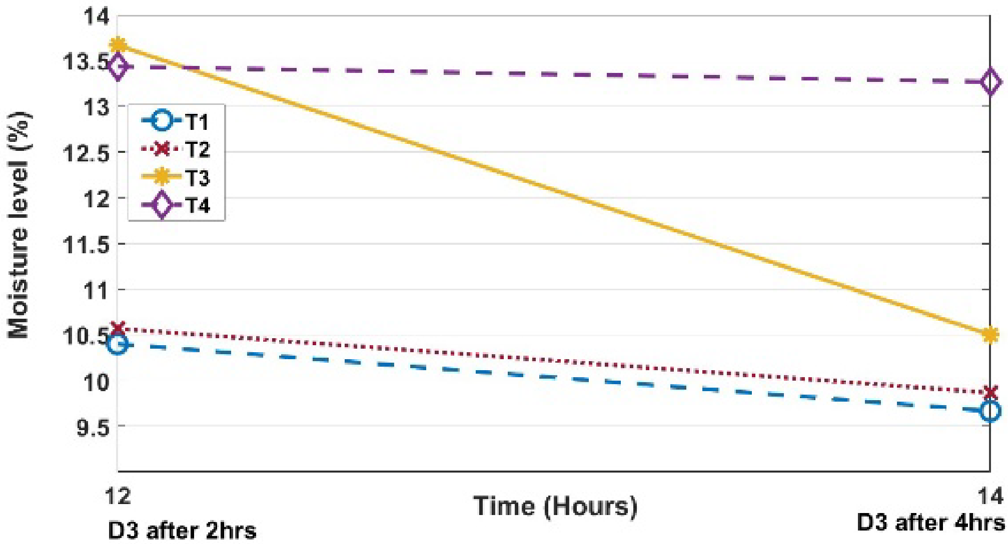
Figure 7 showed that variations in the paddy temperature in three days after 1 hour (1100 h), 3 hours (1300 h) and 5 hours (1500 h) interval from the initial time at 1000 h. In three days, paddy temperature did not exceed 43°C, which aligns with the safe maximum temperature of drying seed grains and paddy grains mentioned by Bala (1997). Bala (1997) also emphasized that excessive high-temperature drying can cause physical and chemical changes in rice grains, leading to an increase in breakage of whole rice and a reduction in rice quantity and quality. Furthermore, Bonazzil et al. (1997) highlighted that the proportion of fissured kernels increases with temperature and the evaporating capacity of the air, further supporting the importance of maintaining optimal paddy temperature during the milling process.



(a) Moisture reduction immediately after tempering on day 1

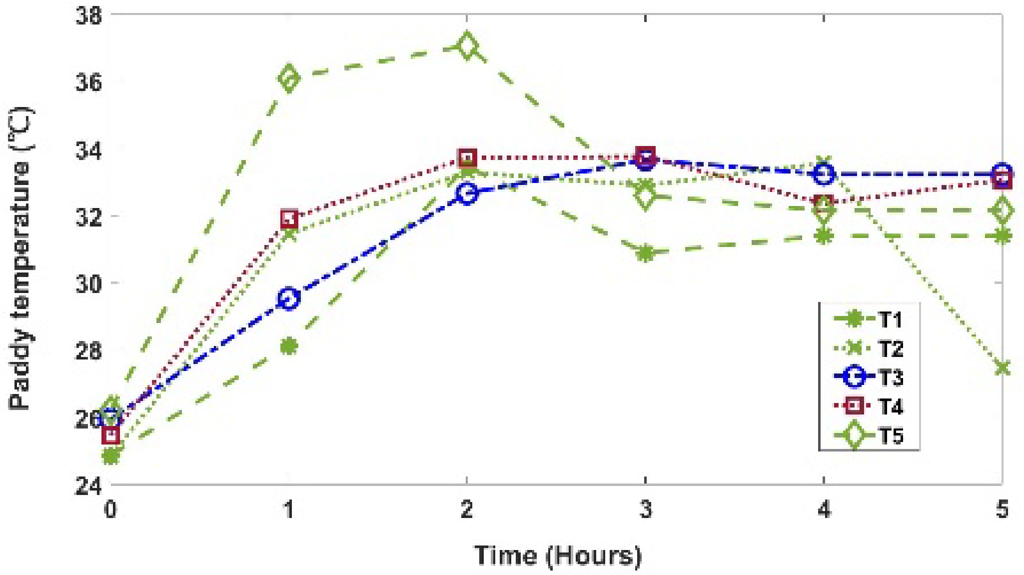


(b) Moisture reduction immediately after tempering on day 2

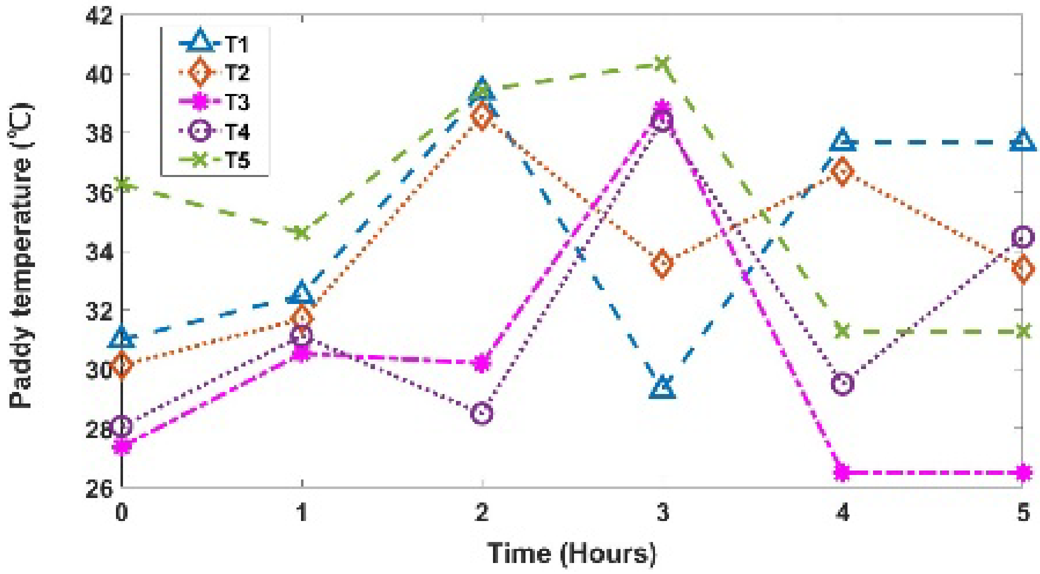


(c) Moisture reduction immediately after tempering on day 3

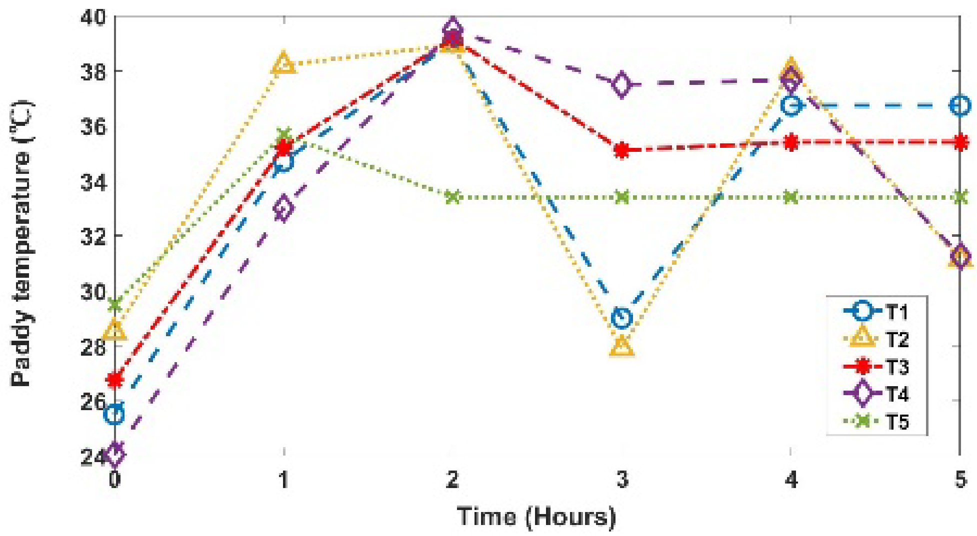
Figure 6 Moisture level immediately after tempering on different days



(a) Paddy temperature before tempering on day 1



(b) Paddy temperature before tempering on day 2



(c) Paddy temperature before tempering on day 3

Figure 7 Paddy temperature before tempering on day 1 (a), day 2 (b), and day 3 (c)

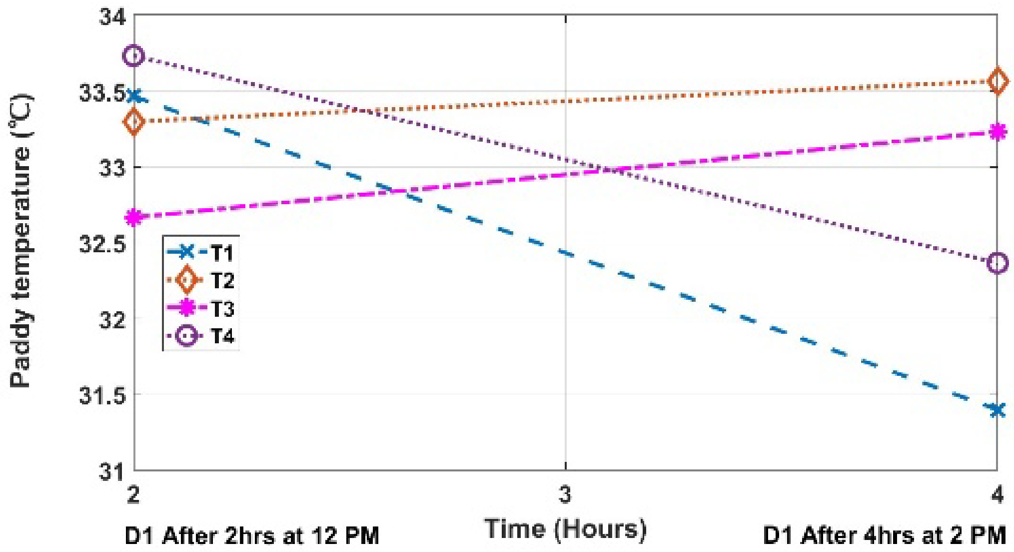
3.5 Paddy temperature at different time (immediately after tempering)

Figure 8 demonstrates that paddy temperature undergoes significant changes with tempering. Over the course of three days, different tempering and drying procedures were applied to various treatments, leading to varying paddy temperature patterns. Notably, shorter tempering times (half hour) generally resulted in lower paddy temperatures, while longer tempering times (1 hour) led to higher paddy temperatures. Each treatment showed specific temperature outcomes after the first and second tempering stages. According to Iguaz et al. (2006), tempering allows moisture diffusion from the interior to the external surface of the grain kernels to decrease the moisture gradients and then reduces the rice fissuring. Poomsa-ad et al. (2002) said that as compared with no tempering, the faster drying rate can be obtained by tempering treatment between drying stages. Poomsa-ad et al., (2002) also stated that the tempering time for 35 min is recommended for the continuous fluidized bed dryers being operated in rice mills. The present study also recommends that half hour tempering is better for improving milling performance of the unparboiled paddy in traditional postharvest process. According to Elbert et al. (2001), the drying temperature has a negative effect while the tempering time has a positive effect on HRY which is consistent with the present study.

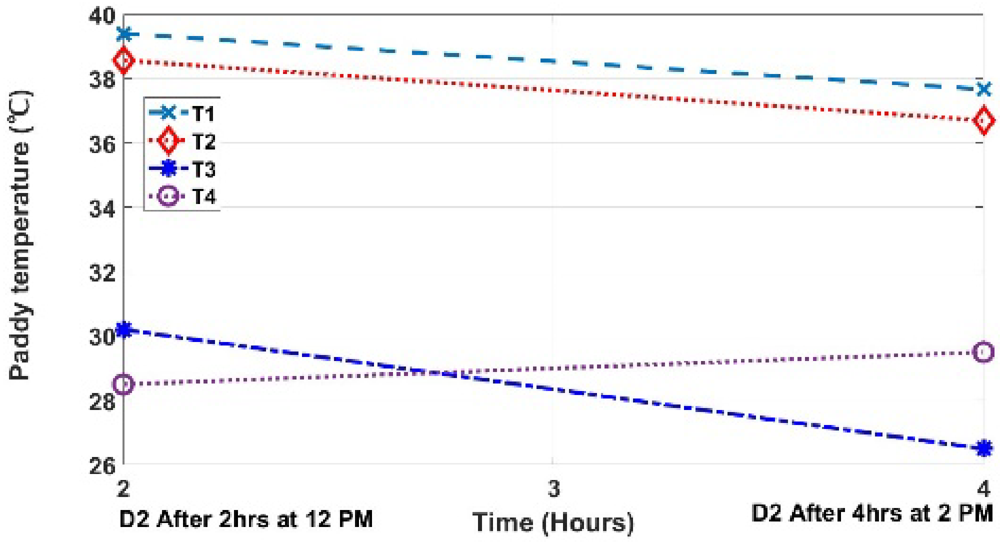
3.6 Kernel strength at different stages of drying

Kernel strength of paddy (rice) was varied significantly following the time and days based on drying and tempering. From Figure 9, this study represents that T2 gives the higher kernel strength (34.933 N m^{-1}) after three days of drying and tempering period which contains daily 5 h sun drying maintaining the procedure of 1 hour drying and half hour tempering until moisture content reduce to 10% (wet basis). Dong et al. (2010) reported that drying and tempering processes had significant effects on the moisture gradient and rice fissuring and the percentage of fissured kernels increased with increasing drying time and decreasing tempering time which contradicts the findings of the present study. The study suggests that kernel strength of unparboiled paddy increases with increasing drying time and decreasing tempering time. According to Cnossen et al. (2003), rice kernel fissuring depends not only on variety and crop management but also on the post-harvest operations, especially on drying conditions. Improper drying and tempering processes can be a major cause of fissuring. The present study aligns with this observation as it focuses on the effects of different drying and tempering treatments on rice kernel strength, implying that the drying conditions can influence fissuring. Zhang et al. (2003) also reported that fissured kernels usually break during milling and lead to a reduction in head rice yield (HRY), then cause very poor cooking quality and lower the market value. This consistent with the present study's focus on kernel strength, as stronger kernels are less likely to fissure during milling, which can have a positive impact on rice quality and market value. Sharma and Kunze (1982) observed that fissures did not occur until after drying had ceased. Sharma and Kunze (1982) also stated that few whole rough rice kernels would fissure during the drying process itself.

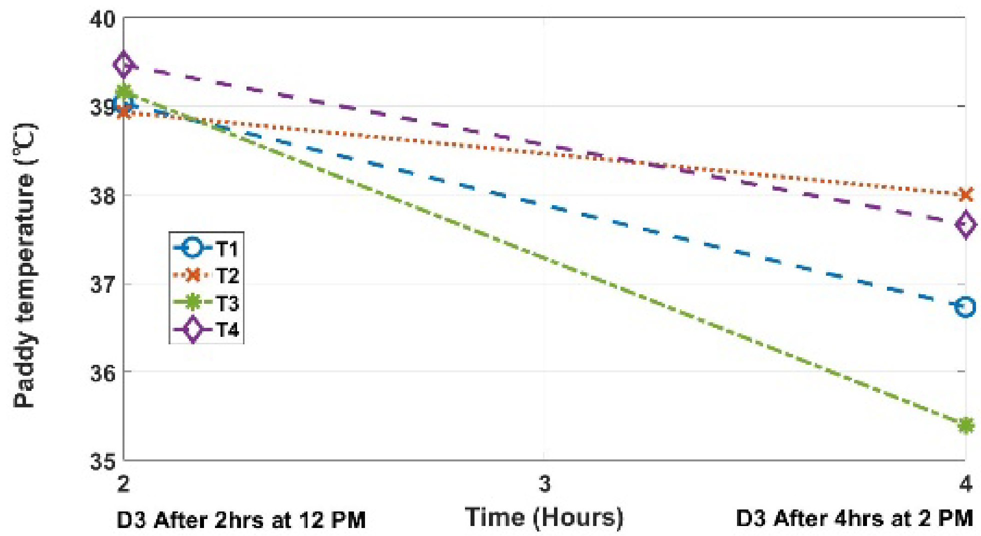
Severe drying conditions increased the number of kernels that fissured after drying. Since most kernels are not fissured immediately after drying, Sharma and Kunze (1982) suggested that developing some post-drying treatment or procedure can prevent the subsequent fissures. The present study's findings on the influence of specific drying and tempering treatments on kernel strength and fissuring resonate with these previous studies, as they all emphasize the importance of post-drying processes in mitigating fissure occurrence. According to Aquerreta et al. (2007), the percentage of fissured kernels was drastically reduced when drying was performed in two or three steps compared to drying in one step is in line with the present study's approach of alternating drying and tempering periods. Cnossen et al. (2003) stated that to maximize the full kernel yield, the tempering stage was recommended after the first stage of drying for reducing moistures stresses which is consistent with present study.



(a) Paddy temperature immediately after tempering on day 1



(b) Paddy temperature immediately after tempering on day 2



(c) Paddy temperature immediately after tempering on day 3

Figure 8 Paddy temperature immediately after tempering on day 1 (a), day 2 (b), and day 3 (c)

3.6 Kernel strength at different stages of drying

Kernel strength of paddy (rice) was varied significantly following the time and days based on drying and tempering. From Figure 9, this study represents that T2 gives the higher kernel strength (34.933 N m^{-1}) after three days of drying and tempering period which contains daily 5 h sun drying maintaining the procedure of 1 hour drying and half hour tempering until moisture content reduce to 10% (wet basis). Dong et al. (2010) reported that drying and tempering processes had significant effects on the moisture gradient and rice fissuring and the percentage of fissured kernels increased with increasing drying time and decreasing tempering time which contradicts the findings of the present study. The study suggests that kernel strength of unparboiled paddy increases with increasing drying time and decreasing tempering time. According to Cnossen et al. (2003), rice kernel fissuring depends not only on variety and crop management but also on the post-harvest operations, especially on drying conditions. Improper drying and tempering processes can be a major cause of fissuring. The present study aligns with this observation as it focuses on the effects of different drying and tempering treatments on rice kernel strength, implying that the drying conditions can influence fissuring. Zhang et al. (2003) also reported that fissured kernels usually break during milling and lead to a reduction in head rice yield (HRY), then cause very poor cooking quality and lower the market value. This consistent with the present study's focus on kernel strength, as stronger kernels are less likely to fissure during milling, which can have a positive impact on rice quality and market value. Sharma and Kunze (1982) observed that fissures did not occur until after drying had ceased. Sharma and Kunze (1982) also stated that few whole rough rice kernels would fissure during the drying process itself.

Severe drying conditions increased the number of kernels that fissured after drying. Since most kernels are not fissured immediately after drying, Sharma and Kunze (1982) suggested that developing some post-drying treatment or procedure can prevent the subsequent fissures. The present study's findings on the influence of specific drying and tempering treatments on kernel strength and fissuring resonate with these previous studies, as they all emphasize the importance of post-drying processes in mitigating fissure occurrence. According to Aquerreta et al. (2007), the percentage of fissured kernels was drastically reduced when drying was performed in two or three steps compared to drying in one step is in line with the present study's approach of alternating drying and tempering periods. Cnossen et al. (2003) stated that to maximize the full kernel yield, the tempering stage was recommended after the first stage of drying for reducing moistures stresses which is consistent with present study.

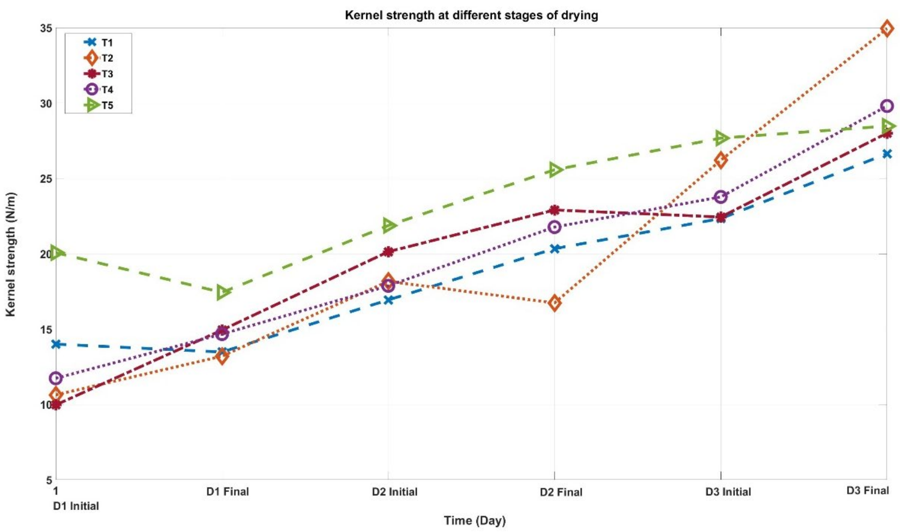


Figure 9 Effect of drying and tempering on kernel strength

3.7 Milling recovery

Figure 10 shows that the highest milling yield was observed in T4 based on total milling yield, which was significantly similar to that of T1 and T2. However, it was seen that head rice recovery after milling was higher for T_1 and lower for T_5. There were variations for other treatments. The treatments that are designed in this experiment can be effective in increasing total milling yield and head rice percentage when compared with the traditional method of drying. Considering the total milling yield and head rice yield drying paddy sample for 5 hours daily maintaining 1 hour drying and half hour tempering until moisture content reduce to 10% (wet basis) and 4 hours daily maintaining 1 hour drying and half hour tempering until moisture content reduce to 10% (wet basis) gave the satisfactory results. Moreover, drying paddy 4 hours daily maintaining 1 hour drying and half hour tempering until moisture content reduce to 10% (wet basis) reduces highest amount of loss. On the other hand, farmers practice maintaining traditional method of drying results in highest paddy loss and lowest head rice recovery. Bautista et al. (2000) said that addressing the fissuring issue and optimizing the milling process are essential for enhancing the overall efficiency and quality of the rice industry. Proper harvesting techniques and environmental conditions play a vital role in minimizing breakage during milling and achieving better results in terms of milling yield and rice quality. The present study maintains all the post-harvest techniques (except T5) and gives a higher milling recovery which is consistent with the previous researcher.

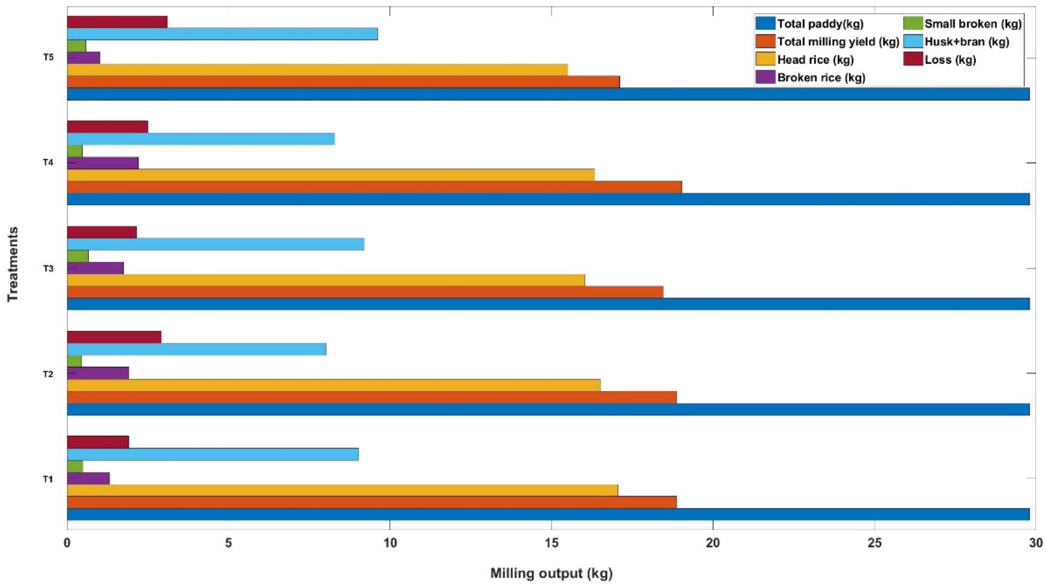


Figure 10 Milling output (kg) after 3 days of drying and tempering

3.8 Temperature and moisture variation during milling operation

It was observed that the highest moisture content during milling was 13.7% for T3, followed by T4, while T5 had the lowest moisture content. Additionally, the moisture content in treatments T1 and T2 was also significant. Afzalinia et al. (2004) reported that the ideal paddy moisture content for the milling process ranged from 12% to 14% wet basis (wet basis), which resulted in the least rice breakage. Similarly, Pominski et al. (1961) opined that paddy moisture content significantly influenced the milling system yield. For every 1% reduction in paddy moisture within the range of 10% to 14%, the milling system's performance increased by 0.7% to 3%. The present findings supported these previous studies as the paddy moisture content for all treatments was in the range of 12%-14% except for Treatment 5 (T5) which is farmer’s practice.

In case of temperature, the highest paddy temperature during milling was observed for T_3 (21%) and lowest paddy temperature was for T_1 (20.5%)

which is similar as T_5. Moreover, T_2 and T_4 are also significant with each other. Whereas in the case of paddy temperature after milling, it was seen that all the treatments are significant at the same time. Regarding paddy temperature during milling, it was observed that all treatments showed significant variations. These variations in moisture content and paddy temperature were attributed to the differences in drying and tempering time among the treatments, except for Treatment 5 (T5).

3.9 Milling recovery compared with traditional method

The scientific treatments (T1, T2, T3, and T4) that utilized the drying and tempering process demonstrated higher milling recovery compared to the farmers practice (T5). Notably, Treatment T1 showed a remarkable increase of approximately 5% head rice recovery and T4 showed 6% increase of total milling yield when compared to the traditional treatment (T5). This highlights the significant positive impact of incorporating the drying and tempering process on the overall milling efficiency and recovery of rice.

4 Conclusion

In response to increasing rice consumption due to population growth, inadequate post-harvest processing knowledge has diminished rice quality, quantity, and market value. Proper drying and tempering methods were explored as effective alternatives, enhancing head rice yield, quality, and market value. Significant improvements were observed in moisture removal rate, paddy temperature, paddy strength, and milling recovery. Treatment T4, involving 5 hours daily drying maintaining the procedure of 1-hour drying and 1-hour tempering until reaching 10% moisture content, boosted total milling yield. Moreover, Treatment T1, involving 4 hours daily drying maintaining the procedure of 1 hour drying and half hour tempering yielded the best result for head rice recovery and in loss reduction compared to the farmers practice for unparboiled paddy. This highlights the importance of proper drying and tempering in achieving higher milling recovery along with reduced losses which will offer potential benefits to the farmers.

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References

Afzalinia, S., M. Shaker, and E. Zare. 2004. Comparison of different rice milling methods. *Canadian Biosystems Engineering*, 46(3): 63-66.

Aghbashlo, M., J. Müller, H. Mobli, A. Madadlou, and S. Rafiee. 2015. Modeling and simulation of deep-bed solar greenhouse drying of chamomile flowers. *Drying Technology*, 33(6): 684-695.

Alam, M. A., C. K. Saha, and M. M. Alam. 2019. Mechanical drying of paddy using BAU-STR dryer for reducing drying losses in Bangladesh. *Progre ssive Agriculture*, 30: 42-50.

Alam, M. A., C. K. Saha, M. M. Alam, M. R. Manir, M. Hasan, and M. Rashid. 2020. Experimental investigation of solar bubble dryer for rough rice drying in Bangladesh. *Journal of Bioscience and Agriculture Research*, 23(2): 1920-1930.

Aquerreta, J., A. Iguaz, C. Arroqui, and P. Virseda. 2007. Effect of high temperature intermittent drying and tempering on rough rice quality. *Journal of Food Engineering*, 80(2): 611-618.

Atungulu, G. G., and S. Sadaka. 2019. Postharvest technology: rice drying. In *Rice: Chemistry and Technology*, 4th ed, ed. J Bao, ch. 15, 473-515. Saint Paul, Minnesota, USA: AACC International Press

Bala, B. K. 1997. *Drying and storage of Cereal Grain*s. New Delhi, India: Oxford & IBH Publishing Co.

Bala, B. K., M. A. Haque, Md Anower Hossain, and Shankar Majumdar. Post harvest loss and technical efficiency of rice, wheat and maize production system: assessment and measures for strengthening food security. *Final Report CF* 6, no. 08, 2010.

Bautista, R. C., T. J. Siebenmorgen, and A. G. Cnossen. 2000. Fissure formation characterization in rice kernels using video microscopy. In *Proc. of the 2000 Drying Symposium*, 325-330. Noordwijkerhout, the Netherlands, 28–31 August 2000.

Belsnio, B. 1980. Physical grain characteristics of paddy/milled rice and its grades and standards. *NFA standard specification for milled rice (Second revision) TRED*, SQAD No. 2.

Bonazzil, C., M. A. Du Peuty, and A. Themelin. 1997. Influence of drying conditions on the processing quality of rough rice. *Drying Technology*, 15(3-4): 1141-1157.

Cnossen, A. G., M. J. Jimenez, and T. J. Siebenmorgen. 2003. Rice fissuring response to high drying and tempering temperatures. *Journal of Food Engineering*, 59(1): 61-69.

Dong, R., Z. Lu, Z. Liu, S. Koide, and W. Cao. 2010. Effect of drying and tempering on rice fissuring analysed by integrating intra-kernel moisture distribution. *Journal of Food Engineering*, 97(2): 161-167.

Elbert, G., M. P. Tolaba, and C. Suarez. 2001. Model application: hydration and gelatinization during rice parboiling. *Drying Technology*, 19(3-4): 571-581.

Firouzi, S. 2014. Effect of pre-milling on milled rice breakage-a review. *Thai Journal of Agricultural Science*, 47(4): 241-250.

Gomez, K. A., and A. A. Gomez. 1984. *Statistical Procedures for Agricultural Research*. 2nd ed. New York, USA: John Wiley and Sons.

Iguaz, A., M. Rodriguez, and P. Virseda. 2006. Influence of handling and processing of rough rice on fissures and head rice yields. *Journal of Food Engineering*, 77(4): 803-809.

Islam, M. S., M. A. Ghani, A. K. M. S. Islam, and M. A. Rahman. 2003. Effect of drying and tempering on the milling quality of long grain aromatic paddy processing in Bangladesh. *Pakistan Journal of Biological Science*, 6(19): 1675-1680.

Jin, Y., K. W. Wong, Z. Wu, D. Qi, R. Wang, F. Han, and W. Wu. 2019. Relationship between accumulated temperature and quality of paddy. *International Journal of Food Properties*, 22(1): 19-33.

Kabir, M. S., M. U. Salam, A. Chowdhury, N. M. F. Rahman, K. M. Iftekharuddaula, M. S. Rahman, and J. K. Biswas. 2015. Rice vision for Bangladesh: 2050 and beyond. *Bangladesh Rice Journal*, 19(2): 1-18.

Li, Y., C. Cao, Q. Yu, and Q. Zhong. 1998. Study on rough rice fissuring during intermittent drying. *Drying Technology*, 17(9): 1779-1793.

Nath, B. C., M. A. Hossen, A. K. M. S. Islam, M. D. Huda, S. Paul, and M. A. Rahman. 2016. Postharvest loss assessment of rice at selected areas of Gazipur district. *Bangladesh Rice Journal*, 20(1): 23-32.

Nguyen, V. H., H. T. Duong, and M. Gummert. 2016. Building a model for the paddy columnar dryer and analyzing a reverse-airflow approach to achieve uniform grain temperature. *International Agricultural Engineering Journal*, 25(1): 64-73.

Omar, S. J., and R. Yamashita. 1987. Rice drying, husking and milling. Part I: Drying. *Agricultural Mechanization in Asia, Africa and Latin America*, 18(2): 43-46.

Peng, S., J. Huang, J. E. Sheehy, R. C. Laza, R. M. Visperas, X. Zhong, and K. G. Cassman. 2004. Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences*, 101(27): 9971-9975.

Pominski, J., T. Wasserman, E. F. Schultz, and J. J. Spadaro. 1961. Increasing laboratory head and total yields of rough rice by milling at low moisture levels. *Rice Journal*, 64(10): 11-15.

Poomsa-ad, N., S. Soponronnarit, S. Prachayawarakorn, and A. Terdyothin. 2002. Effect of tempering on subsequent drying of paddy using fluidisation technique. *Drying Technology*, 20(1): 195-210.

Prasetyo, T., L. Riska, R. Arlanta, and S. Sumardiono. 2018. Experimental study of paddy grain drying in continuous recirculation system pneumatic conveyor. *MATEC Web of Conferences*, 156: 05022.

Sangeetha, S. P., A. Balakrishnan, and P. Devasenapathy. 2013. Influence of organic manures on yield and quality of rice (*Oryza sativa* L.) and blackgram (*Vigna mungo* L.) in rice-blackgram cropping sequence. *American Journal of Plant Sciences*, 4(5): 1151-1157.

Schmidley, A., M. Choudhury, A. Salahuddin, and D. E. Maier. Reducing losses and improving actor incomes in Bangladesh's postharvest rice value chains: Initial assessment results and recommendations for the future. In *Proceedings of the International Working Conference on Stored Product Protection, Chiang Mai, Thailand*, pp. 24-28, 2-4 May 2015.

Sharma, A. D., and O. R. Kunze. 1982. Post-drying fissure developments in rough rice. *Transactions of the ASAE*, 25(2): 465-468.

Siebenmorgen, T. J., P. A. Counce, and C. E. Wilson. 2011. Factors affecting rice milling quality. Fact Sheet 2164. Department of Agriculture and county governments cooperating, University of Arkansas Cooperative Extension Service.

WAP. 2022. Rice Production by Country, World Agricultural Production 2020/2021. Available at: http://www.worldagriculturalproduction.com/crops/rice.aspx. Accessed 22 February 2022.

Worldometer. 2022. Bangladesh Population. Available at: https://www.worldometers.info/world-population/bangladesh-population/. Accessed 22 February 2022.

Yang, W., C. Jia, T. J. Siebenmorgen, T. A. Howell, and A. G. Cnossen. 2002. Intra–kernel moisture responses of rice to drying and tempering treatments by finite element simulation. *Transactions of the ASAE*, 45(4): 1037-1044.

Zhang, Q., W. Yang, and Z. Sun. 2003. Mechanical properties of sound and fissured rice kernels and their implications for rice breakage. ASAE Paper No. 036018. St. Joseph, Mich.: ASAE.