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Effect of Four Different Operational Methods for Drying Parboiled Paddy in BAU-STR Dryer

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ABSTRACT

The study was conducted with a view to develop a suitable method for drying parboiled paddy in BAU-STR dryer. The experiment was conducted at Moti auto rice mill, Shyamganj bazar, Purbadhala, Netrokona, Bangladesh. The dryer was evaluated with 4 treatments using variety BRRI dhan28. Each Treatment had four steps of drying. Treatment 1 (T_1) was comprised with first sun drying until moisture content reached 25% (wb) and then drying in BAU-STR dryer with high temperature (45±2.65°C). Treatment 2 (T_2) was encompassed with first low temperature (35±2.15°C) drying until moisture content reached 25% (wb) and then drying in BAU-STR dryer with high temperature (45±2.65°C). Treatment 3 (T_3) was contained with first only air flow until moisture content reached 25% (wb) and then drying in BAU-STR dryer with high temperature (45±2.65°C). Treatment 4 (T_4) was comprised with first high temperature drying until moisture content reached 14% (wb) in inner part of grain and ambient air flow until the moisture gradient remain same in inner and outer grain. Each of the drying treatment had 2 hr ambient air flow when inner grain moisture reached 18% (wb). The total drying time were (7.5 hr sundry + 5.5 hr in dryer), 7 hr, 9 hr and 9 hr for T_1, T_2, T_3 and T_4, respectively. Parboiled paddy was dried from average initial moisture content 31.9% (wb) to final moisture content 15.1% (wb). The variation of moisture between inner and outer grain was 6%, 8.5%, 8.6% and 3% in T_1, T_2, T_3 and T_4, respectively. The drying rate was found 1.1%MC/hr, 2.0%MC/hr, 1.6%MC/hr and 1.9%MC/hr for T_1, T_2, T_3 and T_4, respectively. The efficiency of the dryer was found 53.2%, 62.9%, 62.7% and 66.9% for T_1, T_2, T_3 and T_4, respectively. The head rice yield was 45.27%, 43.38%, 45.76% and 52.47% for T_1, T_2, T_3 and T_4, respectively. All four solutions have higher running costs than the conventional sun drying method. In each treatment, the benefit cost ratio (BCR) was less than one (1.0). Although the head rice output was below the required level, the milling recovery of rice dried in a BAU-STR dryer was adequate.

Keywords: Parboiled paddy, BAU-STR dryer, Milling recovery, Moisture content.

INTRODUCTION

Paddy (*Oryza sativa* L.) is the most important cereal and staple food crop in Bangladesh. It has been reported that as much as 75% of the daily calorie intake of the people in some Asian countries is derived from rice (Nations, 2025). The majority of people living in rural areas work in the fields of production, processing, and marketing. It is the most common food crop, making up over 75% of the land used for agriculture and 28% of the sector's GDP. Currently, Bangladesh produces over 50.8 million tons of paddy to feed roughly 164 million people (Department of Economic and Social Affairs, 2024). Bangladesh ranks 4^{th} in terms of rice production due to use high yield variety (HYV) and modern paddy production technology.

Achieving food security for everyone and sustainable food production are two of Bangladesh's biggest issues. For Bangladesh, food security has been and will continue to be a top priority. By 2050, Bangladesh's population is predicted to have grown to 202 million (Affairs, 2017).

Reducing post-harvest loss can therefore be extremely important for global and national food security. Reducing losses and preserving crop quality until it reaches the end user are the goals of an effective post-harvest system. Every step of the rice production supply chain, including harvesting, threshing, cleaning, drying, storing, processing/milling, marketing, and consumer level, experiences post-harvest loss. The crucial step following rice harvesting is dying. Incomplete, inefficient, or delayed drying will lower grain quality and cause losses. Grain moisture content (MC) ranges from 20 to 25% (wet basis) when paddy is typically harvested, and 35% moisture is present when paddy is parboiled ((IRRI), 2018)

Poor or defective drying facilities or incorrect drying procedures may result in very fast drying rates, incomplete drying, moisture re-absorption and uneven moisture distribution within the grain mass (M, 2004). Improper drying results in high costs, low efficiencies, high milling losses and poor quality of milled rice. Unless the grain is dried immediately and properly stored after harvest, losses are likely to be incurred at the pre-milling and milling stages. A grain drier can be evaluated properly only after reliable tests have been performed (United Nations. Economic and Social Commission for Asia and the Pacific, RNAM, 1995). The best temperature for drying paddy grain is 60^0 C with the weight loading of 150 g. (Prasetyo, 2018).

Paddy rice parboiling is a crucial step in the post-harvest rice processing process. When compared to raw rice during processing, parboiled rice is known for having a higher milling yield and less breakage. Furthermore, parboiled rice has several health advantages and improved glycemic control (Jhauharotul Muchlisyiyah, 2023). It is a hydrothermal treatment followed by drying before milling for the production of milled parboiled grain. Parboiling of paddy has been known in the Orient for centuries. The quality of parboiled paddy depends on three major processes soaking, steaming, and drying. Parboiled paddy should be dried to 14% moisture for safe storage or milling (Bala, 2016). However, unpredictable weather and unexpected rainfall can damage the grain and quality deterioration.

Due to its significantly higher moisture content, parboiled rice is more difficult to dry and uses more energy than non-parboiled paddy. Higher air temperatures, however, aid in shortening the drying period. Grain will develop internal tensions if drying is done too quickly, which will lead to breakage during milling. Depending on the variety, drying temperatures between 35°C and 45°C had a less fissuring impact. For parboiled paddy, a consistent drying mechanism is therefore crucial. Samples of varieties AVAXI and 424 were then quickly parboiled and sun-dried in preparation for grinding. According to the milling results, less broken rice was discovered and more head rice was produced (Meghwal, 2015).

After drying is completed, the paddy should be allowed to stand for at least several hours - preferably for 1 or 2 days - before it is milled, to permit internal moisture differences and stresses to equalize. Moisture reduction takes place rapidly during the first part of drying from 36 to 18% moisture level but is slow from 18 to 14%. The drying process should be stopped at about 18% moisture to allow the paddy to temper or equalize for several hours before continuing the drying to 14% ((IRRI), 2018)

Drying is dependent on weather conditions and unexpected rainfall can result in delayed drying, re-wetted grains, and quality deterioration Depending on drying air temperature and relative humidity, sun-drying usually takes 3 to 4 days. Sun-drying paddy from 36% to 14% moisture in a single stage causes considerable damage to its milled quality ((IRRI), 2018). It is recommended that the parboiled paddy be dried using any two-stage drying scheme in order to produce high-quality dried grain with the least amount of energy. (Md. Akhtaruzzaman, 2022).

The BAU-STR dryer is very efficient and suitable for drying harvested paddy. (M. Alam,2019). The hot air temperature was uniformly distributed throughout the dryer and the paddy dried uniformly. The moisture content of paddy reduced from 23.9% to 10.4%, 22.9% to 10.6% and 21.6% to 10.7 % in between 3.7 to 4.5 hours (Alam M. S., 2016). But it is a great problem for drying parboiled paddy for its high moisture content. To address this problem dryer might be suitable for parboiled paddy drying at the small-scale traders and farmers level of the country which leads to a greater quality of milled rice. (Alam.M,2018)

Objectives

The objectives of the proposed study were

1. to find out a suitable method for drying parboiled paddy in BAU-STR dryer.
2. to investigate the technical performance of BAU-STR dryer.

MATERIALS AND METHODS

Experimental Site and Materials

The study was conducted at Moti auto rice mill, Shyamganj bazar, Purbadhala, Netrokona, Bangladesh. The dryer was evaluated using the BRRI dhan28 variety. The paddy samples were collected from the Moti auto rice mill.

Description of BAU-STR Dryer

The BAU-STR dryer consists of two perforated (stainless steel wire mesh) concentric cylinders with grains inside the annular space with a blower to provide the heated air though the grains. It also requires biomass stove (Chula), hot air conveyor pipe, bricks or stone or soil clod, polythene sheet (covering material), bamboo and rope (Fig. 1).

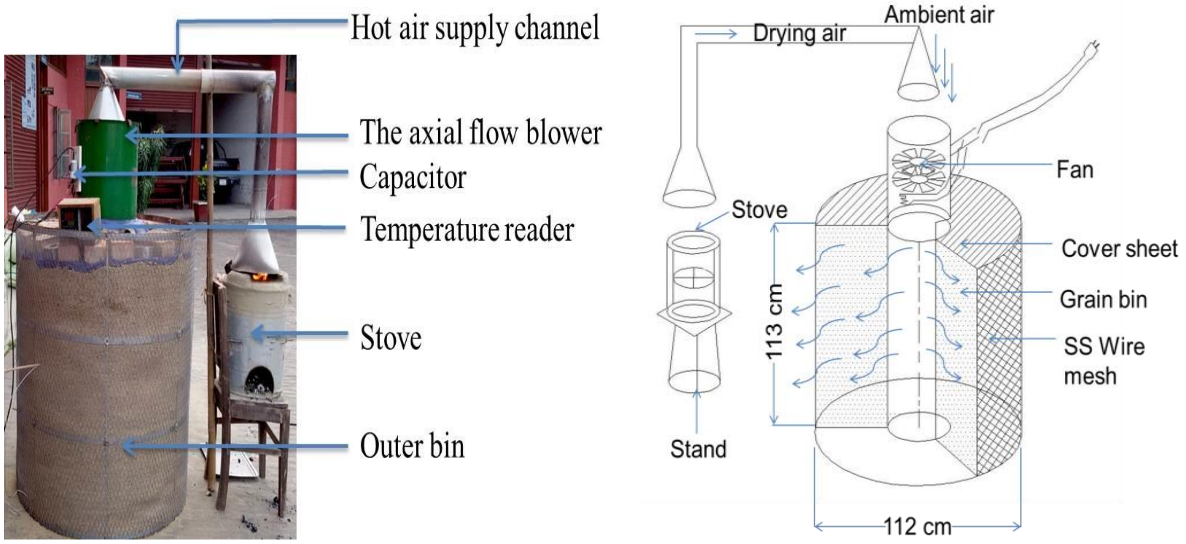


Fig. 1: (a) Photographic view and (b) Schematic view of BAU-STR dryer

The dryer is consists of two type of bin named inner and outer bins. The paddy is just placed between the inner and outer bin. The diameter of inner bin is fixed while the diameter of the outer bin is adjustable to hold desired volume of paddy grains. The top of the cylinders' annular space was closed with the plastic sheet with bricks on it. Air is passed from the inner cylinder through walls with bottom and top closed to dry the grains inside the annular space. An axial flow blower was used to suck the hot air from the stove (Chula) through hot air supply pipe and force the air radially through perforated bins. Electricity was used for running the blower. A diesel generator was used as an alternative way for running the blower in absence of electricity. Rice husk brequite is used as fuel.

BAU-STR Dryer Installation and Experimental Set-Up

The BAU-STR dryer was installed at Chatal (concrete drying floor) at Moti Auto Rice Mill. At first, inner bin was placed in a plain surface of drying floor. The outer bin was placed around the inner bin in such a way that the distances of outer bin remain same from inner bin in all sides. The blower was set up on the top of the inner bin of the dryer and a thick polythene sheet was used to protect hot air leaking from the paddy of the dryer. Bricks were used as weighty material on polythene sheet. The stove (Chula) was placed in one side of the grain bin and firing was done using rice husk briquette. The hot air supply pipe was attached with the help of bamboo stand which was tied by GI wire whereas suction face of hot air pipe attached with stove and other face attached with blower. Vertical and horizontal drying air temperature distribution was recorded at 1 (one) minute interval using 5 (five) temperature sensors (Model-ACR Smart Button) cum data logger by placing in grain bin according to experimental layout as shown in Fig. 2.

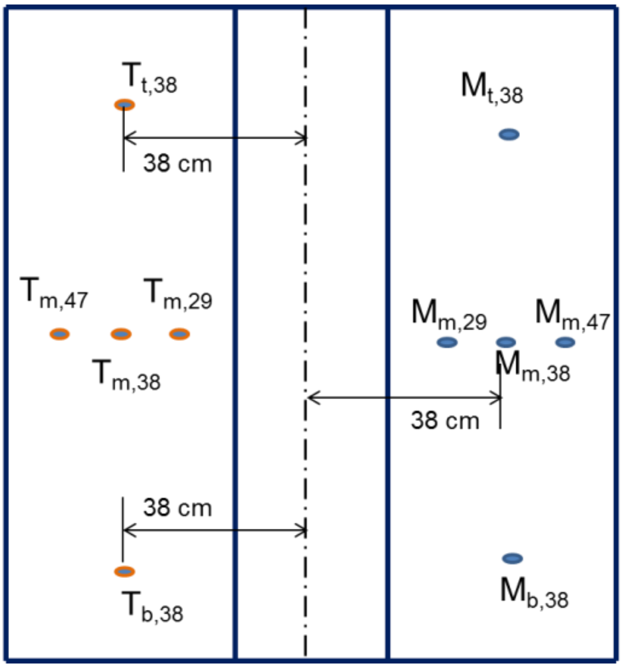


Fig. 2: Experimental layout of BAU-STR dryer (T-temperature sensors, M-moisture sensor, t-top, m-middle, b-bottom, Number in the subscript indicate distance from the centre line in cm)

The temperature sensors named T_m,29, T_m,38 and T_m,47 were placed maintaining 29, 38 and 47 cm distance from the centre line of inner bin to record horizontal temperature distribution in grain bin. T_t,38 and T_b,38 temperature sensors were placed in top and bottom position of grain bin maintaining 28 cm distance from top and bottom grain layer, respectively to record vertical temperature distribution in grain bin. Ambient air temperature and relative humidity were measured continuously at same interval using

ACR TRH-1000 data logger. Four drying treatments were used as drying method for the drying experiments. The dryer was evaluated with 4 treatments using BRRI dhan28 variety. Treatment 1, Treatment 2 and Treatment 3 were taken with 2 replications. Treatment 4 was repeated with 2 replications to justify the suitable treatment for drying parboiled paddy.

For treatment 1, first Sunlight (traditional sun drying) was used to dry paddy until moisture content reached 25% (wb). Then drying was conducted in BAU-STR dryer with high temperature (45±2.65°C). When the inner grain moisture reached to 18% (wb), ambient air was flowed for 2 hr to reduce the inner and outer grain moisture variation. Again paddy was dried with high temperature (45±2.65°C) until the moisture content reached to 14% (wb).

In treatment 2, first low temperature (35°C±2.15) was used in BAU-STR dryer for drying paddy until moisture content reached 25% (wb). Then the paddy was dried in high temperature (45±2.65°C). When the inner grain moisture reached to 18% (wb), ambient air was flowed for 2 hr to reduce the inner and outer grain moisture variation. Then paddy was dried with high temperature (45±2.65°C) until the moisture content reached to 14% (wb).

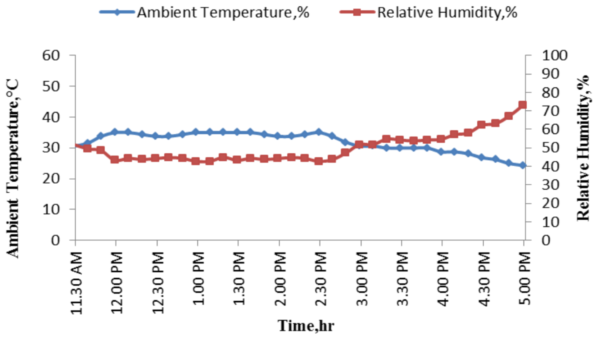
In treatment 3, only air flow was used until moisture content reached to 25% (wb). Then the paddy was dried in high temperature (45±2.65°C). When the inner grain moisture reached to 18% (wb), ambient air was flowed for 2 hr to reduce the inner and outer grain moisture variation. Then paddy was dried with high temperature (45±2.65°C) until the moisture content reached to 14% (wb).

In treatment 4, drying was conducted in BAU-STR dryer with high temperature (45±2.65°C). When the inner grain moisture reached to 18% (wb), ambient air was flowed for 2 hr to reduce the inner and outer grain moisture variation. Again, high temperature (45±2.65°C) was used until moisture content reached to 14% (wb). Then only blower was used to flow ambient air until the moisture gradient became same in inner and outer grain.

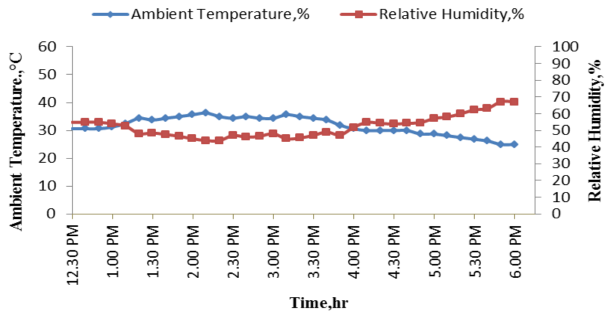
RESULTS AND DISCUSSION

Ambient Temperature and Relative Humidity during drying operation

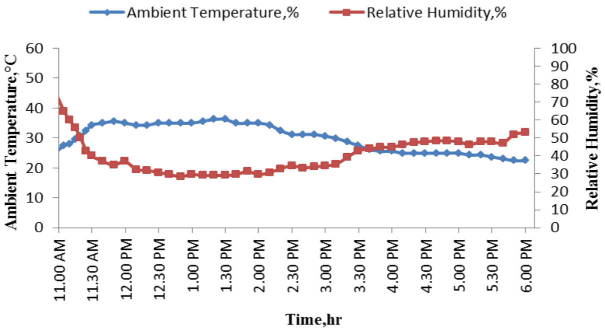
The technical performance evaluation of BAU-STR dryer depends on ambient temperature and relative humidity. The gradient of ambient temperature with the relative humidity of treatment 1, treatment 2 and treatment 3 are presented by Fig. 3.



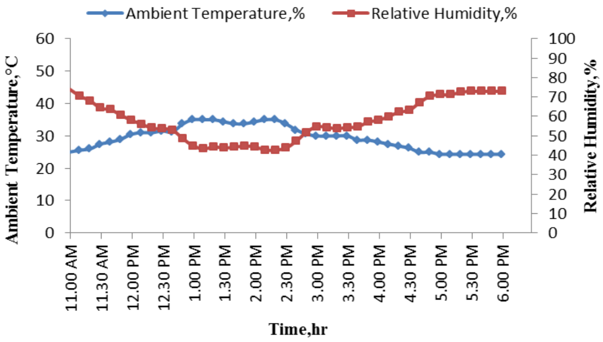
(a) T_1R_1



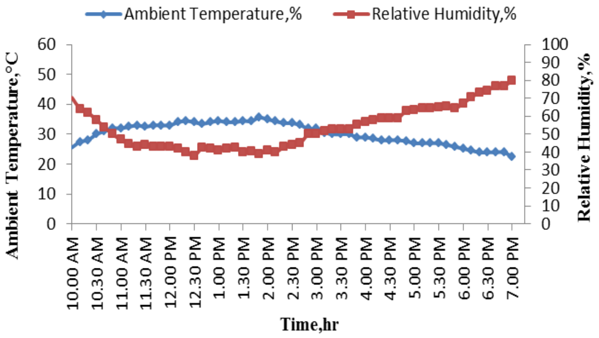
(b) T_1R_2



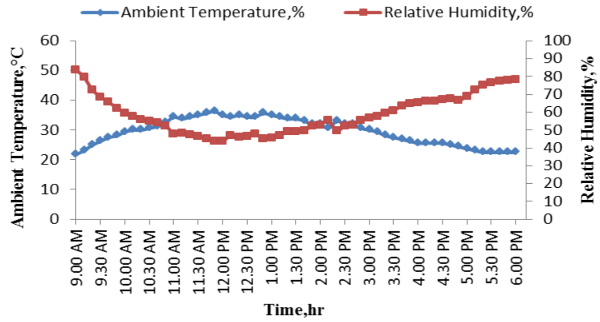
(c) T_2R_1



(d) T_2R_2



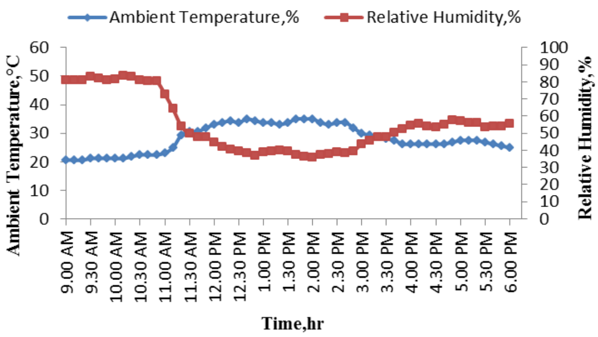
(e) T_3R_1



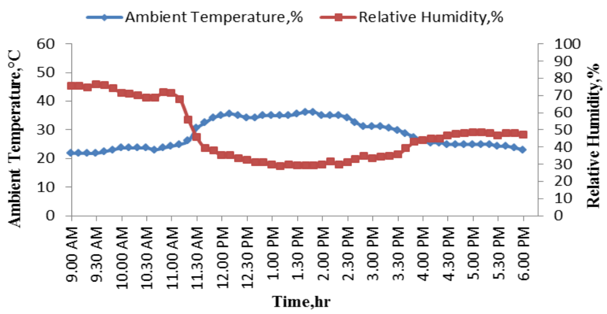
(f) T_3R_2

Fig. 3: Relationship between ambient temperature and relative humidity during drying operations in different treatments (T-Treatment, R-Replication, Number in the subscript indicate the number of treatment and replication)

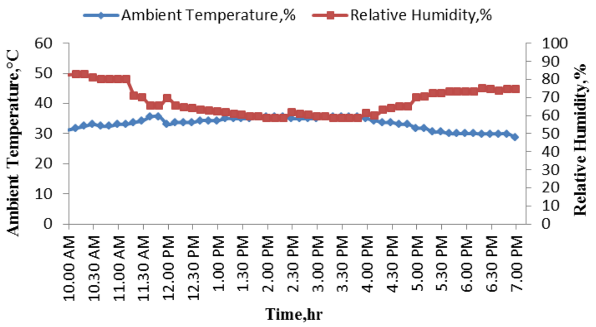
Ambient temperature was inversely related with relative humidity. When the ambient temperature was increased, then the relative humidity was gradually decreased. Ambient temperature was measured in °C and relative humidity was in %. The low air temperature and high relative humidity decreased the drying rate of paddy. The gradient of ambient temperature with the relative humidity of treatment 4 is presented by Fig. 4.



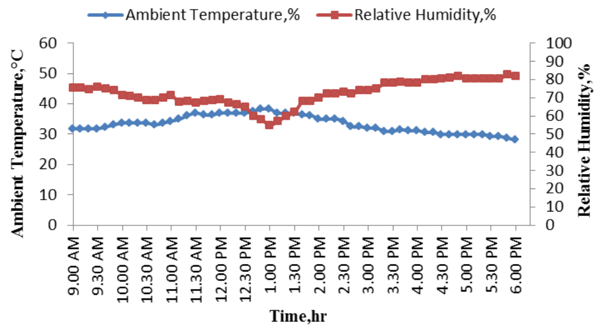
(a) T_4R_1



(b) T_4R_2



(c) T_4R_3



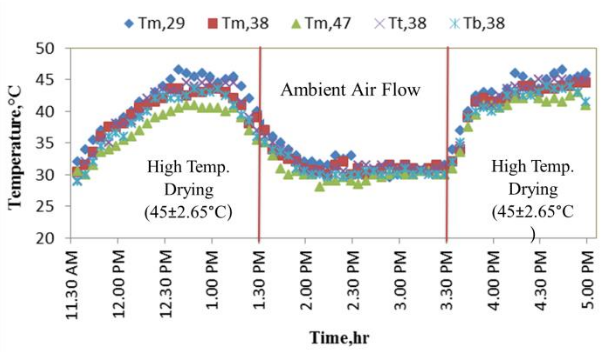
(d) T_4R_4

Fig.4: Relationship between ambient temperature and relative humidity in treatment 4 during drying operation from 4 February 2018 to 7 June 2018 (T-Treatment, R-Replication, Number in the subscript indicate the number of treatment and replication)

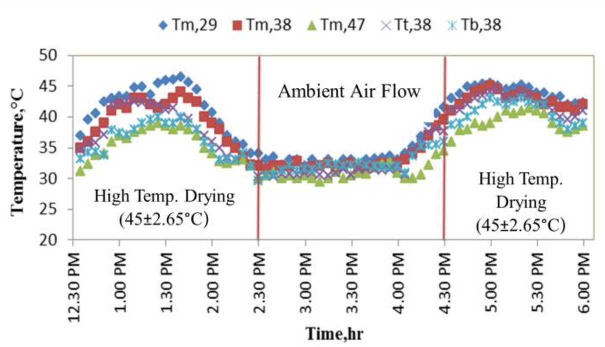
The graph shows that the temperature was low and relative humidity was high at 9.00 AM. The temperature was increased gradually and relative humidity became low at 12.00 PM. After 3.30 PM the temperature was decreased again and relative humidity became high. The average minimum and maximum ambient temperature was 24°C and 33.5°C, respectively. The average minimum and maximum relative humidity was 45% and 78%, respectively.

Temperature distribution inside BAU-STR dryer

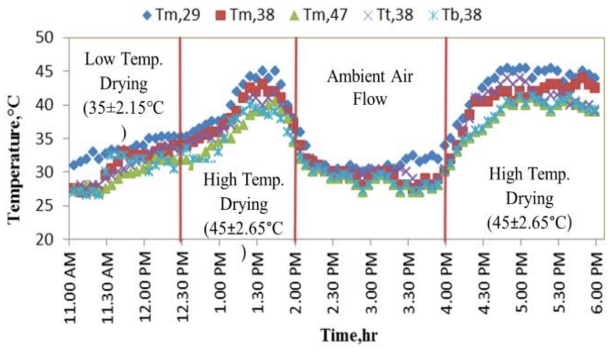
The temperature sensors were set at the different distance from the centre line of the inner bin from where hot air was entering into grain pile.



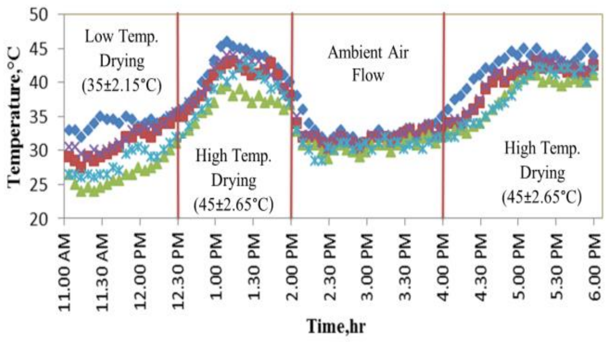
(a) T_1R_1



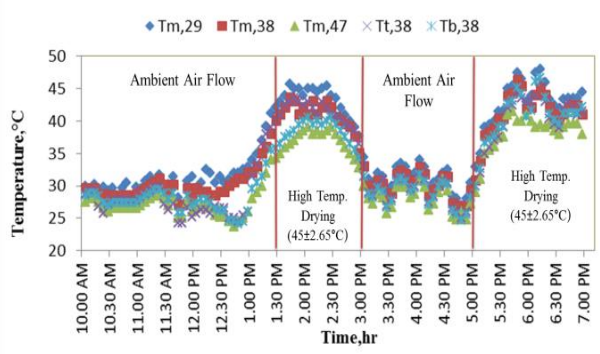
(b) T_1R_2



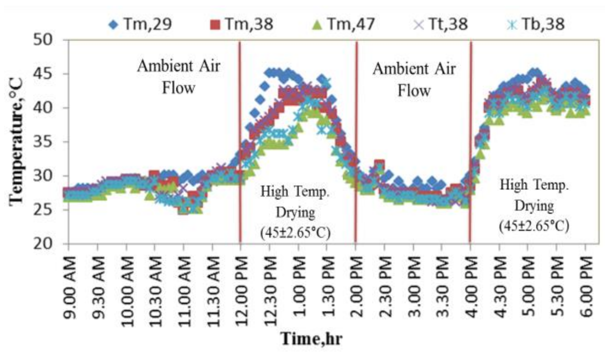
(c) T_2R_1



(d) T_2R_2



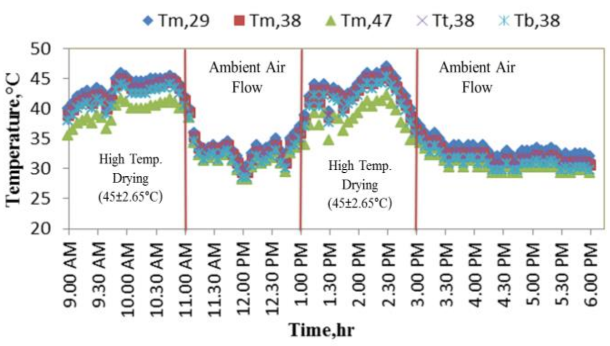
(e) T_3R_1



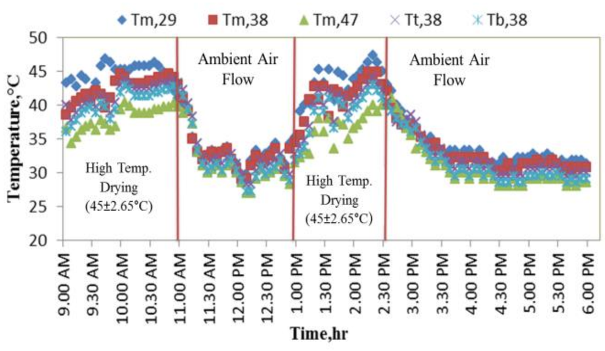
(f) T_3R_2

Fig. 5: Variation of temperature inside BAU-STR dryer in different treatments during drying operations from 13 March 2017 to 23 March 2017 (T-Treatment, R-Replication, Number in the subscript indicate the treatment and replication number)

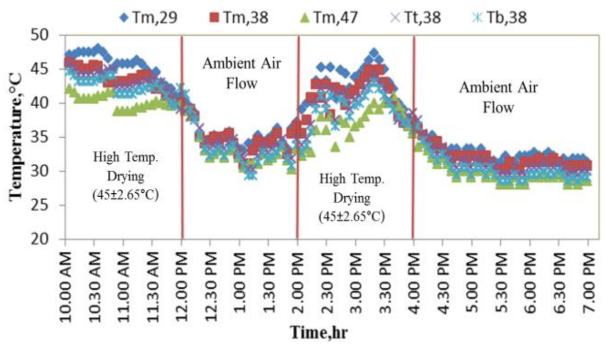
The drying temperature distribution during the drying operation of treatment 1, treatment 2 and treatment 3 are presented in Fig. 5. The vertical temperature distribution $T_{b,38}$, $T_{m,38}$ and $T_{t,38}$ was remained same. But the horizontal temperature distribution was varied because the distances from the centre of the inner bin were different. The drying temperature was almost 45 ±2.65°C. The temperature was gradually decreasing at the time of ambient air flow. Temperature at $T_{m,47}$ location was 6-8°C lower than temperature at $T_{m,29}$. The drying temperature distribution of treatment 4 is presented in Fig. 6 during the drying operation.



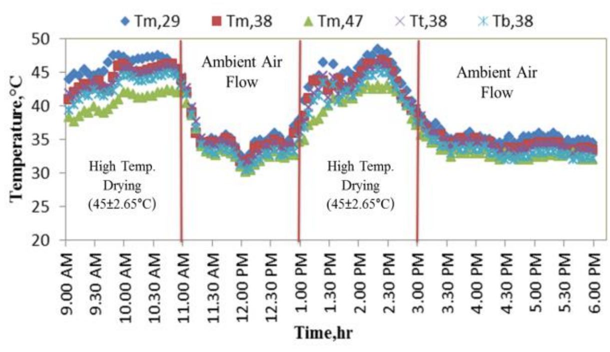
(a) T_4 R_1



(b) T_4 R_2



(c) T_4 R_3



(d) T_4 R_4

Fig. 6: Variation of temperature inside BAU-STR dryer in treatment 4 during drying operation (T-Treatment, R-Replication, Number in the subscript indicate the treatment and replication number)

Moisture removal rate in different treatments of BAU-STR Dryer

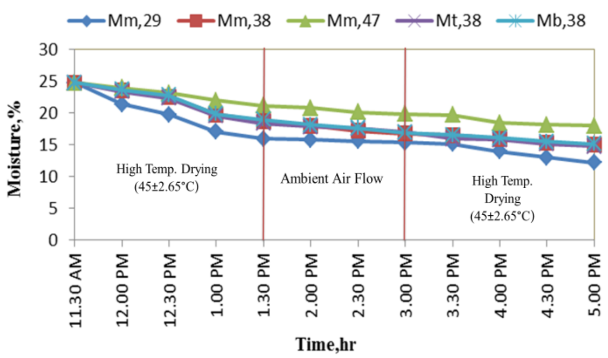
The moisture removal rate of treatment 1, treatment 2 and treatment 3 are presented by Fig. 7 during the drying operation.

In treatment 1, the initial moisture content of parboiled paddy was 30.6%. The first step of drying was sun drying treatment which took about 7.5 hours to reach moisture content 30.6% to 25%. The second step was done in the BAU-STR Dryer. The required time was 5.5 hour to reach the moisture content 25% to 14%. But the variation of moisture content between inner and outer grain was not uniform. The moisture content variation was about 6% between $M_{m,29}$ and $M_{m,47}$.

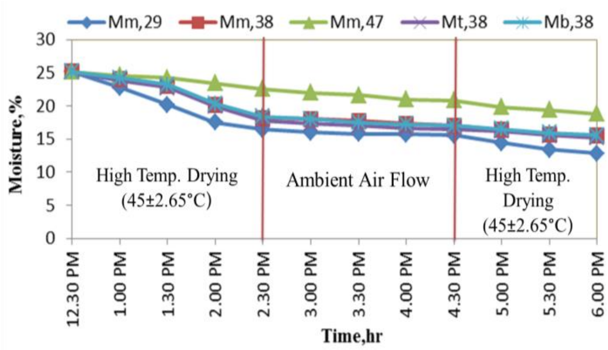
In treatment 2, the initial moisture content of parboiled paddy was 30.2%. The first stage dried in low temperature (35°C±2.15) and the moisture removal rate was very low. It takes 2 hours to reach moisture 30.2% to 25% in low temperature drying. The dryer needed 7 hours to reach the moisture content 30.2% to 14%. But the moisture variation between inner and outer was not uniform. The moisture variation was about 8.5% between $M_{m,29}$ and $M_{m,47}$.

In treatment 3, the initial moisture content of parboiled paddy was 30.4%. In the first stage, paddy was dried in ambient air flow to reach moisture content at 25%. But the moisture removal rate was very low and it almost took 3 hours to remove only 3% moisture content. The moisture reached 30.2% to 27% with 3 hours drying operation. Paddy was dried in 9 hours to reach the moisture content 30.4% to 14%. But the moisture variation between inner and outer was not uniform. The moisture variation was about 8.6% between $M_{m,29}$ and $M_{m,47}$.

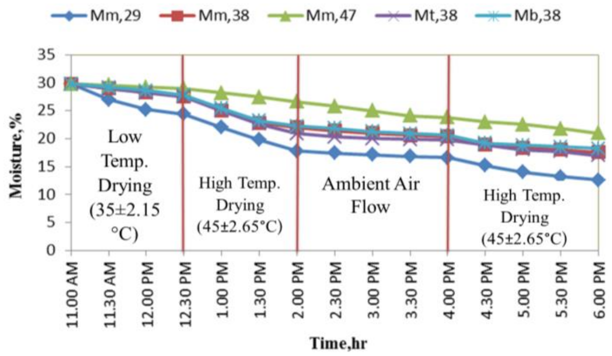
In treatment 4, the initial moisture content of parboiled paddy was 31.9%. In first stage, paddy was dried in high temperature (45±2.65°C) to reach the moisture content 18% at inner. The moisture removal rate was significant and it took 2 hours to reach the moisture content 31.9% to 18%. The dryer took 6 hours' time to reach the moisture content 31.9% to 14%. But the moisture variation between inner and outer was not uniform. The moisture variation was about 8.6% between $M_{m,29}$ and $M_{m,47}$.

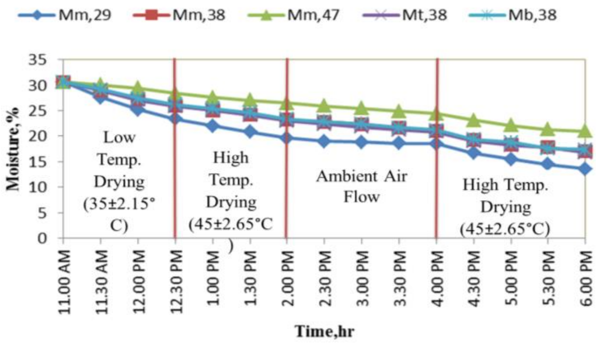


(a) T_1R_1

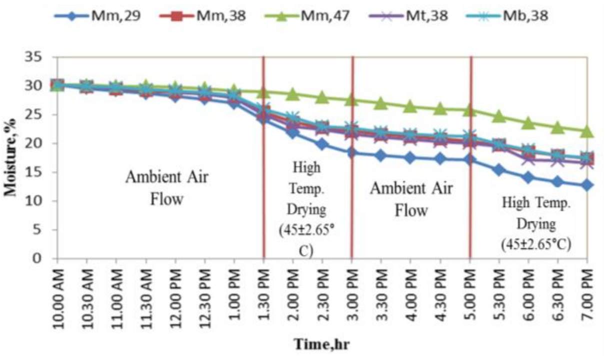


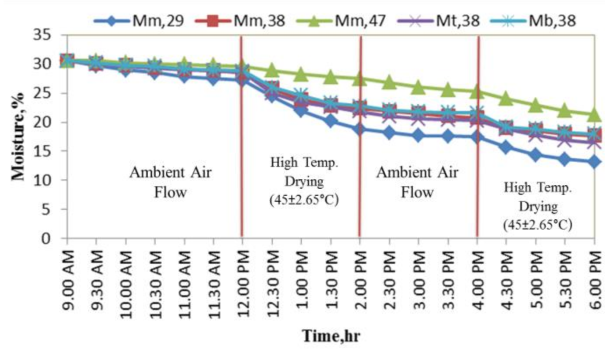
(b) T_1R_2





(c) T_2R_1 (d) T_2R_2



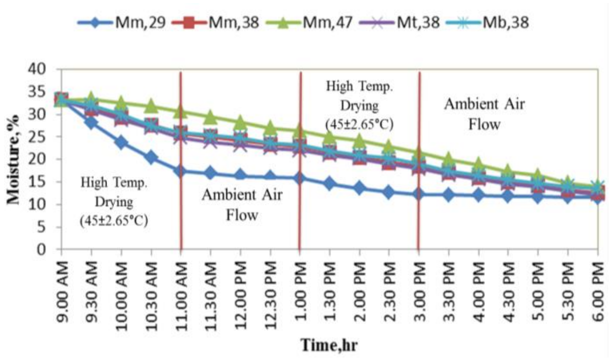


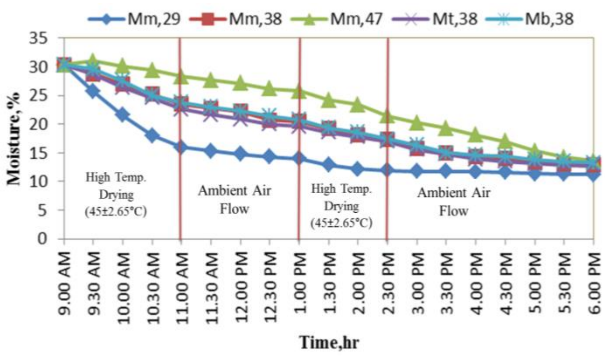
(e) T_3R_1 (f) T_3R_2

Fig. 7: Moisture removal rate in different treatments during drying operations in BAU-STR Dryer (T-Treatment, R-Replication, Number in the subscript indicate the treatment and replication number)

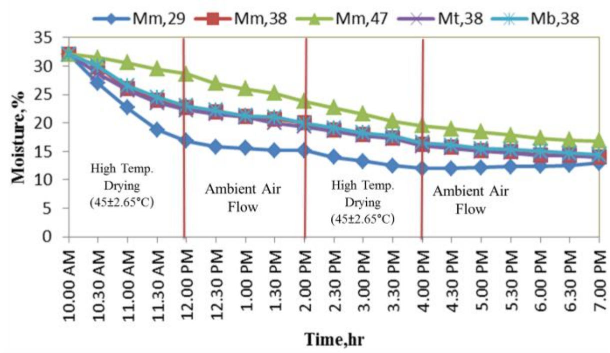
So, ambient air flow passed through the bin until the moisture variation became lower between inner and outer. The ambient air flow was needed 3 to 3.5 hours to reduce the moisture variation between inner and outer grain. After ambient air flow the moisture variation became 2-4% between $M_{m,29}$ and $M_{m,47}$.

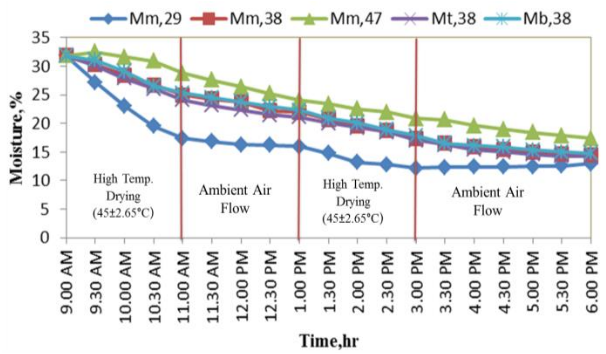
The moisture removal rate of treatment 4 is presented by Fig. 8





(a) T_4R_1 (b) T_4R_2





(c) T_4R_3 (d) T_4R_4

Fig. 8: Moisture removal rate in treatment 4 during drying operations (T-Treatment, R-Replication, Number in the subscript indicate the treatment and replication number)

Each treatment was introduced 2 hours ambient air flow to reduce the moisture content variation between inner and outer. The variation of moisture content 2% recommended for dried paddy (http://www.knowledgebank.irri.org). The treatment 1, 2 and 3 moisture content variations between inner and outer grain were too high to accomplish the recommended moisture variation. But the moisture variation between inner and outer grain of treatment 4 was closer to the recommended value (2%).

Technical performance of BAU-STR dryer

Drying capacity, drying efficiency, moisture removal rate were measured to determine the technical performance of BAU-STR dryer in different treatment. Paddy was dried from average initial moisture content 31.9% (wb) to final moisture content 15.1% (wb). Temperature variation was occurred at horizontal and vertical position of BAU-STR dryer. The moisture content of the paddy was more at the beginning of the experiment and inside the dryer drying air temperature was remained lower than the ambient temperature because of vaporizing moisture. The total drying time for treatment 1, treatment 2, treatment 3 and treatment 4 was 5.5 hr, 7 hr, 9 hr and 9 hr, respectively. Sun drying was the first step for treatment 1 to reach the moisture content 25% (wb). The time required for sun drying was 7.5 hours in treatment 1.

Drying performance and fundamental parameter of paddy in BAU-STR dryer are shown in Table 1. The drying rate, drying capacity, drying efficiency were varied with the variation of hot air temperature, ambient air flow and relative humidity. The drying rate was found 1.1%MC/hr, 2.0%MC/hr, 1.6%MC/hr and 1.9%MC/hr for treatment 1, treatment 2, treatment 3 and treatment 4 respectively. The efficiency of the dryer was found 53.2%, 62.9%, 62.7% and 66.9% for treatment 1, treatment 2, treatment 3 and treatment 4 respectively.

Table 1: Technical Performance of BAU-STR Dryer

Treatment	Initial Moisture,%	Final Moisture,%	Initial Weight of Paddy, kg	Moisture removed, %	Drying time, hr	Drying rate, %MC/hr	Drying Efficiency, %
T_1R_1	30.4	14.6	510	15.8	15.0	1.1	55.2
T_1R_2	30.8	15.0	508	15.8	15.0	1.1	51.2
T_2R_1	29.8	15.9	515	13.9	7.0	1.9	62.9
T_2R_2	30.6	15.4	519	15.2	7.0	2.1	62.9
T_3R_1	30.2	16.2	510	14.0	9.0	1.6	64.7
T_3R_2	30.6	16.5	514	14.1	9.0	1.6	60.6
T_4R_1	33.2	14.6	516	18.6	9.0	2.0	68.7
T_4R_2	30.4	13.8	518	16.6	9.0	1.8	65.4
T_4R_3	32.1	14.5	520	17.6	9.0	2.0	68.0
T_4R_4	31.9	14.8	523	17.1	9.0	1.9	65.4

Quality Assessment of dried paddy

Milling recovery and Head rice yield of dried parboiled paddy are shown in Table 4.2. Head rice yield depends on grain final moisture content and temperature. Milling recovery of dried parboiled paddy was 69%, 71.83%, 70.79% and 72.16% for treatment 1, treatment 2, treatment 3 and treatment 4 respectively. The head rice yield was 45.27%, 43.38%, 45.76% and 52.47% for treatment 1, treatment 2, treatment 3 and treatment 4 respectively. The head rice yield depends on drying temperature of dryer during drying operation.

The head rice percentage was the volume or weight of head rice or whole kernel in the rice sample. Head rice normally includes broken kernels that are 75-80% of the whole kernel. High head rice yield is one of the most important criteria for measuring milled rice quality. Head rice yields in Asia range from 35 to 50% of total paddy weight (Knowledge Bank IRRI, 2018).

Table 2: Milling recovery of dried parboiled paddy in BAU-STR dryer

Treatment	Milling Recovery, % (mean ± STD)	Head Rice Yield, % (mean ± STD)	Broken Rice, %
T_1	69.00 ± 1.70	45.27 ± 1.31	27.73
T_2	71.83 ± 0.46	43.38 ± 0.18	28.45
T_3	70.79 ± 2.14	45.76 ± 1.43	25.03
T_4	72.16 ± 0.35	52.47 ± 0.23	19.69

CONCLUSION

Paddy was dried from average initial moisture content 31.9% (wb) to final moisture content 15.1% (wb). In terms of moisture variation in inner and outer layer of grain bin, milling recovery, head rice yield, drying efficiency, treatment 4 (High temperature (45±2.65°C)-Ambient air flow-High temperature (45±2.65°C)-Ambient air flow) was comparatively better than other treatments. The variation of moisture between inner and outer grain was lowest (i.e. 3%) in treatment 4 than other treatments. The drying efficiency was 66.9% in treatment 4. The treatment 4 had acceptable range of moisture variation for drying parboiled paddy. Milling recovery was satisfactory for all treatments. The head rice yield for all four treatments did not pass the standard.

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