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Optimizing Transplanting Time to Mitigate High Temperature Stress and Maximize Yield in Boro Rice Varieties in Barishal Region of Bangladesh

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A R T I C L E I N F O

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A B S T R A C T

Rice yield is highly sensitive to environmental conditions, particularly planting time and temperature. Since rice varieties differ in their tolerance to high-temperature stress, identifying an appropriate transplanting window is essential for ensuring proper tillering, flowering, grain formation, and overall yield. This study examined how high-temperature stress, modulated by different transplanting dates, affects the yield attributes and grain yield of three Boro rice varieties in Barishal. The field experiment was carried out during the 2023–2024 Boro (dry) season at the Sagardi farm of the Bangladesh Rice Research Institute (BRRI), Regional Station, Barishal. The experiment was laid out in a split-plot design with three replications. Six transplanting dates (10 December, 25 December, 10 January, 25 January, 10 February, and 25 February) and three rice varieties (BRRI dhan89, BRRI dhan92, and BRRI dhan102) were evaluated. All three varieties performed best when transplanted on 25 December, producing the highest grain yields: BRRI dhan89 (7233.49 kg ha^{-1}), BRRI dhan92 (7477.91 kg/ha), and BRRI dhan102 (8097.82 kg/ha). These peak yields were accompanied by maximum tiller and panicle production, higher grain numbers per panicle, and greater thousand-grain weight. Conversely, transplanting on 25th February led to the highest spikelet sterility, while 25 December showed the lowest, highlighting the strong influence of temperature during reproductive stages. Based on these findings, farmers in the Barishal region are advised to transplant Boro rice seedlings between 10th December and 10th January to achieve optimum yield and minimize high temperature-induced sterility. Future research should include a broader range of high-yielding varieties and evaluate similar transplanting schedules across diverse rice-growing regions of Bangladesh to strengthen region-specific recommendations.

1. Introduction

Rice (*Oryza sativa* L.) is one of the world's most essential staple foods, sustaining nearly two-thirds of the global population. Beyond its nutritional value, rice is deeply woven into the cultural identity, economic stability, and daily lives of millions across Asia and other regions (Harbinson et al., 2021). As the

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global population continues to rise, the demand for food is expected to reach 14,886 million tons (MT) by 2050, necessitating substantial increases in agricultural production to maintain global food security (Islam et al., 2019).

Currently, global rice production stands at about 503.17 MT, with major contributions from China, India, and Bangladesh, underscoring the crop's worldwide significance (USDA, 2020). In Bangladesh in particular, rice is central to national food security, rural livelihoods, and socioeconomic stability (Jamal et al., 2023). However, rapid population growth, shrinking cultivable land, and the increasing impacts of climate variability place immense pressure on rice production systems. This makes the adoption of effective agronomic strategies more urgent than ever.

Among the available strategies, optimizing the timing of sowing and transplanting plays a pivotal role in achieving high yields. Ideal transplanting time is influenced by soil temperature, weather patterns, varietal characteristics, and regional agroecological conditions (Deshmukh and Patel, 2013; Yoshida and Parao, 1976). Rice requires specific temperature ranges to successfully complete critical growth stages such as panicle initiation, flowering, and grain filling. When transplanting is done at the appropriate time, plants can grow uniformly and benefit from favorable environmental conditions that enhance their development (Vange and Obi, 2006).

Delayed transplanting, however, often shortens the vegetative growth phase, reduces tillering capacity, and ultimately results in lower yields. Selecting the correct transplanting window is therefore essential, as it ensures the accumulation of adequate heat units required for proper plant growth and development (Rani and Maragatham, 2013). Because rice varieties vary in their growth duration, photosensitivity, temperature tolerance, and vegetative lag, the decision regarding when to transplant becomes even more critical. Timely transplanting not only supports vigorous vegetative growth but also helps avoid cold or heat stress during the sensitive reproductive stage, improving grain filling and grain quality (Farrell et al., 2003).

Heat stress (HS) has emerged as one of the most significant abiotic challenges threatening rice productivity. Elevated temperatures can disrupt physiological and morphological processes, increase spikelet sterility, and lead to severe yield losses, particularly when heat coincides with flowering (Shrestha et al., 2022). Studies suggest that rice yield may decline by up to 10% for every 1°C increase in temperature during critical stages of growth (Yang et al., 2017; Peng et al., 2004). As a result, adjusting transplanting dates to avoid periods of high-temperature stress is a critical component during the maturity stages of climate-smart rice cultivation, especially in the Barishal region of Bangladesh (Reddy and Narayana, 1984).

Earlier research has demonstrated that early transplanting can enhance dry matter accumulation, improve physiological efficiency, and increase grain yield compared to late transplanting (Khalifa, 2009; Mukesh et al., 2013). Across diverse environments, planting time consistently emerges as one of the most influential factors shaping rice productivity.

Considering these challenges and opportunities, the present study aims to evaluate the grain yield performance of newly developed long-duration Boro rice varieties across multiple transplanting dates in the Barishal Region of Bangladesh. By aligning varietal responses with temperature variations during the Boro season, this research seeks to identify an optimal transplanting window that minimizes high temperature stress and maximizes productivity for farmers in the region.

2. Materials and methods

2.1. Experimental materials

This experiment was conducted during the Boro season of 2023–2024 to evaluate how different transplanting dates influence the performance of selected Boro rice varieties under progressively delayed planting situations. Three modern, long-duration varieties-BRRI dhan89 (V1), BRRI dhan92 (V2), and BRRI dhan102 (V3)-were used as subplot factors. Six transplanting dates served as the main plot factors: 10 December (D1), 25 December (D2), 10 January (D3), 25 January (D4), 10 February (D5), and 25 February (D6).

All three varieties are suitable for irrigated transplanted cultivation in the Barishal region and are widely recommended for their stable performance under Boro season conditions. Their desirable characteristics are summarized in Table 1.

Table 1
Desirable features of the rice varieties used in the study.

Rice Variety	Yield (t/ha)	Growth Duration (days)	Other Desirable Features
BRRI dhan89	8.0	156	Medium-bold white grains; lifecycle 3–5 days shorter than BRRI dhan29
BRRI dhan92	8.4	156–160	Long slender white grains; requires less water for cultivation
BRRI dhan102	8.1	150	Long slender grains enriched with high zinc content

Source: BRRI (2025), Modern Rice Cultivation, 25th Edition, pp. 14–27.

2.2. Experimental site and design

The experiment was conducted at the Sagardi Farm of the Bangladesh Rice Research Institute (BRRI), Regional Station, Barishal (22.68034° N, 90.357486° E; elevation 2 m), during November 2023–June 2024. Initial soil samples were collected and analyzed at the Soil Resources Development Institute (SRDI), Divisional Laboratory, Barishal. The soil properties of the experimental field are presented in Table 2.

A split-plot design with three replications was used. Each block consisted of six main plots (transplanting dates), and each main plot contained three subplots (varieties), resulting in 54 treatment combinations (6 transplanting dates × 3 varieties × 3 replications).

Seedlings were raised in traditional seedbeds and, at 40 days of age, transplanted into well-prepared, puddled plots according to the treatment layout, with 2-3 seedlings planted per hill. Plant spacing was maintained at 20 cm × 20 cm. Fertilizers were applied at a rate of 170-15-75-17-2 kg ha^{-1} of N-P-K-S-Zn using urea, triple superphosphate, muriate of potash, gypsum, and zinc sulfate. All P, K, S, and Zn were applied as basal doses during final land preparation, while urea was top-dressed in three equal splits at 15, 35, and 50 days after transplanting (DAT).

Intercultural operations, including weeding, irrigation, and pest management, were performed as needed. The first weeding was carried out at 15 DAT and subsequently at 15–20 days intervals. Irrigation was maintained until the hard dough stage, after which plots were allowed to naturally drain during ripening. Daily maximum and minimum air temperatures were recorded using standard manual thermometers (Fig. 1).

2.3. Observations on yield and related traits

The number of tillers and panicles per hill was recorded at the maximum tillering and maturity stages, respectively. To estimate panicles per m^2, twenty-five hills were randomly sampled from each plot. Filled and unfilled grains were counted from five representative panicles per plot.

Grain yield was determined by harvesting a 5 m^2 area from the center of each plot (avoiding border effects) once more than 80% of grains had matured. Harvested grains were sun-dried, weighed, and adjusted to 14% moisture content before converting to kg ha^{-1}.

2.4. Growing degree days (GDD) calculation

To assess accumulated heat units during the crop growth period, Growing Degree Days (GDD) were calculated using the following formula (Liu et al., 2022):

$$GDD = \Sigma \left(\frac{Tmax + Tmin}{2} - Tbase \right)$$

Where:

Tmax = Maximum daily temperature (°C)
Tmin = Minimum daily temperature (°C)
Tbase = Base temperature below which rice growth ceases (10°C)

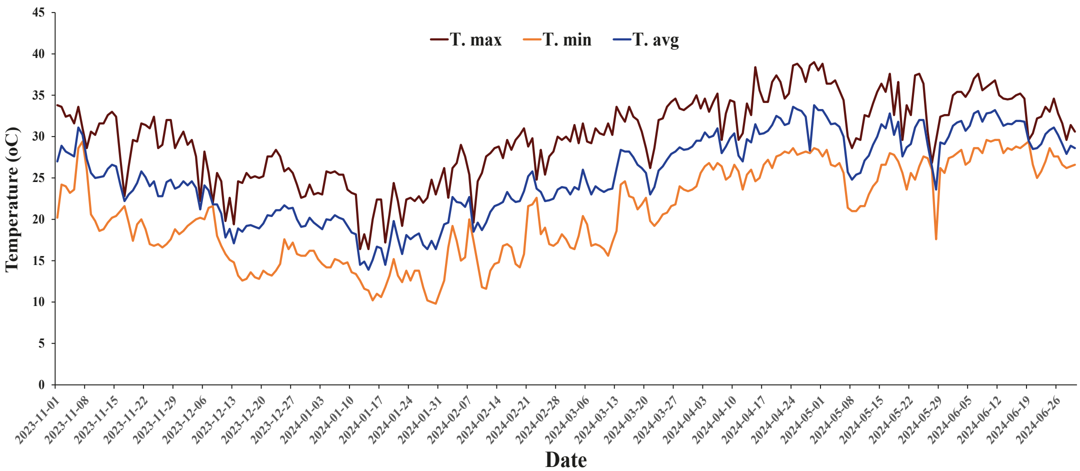

Fig. 1. Maximum, minimum and average air temperature during Boro 2023-24 season (Nov. 2023 – June 2024) at Sagardi Farm, BRRI Regional Station, Barishal.

2.5. Heat use efficiency (HUE) calculation

Heat Use Efficiency (HUE) was computed to evaluate how efficiently accumulated heat contributed to grain production (Gurleen et al. 2025):

$$HUE = \frac{(Grain\ Yield\ (kg/ha))}{CGDD}$$

Where:
CGDD = Cumulative Growing Degree Days from sowing to maturity

Soil Characteristics of the Experimental Site

Table 2
Soil characteristics of the study area, Sagardi Farm, BRRI, Regional Station, Barishal.

Soil Characteristics	Quantity
Texture	Clay
pH	7.1
Electrical Conductivity (dS/m)	1.41
Organic Matter (%)	2.32
Total Nitrogen (%)	0.116
Phosphorus (µg/g)	14.4
Potassium (meq/100g)	0.26
Sulfur (µg/g)	10.1
Zinc (µg/g)	1.97

Note: Soil characteristics were evaluated following the standard methods (Khan et al. 2009).

2.6. Statistical analysis

All data were analyzed using the Statistical Tool for Agricultural Research (STAR version 2.0.1, 2014), developed by the International Rice Research Institute (IRRI). Treatment means were compared using Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984) at appropriate significance levels to identify statistically meaningful differences among transplanting dates and rice varieties.

3. Results and discussion

3.1. Total tillers and panicles per hill

Transplanting time had a significant effect on the total number of tillers per hill (Fig. 2). All three varieties produced the highest number of tillers when transplanted on 25 December, recording 16.07 (BRRI dhan89), 15.73 (BRRI dhan92), and 20.27 (BRRI dhan102). The lowest tiller counts were consistently observed on the 25 February transplanting date, with values of 11.33, 10.80, and 9.07, respectively.

A similar pattern was observed for panicles per hill (Fig. 3). Panicle production decreased steadily with delayed transplanting. The 25 December transplanting produced the maximum panicles—14.67 (BRRI dhan89), 13.93 (BRRI dhan92), and 18.87 (BRRI dhan102). The 25 February transplanting resulted in the lowest numbers: 9.93, 9.00, and 7.67, respectively.

The decline in tiller and panicle production at later dates is closely linked to increasing daytime temperatures during critical stages like panicle initiation. Early transplanting produced more tillers and panicles because the crop avoided high temperatures during the early reproductive stages. High temperatures above 33 °C are known to suppress tiller formation and inhibit panicle initiation (Sánchez et al., 2014). As shown in Fig. 1, temperatures exceeded 33 °C from mid-April onward, a threshold known to inhibit tillering and panicle formation.

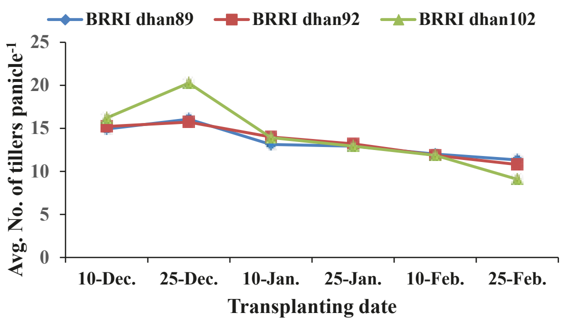

Fig. 2. Avg. No. of total tillers hill-1 of rice varieties as affected by transplanting dates during Boro 2023-24 season at Sagardi Farm, BRRI Regional Station, Barishal.

3.2. Filled grain and sterile spikelet percentage per panicle

Previous studies have highlighted the negative impact of late transplanting on filled grain production. Khan et al. (2022) reported up to a 14% reduction when planting was delayed to mid-February. Our results strongly support this trend.

The greatest number of filled grains per panicle was obtained from the 25 December transplanting for all varieties: 188.8 (BRRI dhan89), 173.0 (BRRI dhan92) and 146.27 (BRRI dhan102). By contrast, the 25 February transplanting produced critically low filled grain numbers: 13.67, 13.53, and 11.33, respectively (Fig. 4).

Spikelet sterility increased sharply with delayed transplanting (Fig. 5). Sterility exceeded 91% across all varieties on 25 February, while the earliest transplanting dates recorded the lowest sterility values. The sharp decrease in filled grains and the rise in spikelet sterility in late transplanting treatments were directly linked to heat stress. Temperatures near or above 35 °C during flowering can damage pollen mother cells, impair meiosis, and reduce fertilization, resulting in very high sterility (Endo et al., 2009; Wu et al., 2016). (Fig. 1 & Table 4). This explains the dramatic spikelet sterility observed in late transplanting treatments. Panicle density also dropped under late transplanting due to heat-induced spikelet degeneration (Fig. 3). Similar reductions have been reported under late-season heat (Sánchez et al., 2014).

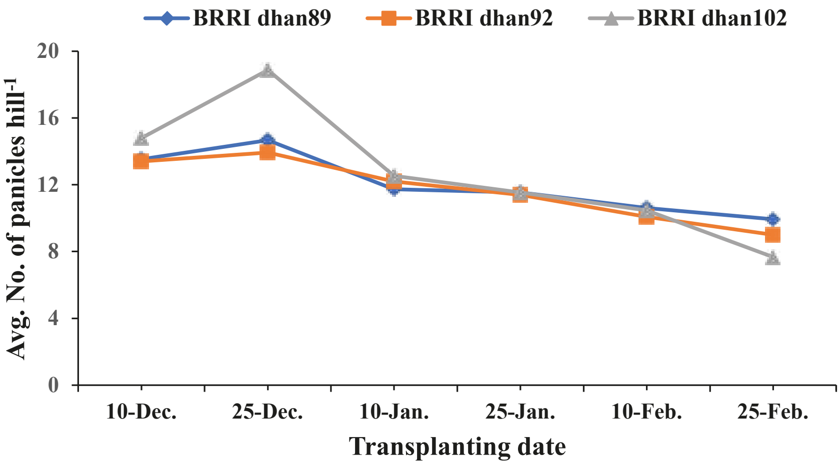

Fig. 3. Avg No. of total tillers hill^{-1} of rice varieties as affected by transplanting dates during Boro 2023-24 season at Sagardi Farm, BRRI Regional Station, Barishal.

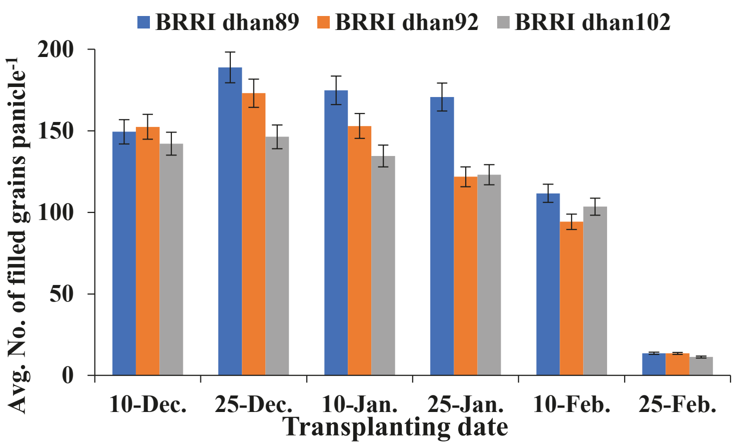

Fig. 4. Avg No. of filled grains panicle^{-1} of rice varieties as affected by transplanting dates during Boro 2023-24 season at Sagardi Farm, BRRI Regional Station, Barishal

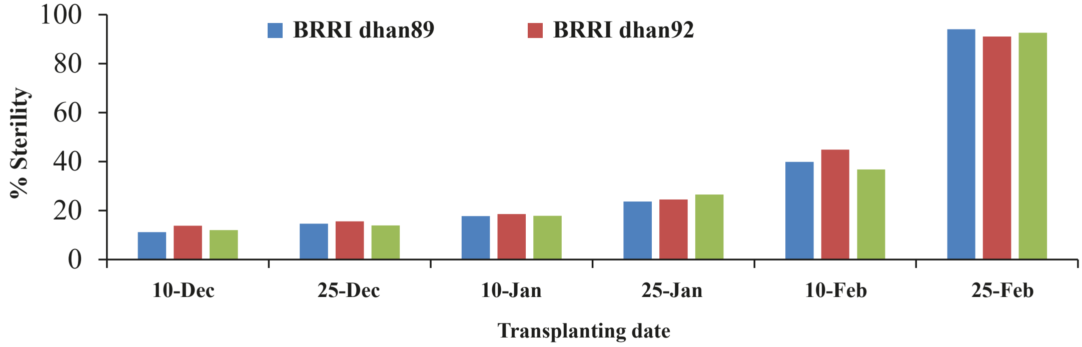

Fig. 5. Spikelet sterility of rice varieties as affected by transplanting dates during Boro 2023-24 season at Sagardi Farm, BRRI Regional Station, Barishal.

3.3. Panicles per square meter

Panicle density (panicles m^{-2}) varied significantly with transplanting dates (Table 3). Again, 25 December provided optimal conditions, producing the highest densities for BRRI dhan89 (492.71), BRRI dhan92 (353.13), and BRRI dhan102 (377.08).

The lowest densities occurred on 25 February, with notable declines to 275, 195.83, and 200 panicles m^{-2}, respectively. These reductions reflect suboptimal conditions for panicle initiation under late-season heat. High temperatures above 33 °C have been shown to impair panicle differentiation and promote spikelet degeneration (Sánchez et al., 2014), consistent with our findings. Thus, delayed transplanting restricts the formation of productive panicles, ultimately lowering yield potential.

3.4. Thousand-grain weight (TGW)

The TGW remained statistically unchanged across planting dates for BRRI dhan89 and BRRI dhan102. However, BRRI dhan92 showed significant variability, indicating greater sensitivity to heat stress during grain filling (Table 3).

For all varieties, the highest TGW was obtained on 25 December (22.82 g, 24.28 g, and 21.84 g for BRRI dhan89, BRRI dhan92, and BRRI dhan102, respectively). The lowest values appeared on 25 February, likely due to heat stress shortening the grain-filling duration and disrupting starch deposition (Arshad et al., 2017).

Table 3
Interaction effect of variety and transplanting date on grain yield and yield contributing characters during Boro 2023-24 season at Sagardi Farm, BRRI Regional Station, Barishal.

Variety	Transplanting date (DT)	Grain Yield (kg/ha)*	Panicle no. m^{-2}*	1000-Grain weight (g)*
BRRI dhan89	10-Dec.	5847.44b	304.69bc	20.02a
	25-Dec.	7233.49a	492.71a	22.82a
	10-Jan.	6562.09ab	322.4b	22.68a
	25-Jan.	4540.42c	302.08bc	22.07a
	10-Feb.	2913.3d	296.88bc	21.57a
	25-Feb.	215.41e	275c	19.33a
BRRI dhan92	10-Dec.	5819.77b	306.25b	23.46ab
	25-Dec.	7477.91a	353.13a	24.28a
	10-Jan.	6277.83b	316.67ab	22.06abc
	25-Jan.	4697.13c	295.83b	20.68bc
	10-Feb.	1929.69d	229.69c	18.83cd
	25-Feb.	405.85e	195.83c	16.45d
BRRI dhan102	10-Dec.	7310.7ab	371.8767a	20.27a
	25-Dec.	8097.82a	377.0833a	21.84a
	10-Jan.	6656.59b	310.42b	21.41a
	25-Jan.	4716.36c	277.6067bc	20.66a
	10-Feb.	3495.66d	248.9567c	20.6a
	25-Feb.	229.69e	200d	19.2a
LSD (0.05)		1008.0585	36.5771	3.5027
CV(DT)%		8.79	4.39	8.99
CV(Variety)%		8.68	5.1	4.92

* Means followed by the same lowercase letter in a column do not differ from each other at 5% level of significance.

3.5. Grain yield

Results clearly demonstrate that transplanting date profoundly influenced grain yield, confirming earlier studies (Al-Amin et al., 2019; Sarwar & Chanda, 2020). The highest yields were consistently recorded on 25 December: 7233.49 kg ha^{-1} (BRRI dhan89); 7477.91 kg ha^{-1} (BRRI dhan92); 8097.82 kg ha^{-1} (BRRI dhan102) (Table 4). Transplanting between 10 December and 10 January reliably produced yields exceeding 5000 kg ha^{-1}. Grain yield followed the combined pattern of tiller number, panicle density, filled grains, and sterility. The highest yields on 25 December matched previous reports that early transplanting ensures favorable temperature conditions for booting and flowering (Yang et al., 2020). Low yields in late planting were caused by heat stress, poor grain filling, and increased sterility.

Table 4

Interaction effect of variety and transplanting date on flowering, growth duration (GD), growing degree days (GDD) and heat use efficiency (HUE) during Boro season at Sagardi Farm, BRRI Regional Station, Barishal.

Variety	Transplanting date	50% Flowering date	100% Flowering date	Growth duration (days)*	GDD at maturity stage(⁰C)*	Heat use efficiency*
BRRI dhan89	10-Dec.	18-Mar.	26-Mar.	175.0a	2363.4b	2.47b
	25-Dec.	29-Mar.	02-Apr.	160.33c	2112.97d	3.42a
	10-Jan.	07-Apr.	12-Apr.	157.67d	2170.32c	3.03a
	25-Jan.	09-Apr.	14-Apr.	147.0e	2067.3e	2.2b
	10-Feb.	01-May	06-May	145.0f	2189.6c	1.33c
	25-Feb.	21-May	27-May	163.0b	2747.55a	0.08d
BRRI dhan92	10-Dec.	22-Mar.	27-Mar.	175.0a	2363.4b	2.46bc
	25-Dec.	28-Mar.	02-Apr.	161.0c	2128.43d	3.51a
	10-Jan.	07-Apr.	12-Apr.	156.33d	2146.12d	2.93b
	25-Jan.	11-Apr.	15-Apr.	147.67e	2078.9e	2.26c
	10-Feb.	02-May	08-May	147.67e	2234.07c	0.86d
	25-Feb.	21-May	27-May	163.0b	2747.55a	0.15e
BRRI dhan102	10-Dec.	24-Mar.	31-Mar.	178.0a	2432.2a	3.01b
	25-Dec.	29-Mar.	01-Apr.	159.67b	2097.33c	3.86a
	10-Jan.	07-Apr.	14-Apr.	156.67c	2151.35b	3.09b
	25-Jan.	09-Apr.	14-Apr.	146.33d	2055.7d	2.29c
	10-Feb.	24-Apr.	30-Apr.	141.33e	2111.77c	1.65d
	25-Feb.	05-May	11-May	148.0d	2440.4a	0.09e
LSD (0.05)		-	-	1.7255	33.6781	0.4829
CV(DT)%		-	-	0.5267	0.6742	9.06
CV(Variety)%		-	-	0.3921	0.5637	9.14

* Means followed by the same lowercase letter in a column do not differ from each other at 5% level of significance

In stark contrast, the 25 February transplanting resulted in severe yield collapse (215–406 kg/ha), driven by extreme spikelet sterility, low panicle density, and impaired grain filling. High temperatures during booting, flowering, and grain filling are widely recognized as major constraints for yield and grain quality (Yang et al., 2020). Heat stress also alters starch biosynthesis and amylose content (Ahmed et al., 2015), while high night-time temperatures further aggravate yield losses (Xu et al., 2021).

3.6. Growing degree days (GDD) and heat use efficiency (HUE)

Cumulative GDD values at maturity were highest for the 25 February transplanting date for BRRI dhan89 and BRRI dhan92 (2747.55 ˚C) and BRRI dhan102 (2440.4 ˚C). Early transplanting dates accumulated fewer heat units (Table 4).

However, higher GDD did not translate into higher yields. Correlation analysis showed a weak negative relationship between GDD and grain yield, indicating that excessive heat accumulation was detrimental to productivity.

Heat Use Efficiency followed a clearer pattern: highest HUE occurred on 25 December (3.42–3.86); lowest HUE occurred on 25 February (0.08–0.15). These results agree with Nayak et al. (2017), who reported higher HUE under early transplanting. Our findings confirm that rice plants utilize heat energy most efficiently when transplanted within the optimal window of late December to early January.

One primary mechanism driving this yield advantage is the alignment of sensitive reproductive stages with favorable thermal environments. Rice development is closely associated with accumulated thermal units, such as GDD and HUE, which integrate temperature and solar radiation influences into crop growth processes. Optimal sowing dates ensure that flowering and grain-filling phases occur under milder temperatures and adequate light conditions, promoting better spikelet fertility, efficient assimilate partitioning, and enhanced grain filling (Halder et al., 2025). Observational studies have demonstrated that variations in sowing date substantially affect accumulated GDD for key phenological phases, with delayed sowing modifying the duration and thermal accumulation patterns, ultimately influencing yield potential (Halder et al., 2025).

4. Conclusion

This study clearly shows that the optimal transplanting window, from 10 December to 10 January, experiences favorable temperature conditions that support vigorous growth and high productivity in the Barishal region. Transplanting after this window exposed the crop to elevated temperatures during critical reproductive stages, leading to increased spikelet sterility and substantial yield reductions. These results underscore how sensitive rice is to temperature fluctuations and emphasize the importance of synchronizing transplanting time with key developmental phases to mitigate the impacts of heat stress. However, to enhance the broader applicability and robustness of these results, similar trials should be conducted across diverse farmers' fields and under varying management practices. Because environmental conditions can differ significantly across regions, region-specific validation is essential. Therefore, it is recommended that comparable experiments be carried out in other rice-growing areas of Bangladesh. Expanding this research will help generate more comprehensive and regionally relevant recommendations, ultimately supporting farmers nationwide in optimizing transplanting time, reducing heat-related yield losses, and ensuring more stable Boro rice production.

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