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Thermal Requirement for the Phenological Development and Yield of Rice as Influenced by Seeding Date

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ABSTRACT

The local climate greatly influences the development of a crop including factors such as temperature, rainfall, light intensity, radiation, and sunshine duration. Thermal units are closely linked to various physiological processes at each stage of crop development and can serve as a valuable tool for assessing thermal response. To explore this, a study was conducted to evaluate the grain yield and thermal unit requirements for the phenological development of four rice varieties under different seeding dates. Seeding took place from 15 November to 30 December, at 15-day intervals. The findings revealed that the seeding date had a significant impact on the thermal unit requirements for crop phenology and yield. Earlier seeding resulted in a higher accumulation of degree days compared to later seeding, as the crops required the most thermal input to complete panicle initiation. Seeding date notably affected the accumulated Growing Degree Days (GDD) from sowing to panicle initiation, heading, full flowering, and maturity. The GDD requirements for physiological maturity were the highest for the November 15 seeding, with the required GDD decreasing as seeding was delayed. The accumulated GDD for physiological maturity across the four varieties under different seeding dates ranged as follows: BRRI dhan96 (1972 to 2112 °C day), BRRI dhan97 (2116 to 2267 °C day), BRRI dhan99 (2097 to 2267 °C day), and BRRI dhan100 (2031 to 2183 °C day). Along with GDD, Heat Use Efficiency (HUE), Helio Thermal Units (HTU), and Photothermal Units (PTU) were identified as useful metrics for estimating crop growth and development based on temperature and solar radiation. In terms of yield, BRRI dhan96 achieved the highest yield when seeded on 30 November, outperforming the other three varieties (BRRI dhan97, BRRI dhan99, and BRRI dhan100). Therefore, the study concludes that seeding between 15 and 30 November optimizes heat use efficiency, leading to better physiological responses and higher yields.

Key words: Rice, Seeding date, Phenology, Growing degree days, Heat use efficiency

INTRODUCTION

Rice is the dominating and staple food crop in many Asian countries along with Bangladesh (Rao et al., 2007; Halder *et al.*, 2016; Kumar and Ladha, 2011). It can grow in diverse environments from below sea levels to hill (Rami *et al.,* 2010). Different weather variable like rainfall, temperature and bright sun shine hours is the key to determine rice crop phenological development and yield. The date and time of specific development of a crop can be described by studying its phenology. It was reported that the growing degree day (GDD), helio-thermal unit (HTU) and photo-thermal unit (PTU) are some general parameters which can draw a relationship among plant growth and st environmental conditions like temperature, bright sunshine hours, and day length (Pandey *et al.*, 2020). The heat unit concept gives assessment of potential yield of a crop in different weather conditions (Kumar *et al.,* 2014). The growth and development of rice is controlled by temperature and photoperiod, however, the

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rate of growth for photo-insensitive rice is mostly depends on temperature. The amount of heat energy an organism accumulates over a period of time is often expressed as a `growing degree-day' (GDD). GDDs are used to relate plant growth, development, and maturity to air temperature and assesses the phenological events of rice of a particular region and crop growing season (Rajput et al. 1987). It also determines the crop growth stage and predict the best time for fertilizer and pesticide applications as well as estimates the heat stress and maturity and harvesting dates (Parthasarathi *et al.*, 2014). The efficiency of heat utilization in relation to crop yield referred to Heat use efficiency (HUE) which has a considerable application in crop field, depends on crop types and its genetic and environmental factors. Temperature directly influences the duration of crop growth stages, which could be predicted by using the aggregate of daily air temperature. So, it is crucially important to know the knowledge of exact span of various phenological stage of a crop grown in a particular environment and their consequences on yield (Dalton, 1967 and Wang, 1960).

Therefore, taking the above facts, the objectives of this study is to determine the optimum seeding date and yield with agro-climatic indices viz. GDD, HUE, HTU and PTU of four BRRI varieties.

MATERIALS AND METHODS

The field experiment was conducted at the research farm of Bangladesh Rice Research Institute, Gazipur in Boro 2021-22 season. It is situated at 23.99° N and 90.40° E. The experiment included four dates of seeding viz. 15 November, 30 November, 15 December and 30 December where transplanting was done at 40 days after seeding as main plot treatments and four varieties namely BRRI dhan96, BRRI dhan97, BRRI dhan99 and BRRI dhan100 as subplot treatments, resulting in 16 treatment combinations. The experiment was laid out in a split-plot design with three replications. Fertilizers were applied @74-60-70-35 kg ha^{-1} Urea-TSP-MoP-Gypsum respectively. All fertilizers were applied during final land preparation except N as a form of urea, which was top dressed in three equal splits at 15, 40 and 65 DAT (days after transplanting). The sub-plot size was 12 m^2 (3m × 4m) having a plot to plot and block to block distance of 0.75 m and 1.0 m respectively and there were 48 plots in the experiment. Weeds were controlled manually after 1st and 2nd top dress of urea. The different phenological stages like panicle initiation, first heading, complete flowering and physiological maturity of rice varieties were recorded by visiting the field from transplanting to harvesting. At maturity grain yield was measured, after discarding border areas on all four sides of the plot, harvesting 5m^2 area and after threshing and cleaning the grain weight was adjusted at 14% moisture by following method described by Gomez, 1972.

Data of weather parameters viz., maximum temperature, minimum temperature and bright sunshine hours during the experiment period were collected from agrometeorological observatory of Plant Physiology Division, BRRI, Gazipur and an automatic weather station (Davis Vantage Pro2 Weather Station) of Plant Physiology Division, BRRI. The Distance between agrometeorological observatory and experiment site is about 500 m. The weather data collected from automatic weather station were used to verify the GDD calculated from manual weather station and all the other indices data generated from manual weather station data were found with minimum variation.

Agrometeorological indices like growing degree days (GDD), helio thermal unit (HTU), photo thermal unit (PTU) and heat use efficiency (HUE) were calculated by using following formulas:

Growing degree days (by Nuttonson, 1948):

Growing Degree Days (GDD)=

$$\sum_{i-1}^{n}\left(\frac{\text{(T Max+T Min)}}{2} - Tbase\right)$$

Where, T max and T min are the maximum and minimum temperature of the day and T base is the minimum threshold temperature of the crop, also called as base temperature or minimum threshold temperature. The base temperature of rice crop of 10 °C was used for computation of GDD on daily basis (Thomas, 1957).

The data on GGDs accumulation were further used to calculate heat use efficiency (HUE; Rajput, 1980) and helio thermal units (HTU; Satake, 1978) as under:

$$\text{Heat Use Efficiency (HUE)} = \frac{\text{Grain Yield }(\frac{\text{kg}}{\text{ha}})}{\text{GDD}}$$

$$\text{Helio Thermal Units} = \text{GDD } \times \text{Actual sunshines hours}$$

Photothermal units (PTU), degree day hrs

Photothermal units are the cumulative value of growing degree days, multiplied by the day length. This can be mathematically represented using the following formula (Dagar *et al.,* 2017):

$$\text{PTU} = \sum (\text{GDD} \times \text{N})$$

Where, GDD = Growing degree day, N = Maximum possible sunshine hours or day length (hrs)

RESULTS AND DISCUSSION

Four BRRI developed Boro rice varieties BRRI dhan96, BRRI dhan97, BRRI dhan99 and BRRI dhan100 were seeded at four different seeding windows starting from 15 November to 15 December at 15-days interval to find out the effect of different agro-climatic indices for different phenological development. During the experimental period the highest maximum temperature 37.5 ºC was recorded at April (Fig. 3) and lowest minimum temperature was recorded at February (10.6 ºC) whereas January was found the coolest month (average temperature was 20.11 ºC) and April was found hottest month (average temperature was 30.04 ºC). During March maximum sunshine hour and solar radiation were harvested by crop (daily average 7.57 hour and 16.95 MJ/day/sqm respectively).

Thermal time requirement for crop phenology

Table 1 presents the henology of four rice varieties under different seeding times. The results indicated that phenology was significantly influence by of seeding date. The numbers of days for attaining different phenological stages differed for seeding date. In case of 1st seeding (15 November), all the varieties require more number of days for attaining panicle initiation (PI), first heading and complete flowering compared to the other three seeding date. The higher growth duration occurred for 1st seeding because after transplanting compared to the others the plant faced lower temperature than critical low temperature for rooting and tillering (16ºC, Yoshida, 1981) for maximum periods (Fig 3). Which might delay the root growth and tiller production resulted the increased growth duration.

The panicle initiation (PI) of BRRI dhan97 required maximum (99) days, followed by BRRI dhan99 (96 days), BRRI dhan96 (89 days) and BRRI dhan100 (87 days). Thermal time required (GDD) from sowing to PI, heading, complete flowering and maturity was significantly affected by sowing date. The range of days to 1st heading were found 96 to 119 days, 110 to129 days, 106 to 127 days and 97 to 117 days for BRRI dhan96, BRRI dhan97, BRRI dhan99 and BRRI dhan100 respectively. In general, 15 November sowing rice plants accumulated higher degree days and with each delay in sowing the degree day accumulation decreased during the crop seasons. Similar result was found by Dagar *et al.,* 2017 and Moti *et al.,* 2015. The highest GDD was accumulated from seeding to PI by the first (15 Nov.) seeding followed by second (30 November), third (15 December) and fourth seeding (30 Dec.) for all the variety except BRRI dhan97. Among the variety BRRI dhan99 required highest GDD to PI (1484 °C day) followed by BRRI dhan97 (1108 °C day), BRRI dhan96 (1005 °C day) and BRRI dhan100 (981 °C day) at 15 November sowing. Similarly, the highest thermal requirement was observed for heading and complete flowering for most of the varieties at 15 November sowing. Where, The GDD values for heading and complete flowering was the highest in BRRI dhan97 (1594 °C day and 1787 °C day respectively) followed by BRRI dhan99 (1555 °C day and 1767 °C day respectively) at 15 November seeding. BRRI dhan96 required highest GDD for first Heading (1407° C/day) but less GDD to complete flowering (1555 °C day) than BRRI dhan100, which GDD value for first heading and complete flowering was 1375 °C day and 1613 °C day respectively. The total GDD required for physiological maturity was maximum in 15 November seeding and it was gradually decrease with delay seeding up to fourth seeding for BRRI dhan96 and BRRI dhan100. Similar GDD value was found in BRRI dhan97 and BRRI dhan99 (2267 °C day) for physiological maturity and among the four seeding it was highest and the requirement of thermal unit decrease in delay seeding up to 15 December seeding then it was slightly increase at fourth seeding (30 December). The maximum heat unit of BRRI dhan96 and BRRI dhan100 was 2112 and 2183 °C day respectively at 15 November seeding. The reason behind the higher degree days of 15 Nov. and later on seeding time can be explained from table 3 where, we observed the higher GDD acquired by plant at seedling stage was higher in 1st seeding then 2nd seeding for most of the variety. The seedling of last two seeding faces cooler period than first two seeding. The range of GDD for seedling stage and transplanting to panicle initiation for all the variety was 345 to 389 and transplanting to panicle initiation stage it was 344 to 431, 480-556, 502 to 522 and 360 to 408 for BRRI dhan96, BRRI dhan97, BRRI dhan99 and BRRI dhan100 respectively. Here an interesting thing we observed that, the GDD calculated from automatic weather station data is quite lower than the manual weather station. This is because the manual weather station had only two data point but automatic weather station had 12 data point (every 30 minute) in each day and the most of the growing condition faced cooler period specially for the first two seedings. So the average maximum temperature was lower than the manual weather station. The cooler period delays the growth of first seeding causes higher growth duration and gradually enhance the growth as the temperature increased results of growth duration reduction with the advancement of season.

So, it was observed that, early seeded crop had higher degree days and with the delay in each seeding time the requirements of degree days decreased during the crop season mainly due to the GDD acquired by seedling stage. Similar result was reported by Sing and Paul, 2003 and Khan *et al.,* 2006. They reported that at wet season under advance transplanting the Growing degree days is higher and subsequently decreasing at delay transplanting.

They found that the GDD requirement for the maturity was the highest in Lal Swarna (2385 degree C/day), followed by IR-36 (1975 degree C/day) and Kshitish (1913 degree C/day).

The range of accumulated GDD reached physiological maturity under different seeding date from 15 November to 30 December of BRRI dhan96, BRRI dhan97, BRRI dhan99 and BRRI dhan100 was 1972 to 2112 °C day, 2116 to 2267 °C day, 2097 to 2267 °C day and 2031 to 2183 °C day respectively. Dagar *et al.,* 2017 observed for different transplanting dates, accumulated GDD ranged from 1791.0 to 2342.9 degree days, 1802.2 to 2133.9 degree days, 1802.2 to 2118.7 degree days and 1575.3 to 1903.6 degree days for varieties CSR 30, HB 2, PB 1121 and PB 1509 respectively.

Table 1. Days required for development of crop phenology of four varieties under different seeding date.

		Phenological stages			
	Seeding date	Day to panicle initiation	Day to first heading	Day to complete flowering	Growth duration (day)
BRRI dhan96	15 Nov	89	119	127	154
	30 Nov	80	110	124	142
	15 Dec	72	102	116	136
	30 Dec	66	96	108	129
BRRI dhan97	15 Nov	99	129	139	163
	30 Nov	86	116	130	151
	15 Dec	83	113	129	146
	30 Dec	80	110	123	143
BRRI dhan99	15 Nov	97	127	138	163
	30 Nov	89	119	132	152
	15 Dec	82	112	125	145
	30 Dec	76	106	116	142
BRRI dhan100	15 Nov	87	117	130	159
	30 Nov	81	111	126	149
	15 Dec	73	103	118	143
	30 Dec	67	97	108	135
CV%		2.28	1.67	1.37	5.82
LSD (0.05) for seeding date		1.55	1.15	1.42	1.71
LSD (0.05) for variety		1.55	1.55	1.42	1.71
LSD (0.05) for variety*seeding date		3.10	3.10	2.84	3.42

Table 2. Required total growing degree days (GDD) at different phenophases of four varieties under different seeding dates.

Variety		Growing degree day (°C)			
		15th Nov	30th Nov	15th Dec	30th Dec
BRRI dhan96	Panicle initiation	1005	852	742	713
	First heading	1407	1309	1249	1264
	Complete flowering	1555	1577	1524	1528
	Maturity	2112	1936	1926	1917
BRRI dhan97	Panicle initiation	1108	921	903	955
	First heading	1594	1422	1464	1548
	Complete flowering	1787	1678	1779	1806
	Maturity	2267	2120	2116	2188
BRRI dhan99	Panicle initiation	1484	965	888	882
	First heading	1555	1480	1444	1666
	Complete flowering	1768	1738	1708	1682
	Maturity	2267	2139	2097	2172
BRRI dhan100	Panicle initiation	981	864	757	728
	First heading	1375	1372	1269	1284
	Complete flowering	1613	1597	1564	1528
	Maturity	2183	2077	2056	2031

Table 3. Required total growing degree days (GDD) for different vegetative periods of four varieties under different seeding dates. (Data were taken from Davis Vantage Pro2 Automatic Weather Station) of Plant Physiology Division, BRRI).

Variety		Growing degree days (°C)			
		15th Nov	30th Nov	15th Dec	30th Dec
BRRI dhan96	Panicle initiation	919	784	705	690
	seedling	489	392	334	345
	TP to PI	431	392	371	344
BRRI dhan97	Panicle initiation	1039	872	866	902
	seedling	489	392	334	345
	TP to PI	550	480	532	556
BRRI dhan99	Panicle initiation	1009	914	851	847
	seedling	489	392	334	345
	TP to PI	521	522	517	502
BRRI dhan100	Panicle initiation	896	797	718	705
	seedling	489	392	334	345
	TP to PI	408	405	384	360

Helio Thermal Unit (HTU)

The variation in mean daily temperature and bright sunshine hour among four varieties cropping period under different seeding date resulted in varied accumulated helio-thermal units for life cycle of all of the varieties. The total helio-thermal units were observed for different seeding date ranged from 12,229 to 14,626 °C day hour. The data presented in show that total HTU required during total crop growth period was the highest in 15 November seeding for all of the varieties. BRRI dhan96 required maximum 13,607 °C day hour HTU at 15 November seeding followed by 30 December (12,645 °C day hour), 15 December (12,618 °C day hour) and 30th November seeding (12,229 °C day hour). BRRI dhan97 and BRRI dhan99 had similar HTU (14,226 °C day hour) at 15 November seeding and 15 December Seeding (13,792 °C day hour) as well the required HTU of BRRI dhan100 was maximum 13,902 °C day hour at 15 November seeding followed by 15 December (13,475 °C day hour), 30 November (13,307 °C day hour) and 30th December (12,870 °C day hour) seeding. In a study by Sultana *et al.,* 2019 the maximum helio-thermal units (15141.01 °C day hour) were recorded in BRRI dhan49 followed by (13759.75 °C day hour) in the advanced line BR (Bio) 9786-BC2- 119-1-1 and the lowest (10520.26 °C day hour) in the advanced line BR (Bio) 9786-BC2-119-1-3 at the 5th July Seeding. Mote *et al.,* (2015) observed the range of HTU of rice variety cv. Jaya were 11784 to 12990.7ºC day hr.

Heat Use Efficiency (HUE)

Heat use efficiency (HUE), is the conversion of heat energy into dry matter production and depends on crop type, genetic factors and sowing time (Rao *et al.,* 1999). Total heat energy available to any crop is never completely converted to dry matter even under most favorable agro climatic conditions. Among the seeding dates 30 November seeding crop exhibited maximum HUE in all varieties as because they produced maximum yield within minimum thermal use and had optimum temperature and sunlight and throughout growing period crop utilized heat more efficiently and increased biological activity that confirm higher yield (Fig. 2). These results are matched with the results reported by Chahal et al., 2007 and Jagtap *et al.,* 2018.

The second heat use efficient seeding date was found at 15 November seeding. The heat use efficiency decreased with delay seeding after 30 November seeding. BRRI dhan96 was found maximum heat use efficient variety (3.36 kg °C ha^{-1} days^{-1}) followed by BRRI dhan99 (2.95 kg °C ha^{-1} days^{-1}), BRRI dhan100 (2.78 kg °C ha^{-1} days^{-1}) and BRRI dhan97 (2.77 kg °C ha^{-1} days^{-1}).

Photothermal units

The accumulated photothermal units (PTU) followed the same trend as heat use efficiency (HUE) because both the indices depend on time period required for attaining physiological maturity. Here we observed higher PTU was between 15 and 30 December sowing because of longer growth duration and crop exposed to brighter sunshine. BRRI dhan96 and Bangabandhu100 had higher PTU at 15 November seeding (24,010 and 24,897 days °C hour respectively) whereas BRRI dhan97 and BRRI dhan99 had highest PTU at 30 December (2,682 and 26,079 days °C hour). Among all the seeding dates the lowest Photothermal units was observed at 30 November seeding (22146 to 24983 days °C hour). The highest grain yield at 30 Nov. seeding with minimum photothermal unit indicated that optimum environment prevailed for better growth and development for that seeding time.

Table 4. Response of yield to heliothermal units and heat use efficiency across different seeding dates and genotypes.

Variety		Seeding date			
		15th Nov	30th Nov	15th Dec	30th Dec
BRRI dhan96	Yield (kg/ha)	5900	6500	4600	3667
	HTU (days °C hour)	13607	12229	12618	12645
	HUE (Kg/ha/°C days)	2.79	3.36	2.39	1.91
BRRI dhan97	Yield (kg/ha)	5300	5867	5733	4300
	HTU (days °C hour)	14626	13670	13792	13845
	HUE (Kg/ha/°C days)	2.34	2.77	2.71	1.97
BRRI dhan99	Yield (kg/ha)	5267	6300	5167	4233
	HTU (days °C hour)	14626	13828	13792	13790
	HUE (Kg/ha/°C days)	2.32	2.95	2.46	1.95
BRRI dhan100	Yield (kg/ha)	5733	5767	4633	3200
	HTU (days °C hour)	13902	13307	13475	12870
	HUE (Kg/ha/°C days)	2.63	2.78	2.25	1.58

Table 5. Photothermal units (PTU) requirement of four varieties under different seeding dates.

Variety	Photothermal units (PTU) in days °C hour			
	15th Nov	30th Nov	15th Dec	30th Dec
BRRI dhan96	24010	22146	22392	22677
BRRI dhan97	25947	24442	24902	26282
BRRI dhan99	25947	24683	24651	26079
BRRI dhan100	24897	23909	24105	24197

Grain yield

Among the varieties, BRRI dhan96 produced statistically similar yield at 15 Nov. and 30 Nov. seeding (6.5 and 5.9 t/ha respectively). Similarly, there was no significant differences found in yield between 15 Nov and 30 Nov seeding for BRRI dhan97, BRRI dhan99 and BRRI dhan100, and the range of yield was 5.3 to 5.87 t/ha, 5.17 to 6.30 t/ha and 4.63 to 5.73 t/ha respectively (Fig. 1). The higher yield of 15 and 30 Nov seeding plant as it got maximum sunshine shine/solar radiation (Fig. 2) during their reproductive phase for photosynthetic activity. The average temperature was also optimum for crop growth (Fig. 2). This two sets plant also received maximum heat for a longer period of time which mean they got optimum temperature with lower minimum temperature at their vegetative phase which accumulate maximum food reservoir for grain development. It was found that if vegetative stage is too short to produce sufficient dry-matter the number of spikelet will be small (Vergara et al. 1964)

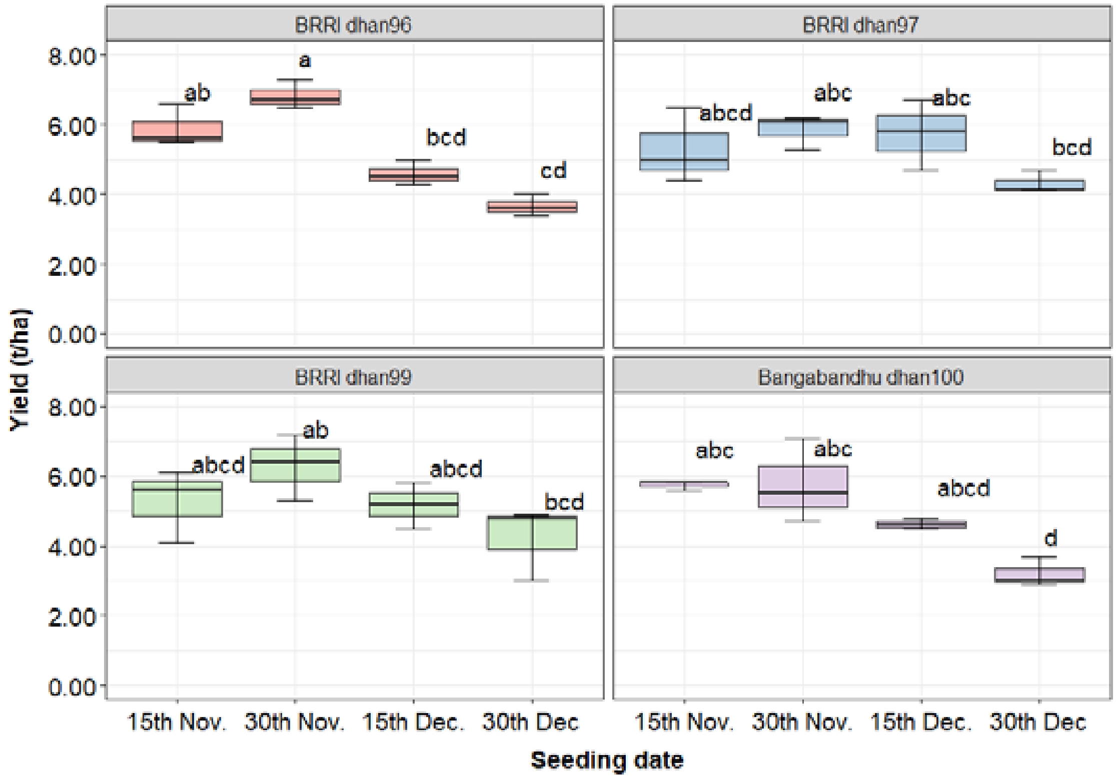
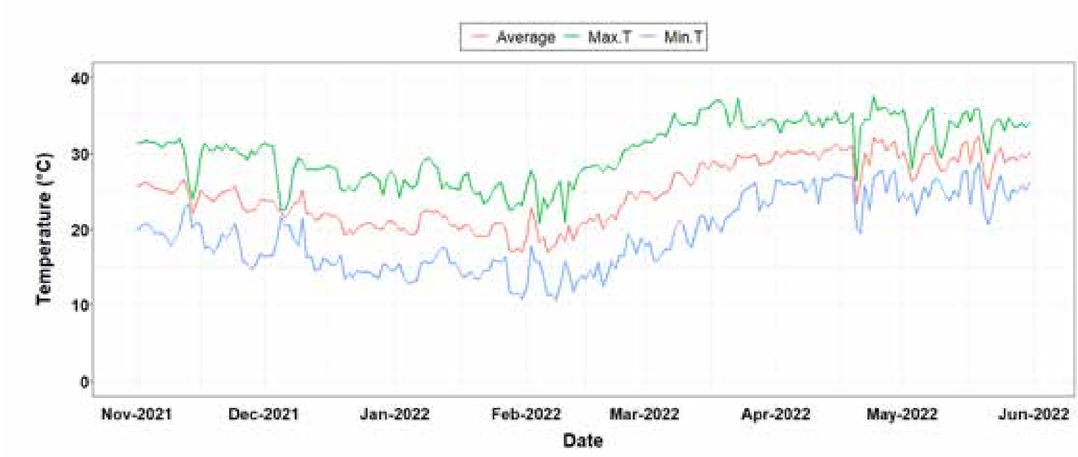


Fig. 1. Yield of four BRRI varieties under different seeding dates.



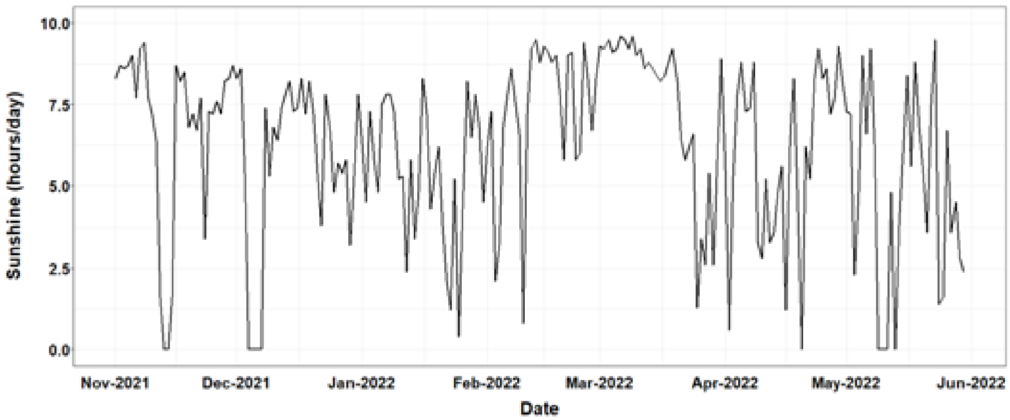


Fig. 2. Daily Maximum (Max.T), Minimum (Min.T), Average temperature (above graph) and daily sunshine hours during the crop growing period (below graph).

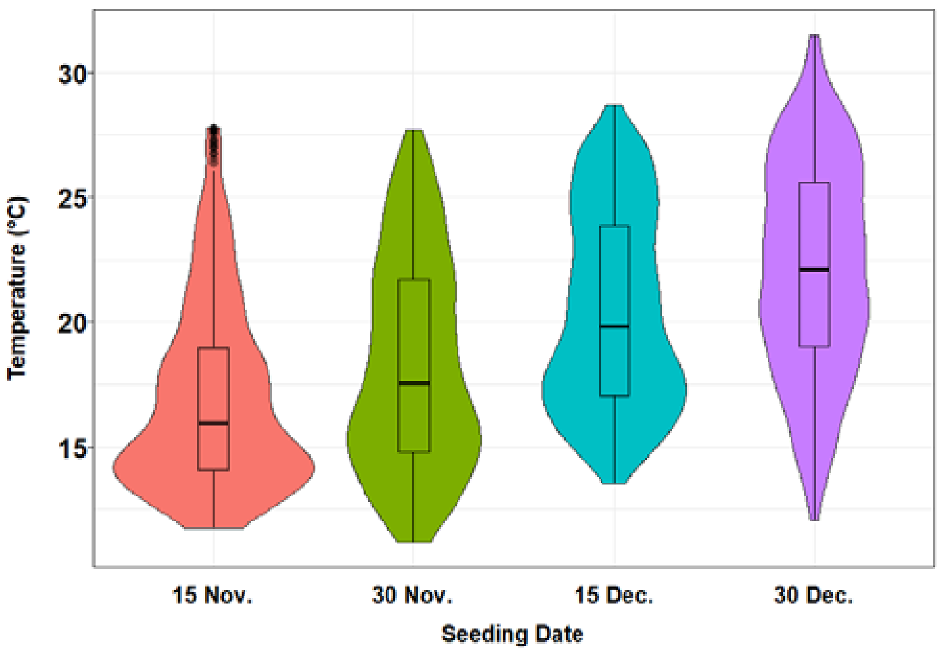


Fig. 3. The aggregated average temperature of every half an hour for 1st 15 days after transplanting of four different varieties. The data were taken from an automatic weather station (Davis Vantage Pro2 Weather Station) of the Plant Physiology Division, BRRI.

CONCLUSIONS

In conclusion, seeding in the last week of November resulted in higher heat use efficiency and produced a higher yield due to the crop experiencing optimal growing conditions. The total Growing Degree Days (GDD) required for physiological maturity was highest for the 15 November seeding and gradually decreased with later seeding dates up to the fourth seeding. It was observed that higher degree days up to the panicle initiation stage delayed crop maturity, while a decrease in degree days ultimately shortened the crop growth duration. Earlier seeding allowed the crop to accumulate more degree days, with each delay in transplanting reducing the degree day accumulation during the growing season. The Photothermal Units (PTU) were higher between 15 and 30 December sowing, attributed to the longer growth duration and increased exposure to brighter sunshine.

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