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Research Article

Assessment of Phenology and Agro-climatic Indices of Direct-seeded and Transplanted Rice Crop under Punjab Conditions

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ABSTRACT

The field experiments were conducted at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *Kharif* seasons of 2021 and 2022. The rice varieties *viz*., PR 126 and PR 128 were sown on 20th May and 30th May and transplanted on 20th June and 30th June. The experiment was laid out in the split-split plot design. Different meteorological parameters were recorded throughout crop growing stages. Crop phenology was recorded visually. Three agro-climatic indices i.e. accumulated growing degree days (AGDDs), accumulated helio-thermal units (AHTUs) and accumulated photo-thermal units (APTUs) were calculated to understand the effect of different sowing methods on the two rice varieties. Results showed that variety PR 126 matured early compared to variety PR 128 in both the seasons. Rice varieties transplanted on 20th June took one to two days extra to reach physiological maturity compared to 30th June transplanted varieties. Direct sown rice varieties matured 1 to 4 days early compared to transplanted rice varieties. The accumulation of GDDs, HTUs and PTUs were highest (2986.5°C day, 21422.0 °C day hr, 39373.7°C day hr) in variety PR 128 transplanted on 20th June followed by 20th May direct sown crop (2938.2°C day, 21176.5°C day hr, 38834.5°C day hr), 30th June transplanted crop (2888.7°C day, 20398.7°C day hr, 37754.8°C day hr) and 30th May direct sown crop (2857.9°C day, 20322.1°C day hr, 37242.3°C day hr). Similar variations in AGDDs, AHTUs and APTUs were also obtained in variety PR 126.

Key words: Puddled transplanted rice, Direct seeded rice, Phenology, Agro-climatic indices, Sowing methods

Introduction

Rice holds significant importance in Punjab's agricultural landscape, despite the state covering only a small fraction of India's geographical area. Contributing nearly 28 per cent of rice to the country's central pool, Punjab plays a crucial role in India's overall rice production (Indiastat, 2023). With approximately 31.45 lakh hectares dedicated to rice cultivation and a total production of about 203.71 lakh tons, rice is a cornerstone of Punjab's agricultural output (Anonymous, 2023). Moreover, given the population growth and evolving dietary preferences in India, the demand for rice is expected to rise steadily. Consequently, there is a pressing need to enhance rice yields to meet this growing demand, especially considering the declining water table and increasing labour challenges. Maintaining the sustainability of the rice ecosystem in Punjab is paramount to ensuring food security and economic stability in the region.

The potential yield of any crop is significantly impacted by the prevailing weather and climatic conditions of the region. Goswami *et al*. (2006) identified temperature, solar radiation, sunshine hours, relative humidity, and rainfall as primary factors influencing crop productivity and phenology.

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Optimal conditions for rice cultivation typically involve high temperatures, ample sunshine (approximately 900-1000 hours during the growing season), and moderate humidity (Kaur *et al.,* 2021). Rice germination occurs within a temperature range of 25°C to 30°C, with optimal growth observed between 35°C and 42°C under Punjab's climatic conditions (Singh *et al*., 2010). However, the conventional practice of flooding rice fields throughout the growing season necessitates significant water input to maintain adequate moisture levels. This practice, coupled with the prolonged duration of rice cultivation, exerts immense pressure on Punjab's already dwindling groundwater resources (Singh *et al*., 2022). The depletion of groundwater reserves carries profound implications for agriculture, extending beyond water scarcity to impact overall water availability for domestic, industrial, and agricultural purposes. As groundwater levels decline, the costs associated with pumping water increase, water quality deteriorates, and the risk of land subsidence rises. Recognizing the gravity of the situation, efforts are underway to promote sustainable agricultural practices in Punjab. These initiatives include advocating for alternative rice cultivation methods, such as direct-seeded rice, which requires less water compared to traditional transplanting methods (Kamboj *et al*., 2022). Systematic water use, mechanization friendly, higher profit, higher yield and quality along with early maturity are some of the benefits of direct seeded rice compared to the transplanted rice. It also provides an optimum sowing window for the succeeding wheat crop thus maintain the sustainability of the rice-wheat cropping system (Ishfaq *et al*., 2018; Anjum *et al*., 2019).

Growing degree days (GDD), helio-thermal units (HTU), and photo-thermal units (PTU) are indispensable tools in comprehending and guiding the growth dynamics of rice crop, contributing significantly to the optimization of agricultural practices. In the context of rice cultivation, GDD emerges as a crucial determinant, providing predictive insights into key developmental milestones such as germination, tillering, and flowering. This predictive capacity empowers farmers to strategically plan and execute planting and harvesting activities with precision. Helio-thermal units (HTU) further enhance this understanding by amalgamating temperature and solar radiation data, presenting a holistic measure of the thermal conditions essential for rice's intricate processes of photosynthesis and maturation. Moreover, photo-thermal units (PTU) prove invaluable in their consideration of the joint impact of temperature and day length, a particularly crucial factor for rice, given its sensitivity to variations in photoperiod. Collectively, these metrics serve as powerful instruments for refining cultivation strategies. They assist farmers not only in the selection of rice varieties tailored to specific environmental conditions but also in making informed decisions about optimal planting schedules and accurate predictions of harvest timing. The integration of GDD, HTU, and PTU in agricultural operation, make it more finely tuned and efficient endeavour, ultimately contributing to improved yields and the sustainability of rice production. Consequently, the present study was undertaken to deduce the phenological behaviour of rice varieties under different sowing methods and their effect on different agro-meteorological indices.

Materials and Methods

The field experiments were carried out at the Research Farm of the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, during the 2021 and 2022 *Kharif* seasons. A split-split plot design was employed to explore the influence of various factors and their interactions on rice cultivation. The experimental treatments comprised two rice varieties, PR 126 and PR 128, coupled with two sowing methods, Puddled Transplanted Rice (PTR) and Direct Seeded Rice (DSR), and two sowing dates, namely 20th May and 30th May. Under the PTR method, rice varieties were initially sown in a nursery bed and transplanted into the main plot after 30 days, specifically on 20th June and 30th June, respectively. Conversely, in the DSR method, rice varieties were directly sown in the main plot. In the experimental layout, dates of sowing used in the main plot, while varieties and sowing methods were used as sub-plots and sub-sub-plots, respectively. The recommended PAU package and practices were followed to raise the crop (Anonymous, 2023). Daily observations on maximum and minimum temperatures (°C), morning and evening relative humidity (%), sunshine hours (hours) and total rainfall (mm) were recorded at the

Agro-meteorological Observatory, located 150 m away from the experimental site. Crop phenological stages were recorded visually in both the seasons (*kharif* 2021 and 2022). Then phenology wise agro-climatic indices *viz*., growing degree days (GDD), photo-thermal units (PTU) and helio-thermal units (HTU) were calculated.

Growing degree days (GDD)

Growing degree days were calculated employing a straightforward arithmetic accumulation approach reliant on the daily mean temperature. The accumulation was determined by subtracting the base temperature (T_b) from the sum of the daily maximum temperature (T_{max}) and the daily minimum temperature (T_{min}). The GDDs were calculated by using the following formulae:

$$\text{GDD (°C day)} = \frac{T_{max}+T_{min}}{2} - T_{base}$$

Where,

T_{max} - represents the daily maximum temperature in degrees Celsius.

T_{min} - represents the daily minimum temperature in degrees Celsius.

T_{base} - refers to the minimum threshold or base temperature. The base temperature of rice was taken 10°C (Gao *et al.*, 1992).

Helio-thermal units (HTU)

Helio-thermal units (HTUs) are measure of the accumulated heat or thermal energy received by a crop from the sun during its growth period. The HTUs were computed by using the following formulae:

HTU (°C day hr) = (Growing degree days × Actual sunshine duration)

Where,

GDD - Growing degree days (°C day)

SSH - Actual sunshine duration (hours)

Photo-thermal units (PTU)

Photo-thermal units (PTUs) refer to a measure of the accumulated thermal energy received by a plant during its growth period, particularly in relation to the duration and intensity of sunlight exposure. These units are used to quantify the impact of both temperature and photoperiod on the development and maturation of crops.

PTU (°C day hr) = (Growing degree days × Day length)

Where,

GDD - Growing degree days (°C day)

DL - Day length (hours)

Results and Discussions

Weather during rice growing seasons 2021 and 2022

During the crop growing season of *kharif* 2021 the maximum temperature ranged between 26.0 to 38.0°C (Fig. 1). But in *kharif* 2022 the maximum

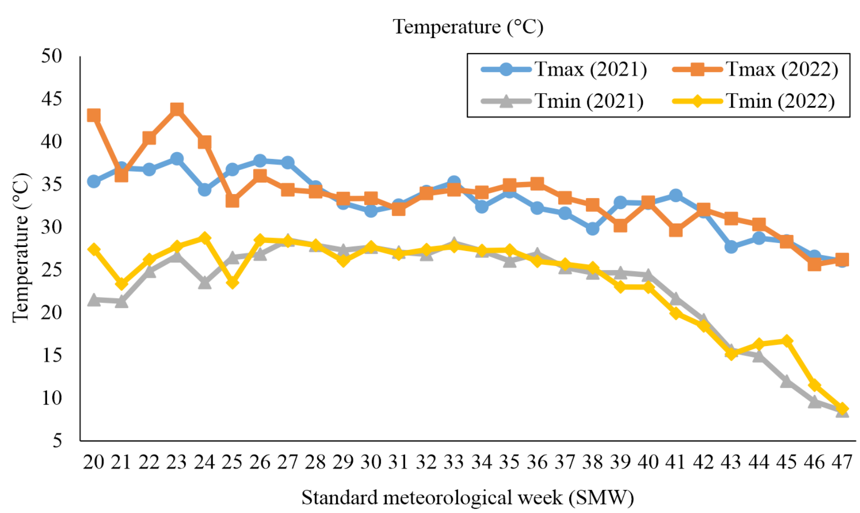

Fig. 1. Variation of maximum and minimum temperature during rice growing seasons (*kharif* 2021 and *kharif* 2022)

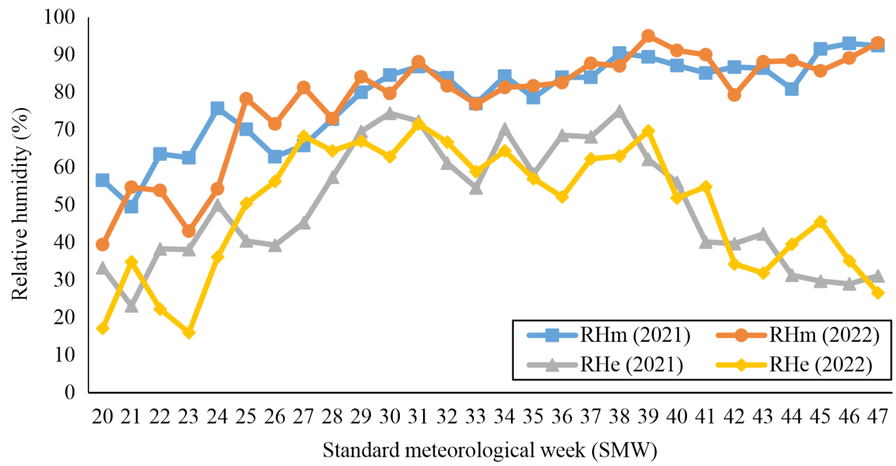

Fig. 2. Variation of morning and evening relative humidity during rice growing seasons (*kharif* 2021 and *kharif* 2022)

temperature ranged between 25.6 to 43.7°C. During the crop growing season of *Kharif* 2021 the minimum temperature ranged between 8.5 to 28.5°C. But in *Kharif* 2022 the minimum temperature ranged between 8.7 to 28.7°C. During *Kharif* 2021, the morning relative humidity ranged between 49.5 to 93.0 per cent and the evening relative humidity ranged between 23.1 to 75.0 per cent (Fig. 2). But in *kharif* 2022 the morning relative humidity ranged between 39.4 to 95 per cent and the evening relative humidity ranged between 16.0 to 71.5 per cent. The total sunshine hours ranged between 3.4 to 10.8 hours during the crop growing season of *Kharif* 2021 (Fig. 3). But in *kharif* 2022 the total sunshine hours ranged between 1.6 to 10.3 hours. The total rainfall was 759.4 mm during the *Kharif* 2021 and 643.7 mm in *Kharif* 2022 (Fig. 3).

Phenological behaviour of rice varieties

The phenological stages of rice varieties (PR 126 and PR 128) transplanted on 20th June and 30th June are presented in Table 1. Phenological stages of variety PR 126 and PR 128 directly sown on 20th May and 30th May are presented in Table 2. It was

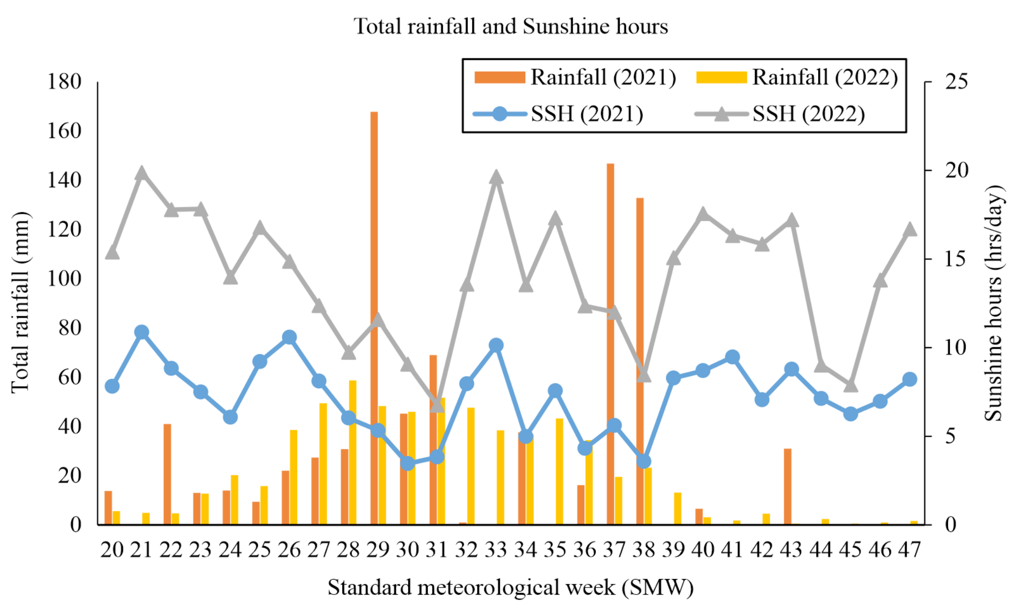

Fig. 3. Variation of total sunshine hours and total rainfall during rice growing seasons (*kharif* 2021 and *kharif* 2022)

observed that variety PR 126 took 76 days in 2021 and 77 days in 2022 *kharif* seasons from sowing to maximum tillering under 20th June transplanting while it took 75 days in 2021 and 77 days in 2022 under 30th June transplanting. It took 75 days in 2021 and 76 days in 2022 from sowing to maximum tillering when sown directly on 20th May whereas it took 74 days and 75 days in 2021 and 2022, respectively under 30th May direct sowing. Variety PR 128 transplanted on 20th June took 84 days and 82 days in 2021 and 2022 respectively from transplanting to maximum tillering. Variety PR 128 directly sown on 20th May took 83 days and 81 days in 2021 and 2022 respectively to attain maximum tillering. Varity PR 128 transplanted on 30th June took 82 days in 2021 and took 83 days in 2022 to attain maximum tillering. Same variety sown directly on 30th May took 82 days in 2021 and 82 days in 2022 to attain maximum tillering. Sreenivasan (1985) found that elevated temperatures accelerate the rate of tillering in rice plants. However, this acceleration is accompanied by a reduction in the duration of the tillering period, resulting in fewer tillers and panicles being produced compared to conditions with lower temperatures. A cessation in tiller production within the fifth week after transplanting when the mean temperature surpassed 26°C. Furthermore, they noted an extension in the duration of tillering to 7-8 weeks following planting (Lalitha *et al*., 2000). Tillering exhibited greater vigor under elevated temperatures compared to lower temperatures (Gao *et al*., 2007). Similarly, Karuna (2019) found that in conditions of elevated temperatures, tillering commenced earlier in crops transplanted later in the season compared to those transplanted earlier.

Similarly, in variety PR 126, flowering took 98 days and 99 days in 2021 and 2022 respectively when transplanted on 20th June, but it took 96 days in both the years when transplanted on 30th June. Variety PR 126 directly sown on 20th May took 97 days in 2021 and 96 days in 2022 to reach flowering whereas same variety sown on 30th May took 95 days in both the *Kharif* seasons (2021 and 2022). In variety PR 128, flowering occurred 107 days after sowing in 2021 and 106 days after sowing in 2022 under 20th June transplanting while it took 105 days in 2021 and 104 days in 2022 under 30th June transplanting. Same variety directly sown on 20th May during 2021 and 2022 took 106 days and 105 days respectively to reach flowering stage, while variety 128 directly sown on 30th May took 104 days in 2021 and 103 days in 2022 to reach flowering stage. Some genotypes experience a reduction of 4 to 5 days in the duration from sowing to heading for every 1°C increase in temperature (Nakagawa *et al*., 2001). Elevated temperatures correspond to an accelerated rate of tillering, leading to a shortened tillering period and an earlier attainment of the phenological stage (Sridevi and Chellamuthu., 2015).

The variety PR 126 transplanted on 20th June took 124 days in 2021 and 126 days in 2022 while transplanted on 30th June took 123 days in 2021 and 124 days respectively from sowing to physiological maturity. The same variety directly sown on 20th May took 123 days in 2021 and 122 days in 2022 whereas the directly sown crop (30th May) took 121 days in 2021 and 120 days in 2022 respectively from sowing to physiological maturity. The variety PR 128 took 142 days in 2021 and 143 days in 2022 to attain physiological maturity under 20th June transplanting and it took 141 days in 2021 and 142 days in 2022 to attain physiological maturity under 30th June transplanting. Variety PR 128 took 141 days in 2021 and 2022 to attain physiological maturity when sown directly on 20th June and it took 139 days in 2021 and 141 days in 2022 when sown directly on 30th May. Rani and Maragatham (2013) also observed that number of days to reach maturity decreases when exposed to high temperature.

It was observed that the rice varieties sown on 20th May took more number of days to reach physiological maturity compared to the varieties sown on 30th May. It was due to the increased temperature due to delayed sowing which leads to reduction in the overall duration of the rice crop. Rising temperatures, or heat stress, have a direct impact on the growth cycle, physical characteristics, and yield of rice crop (Sheehy *et al*., 2006). A temperature increase of 4°C can lead to five and six days early maturity in the wet and dry seasons, respectively (Ziska and Fraser, 1997). The timing of sowing also influences the crop's growth stages. The delay in rice sowing reduces the crop's lifespan due to higher temperatures (Gao *et al*., 2007).

Rice varieties sown on 30th May experienced higher maximum temperature in both *kharif* 2021 and 2022 which enhance the tiller formation and rice varieties attained maximum tillering stage early compared to the 20th May sowing, where low maximum and minimum temperatures enhanced the tiller formation. High minimum temperatures can accelerate the phenological development of rice plants, particularly during the crucial maximum tillering stage. This acceleration may lead to a shorter duration of the tillering phase, potentially affecting the number and development of tillers, which are vital for grain production (Debnath *et al*., 2022). It was observed that under both the methods of sowing, the direct seeded rice varieties mature early compared to the puddle transplanted rice varieties in both the *kharif* seasons (2021 and 2022). Unlike plants that are transplanted, DSR plants are not stressed by uprooting and re-establishing fine rootlets. This permits uninterrupted growth and maturity of the DSR plants. Moreover, DSR saves the plants from transplanting injury, leading to early crop maturity. The outcomes are consistent with Jat *et al*., (2022) findings, indicating that direct-seeded rice varieties exhibit early maturity in comparison to puddled transplanted rice varieties.

Agroclimatic indices accumulation by rice varieties at different rice phenological stages during kharif 2021 and 2022

Accumulated growing degree days (AGDD)

The growing degree days for rice varieties under different methods of sowing (transplanting and direct sowing) were computed from sowing to physiological maturity (Table 3 and Table 4). Accumulated growing degree days were higher in variety PR 128 as compared to variety PR 126 i.e. 2900.5 and 2568.5°C day for 20th June transplanting during 2021. For 30th June transplanting, PR 126 accumulated 2514°C day and variety PR 128 accumulated 2847.0°C day GDDs respectively. Both the varieties accumulated lower degree days in case

Table 1. Phenological behaviour of transplanted rice varieties during *kharif* 2021 and 2022

Phenological stages	20th June transplanting				30th June transplanting			
	PR 126		PR 128		PR 126		PR 128	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillering	46	45	48	49	45	44	47	48
Maximum tillering	76	77	84	82	75	77	82	83
Panicle initiation	83	84	93	93	82	83	91	92
Flowering	98	99	107	106	96	96	105	104
Soft dough	105	106	115	117	101	104	112	112
Hard dough	115	117	127	129	112	114	125	126
Maturity	124	126	142	143	123	124	141	142

Table 2. Phenological behaviour of direct seeded rice varieties during *kharif* 2021 and 2022

Phenological stages	20th May sowing				30th May sowing			
	PR 126		PR 128		PR 126		PR 128	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillering	45	45	47	47	44	43	47	46
Maximum tillering	75	77	83	81	74	75	82	82
Panicle initiation	82	81	93	93	80	81	90	91
Flowering	97	96	106	105	95	95	104	103
Soft dough	104	105	114	113	100	102	112	111
Hard dough	114	113	126	128	110	112	124	126
Maturity	123	122	141	141	121	120	139	141

Table 3. Growing degree days (°C day) accumulation of transplanted and direct seeded variety PR 126 during *kharif* 2021 and 2022

Phenological stages	PTR				DSR			
	D_1		D_2		D_1		D_2	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillering	1005.2	1046.3	1003.6	1029.7	936.3	983.3	963.0	987.0
Maximum tillering	1621.2	1696.4	1608.0	1697.0	1582.8	1657.7	1564.6	1633.5
Panicle initiation	1764.6	1842.7	1755.1	1821.3	1680.3	1737.2	1694.2	1759.3
Flowering	2076.4	2153.6	2032.9	2093.4	1992.1	2030.5	1976.0	2008.1
Soft dough	2214.2	2302.6	2132.7	2256.0	2137.1	2239.1	2112.5	2174.6
Hard dough	2402.9	2523.1	2336.1	2448.3	2332.7	2426.4	2277.8	2352.4
Maturity	2568.5	2688.9	2514.0	2617.9	2516.5	2621.0	2475.2	2527.4

Where, PTR – Puddled transplanted rice; DSR- Direct seeded rice; D_1 (PTR) - 20th June transplanting; D_2 (PTR) - 30th June transplanting; D_1 (DSR)- 20th May sowing; D_2 (DSR)- 30th May sowing

Table 4. Growing degree days (°C day) accumulation of transplanted and direct seeded variety PR 128 during *kharif* 2021 and 2022

Phenological stages	PTR				DSR			
	D_1		D_2		D_1		D_2	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillering	1054.6	1133.8	1049.9	1111.6	981.2	1046.3	1026.5	1049.4
Maximum tillering	1786.5	1800.7	1755.1	1821.3	1808.2	1842.7	1792.1	1780.1
Panicle initiation	1972.9	2030.5	1937.1	2008.1	1992.1	2030.5	1976.0	2008.1
Flowering	2252.4	2302.6	2202.9	2256.0	2232.9	2281.5	2184.3	2238.0
Soft dough	2402.9	2523.1	2336.1	2411.9	2332.7	2404.8	2296.2	2352.4
Hard dough	2617.1	2736.5	2569.8	2654.3	2597.1	2688.9	2550.9	2636.0
Maturity	2953.5	3019.5	2876.0	2901.4	2900.1	2976.3	2845.4	2870.4

Where, PTR – Puddled transplanted rice; DSR- Direct seeded rice; D_1 (PTR) - 20th June transplanting; D_2 (PTR) - 30th June transplanting; D_1 (DSR)- 20th May sowing; D_2 (DSR)- 30th May sowing

of direct sowing method. Variety PR 126 accumulated 2516.0°C day and 2475.2°C day GDDs during 20th May and 30th May sowing in 2021. Similar results were observed during 2022 crop growing season, where direct seeded rice varieties accumulated less number of degree days compared to the transplanted varieties and 30th May sowing along with 30th June transplanted rice varieties matured early hence accumulating less number of growing degree days.

Due to the low average temperatures during both the 2021 and 2022 rice growing seasons, it was observed that early sown rice (20th May) accumulated more heat units to reach physiological maturity than late sown crop (30th May). The presence of distinct phenological phases was directly affected by exposure to varying temperature conditions. Sandhu *et al.* (2013) discovered that early transplanted rice crop (June 15th) accumulated more heat units to reach physiological maturity compared to late transplanted crops (June 30th), which was attributed to lower temperatures. Karuna (2019) also reported that when a crop is transplanted early, it needs a higher number of heat units. Additionally, Kaur (2016) observed that for nearly every rice phenophase, early transplanting (15th June) aquired more degree days than late transplanting (30th June). When transplanting is delayed, less number of heat units are needed (Singh *et al.,* 2010).

However, DSR varieties accumulated less GDDs compared to transplanted rice varieties because DSR required less number of days for maturity where PTR required more number of days to reach maturity. Similar results were obtained by Xu *et al.* (2022). They reported that the crop under DSR matured within 95 days, whereas the total growth duration of puddle transplanted rice (PTR) ranged from 95 to 110 days across seasons and years, resulting in DSR having a total growth duration of 9 days less than that of PTR. This shorter growth duration of DSR leads to the accumulation of fewer GDDs compared to transplanted rice varieties, as DSR requires less time to reach maturity.

Accumulated helio-thermal units (AHTU)

The accumulated helio-thermal units were higher in variety PR 128 during both the years compared to variety PR 126 (Table 5 and Table 6). The AHTUs were 18406.0 and 18756.4°C day hr for variety PR 126 when transplanted on 20th June in both the years to reach physiological maturity. In case of variety PR 128 the AHTUs were 21666.1°C day hr and 21178.01°C day hr during both the years when transplanted on 20th June. Under 30th June transplanting, variety PR 126 accumulated 17318.5°C day hr in 2021 and 18177.5°C day hr of HTUs in 2022. However variety PR 128 accumulated 20352.8°C day hr of HTUs and 20445.5°C day hr of HTUs during 2021 and 2022 respectively to reach physiological maturity. The direct seeded crop sown on 20th May and 30th May accumulated lower HTUs during both the crop growing seasons. The results revealed that PTR varieties accumulated more HTUs followed by DSR as PTR varieties took more number of days to reach maturity in both 2021 and 2022. Similarly, in both rice growing seasons (*kharif* 2021

Table 5. Helio-thermal units (°C day hr) accumulation of transplanted and direct seeded variety PR 126 during *kharif* 2021 and 2022

Phenological stages	PTR				DSR			
	D_1		D_2		D_1		D_2	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillering	8929.8	8147.8	8088.23	7206.0	8288.4	7943.9	7696.4	7019.6
Maximum tillering	12114.2	11178.2	11542.4	10868.6	11889.9	11131.4	11090.9	10480.6
Panicle initiation	13270.5	12229.7	12676.6	12207.1	12485.3	11328.1	12388.8	11642.8
Flowering	15737.8	15040.6	14485.6	14722.1	14923.9	13956.2	14340.5	13834.6
Soft dough	16607.2	16471.2	15026.3	15836.9	16232.1	15823.5	14880.9	15377.7
Hard dough	17388.2	17926.8	16170.1	16968.9	17205.9	17320.5	15837.0	16515.3
Maturity	18406.0	18756.4	17318.5	18177.5	18311.5	18652.7	17080.5	17328.3

Where, PTR – Puddled transplanted rice; DSR- Direct seeded rice; D_1 (PTR) - 20th June transplanting; D_2 (PTR) - 30th June transplanting; D_1 (DSR)- 20th May sowing; D_2 (DSR)- 30th May sowing

Table 6. Helio-thermal units (°C day hr) accumulation of transplanted and direct seeded variety PR 128 during *kharif* 2021 and 2022

Phenological stages	PTR				DSR			
	D_1		D_2		D_1		D_2	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillering	9378.5	8440.1	8597.1	7815.1	8718.6	8147.8	8356.1	7245.4
Maximum tillering	13502.7	11709.9	12676.6	12207.1	13722.0	12229.7	12744.3	11813.3
Panicle initiation	14874.0	13956.2	14052.5	13834.6	14923.9	13956.2	14340.5	13834.6
Flowering	16751.0	16471.2	15208.6	15836.9	16665.2	16237.6	15072.8	15725.3
Soft dough	17388.2	17926.8	16170.1	16903.6	17205.9	17225.5	16021.0	16515.3
Hard dough	18803.9	19077.4	17766.2	18538.3	18803.9	18756.4	17577.2	18359.0
Maturity	21666.1	21178.0	20352.0	20445.5	21360.0	20993.0	20198.8	20445.5

Where, PTR – Puddled transplanted rice; DSR- Direct seeded rice; D_1 (PTR) - 20th June transplanting; D_2 (PTR) - 30th June transplanting; D_1 (DSR)- 20th May sowing; D_2 (DSR)- 30th May sowing and 2022) rice varieties sown on 20th May accumulated more HTUs compared to 30th May sown crop. As the temperature was at lower side in 30th May sown crop, the AGDD was low, hence the AHTU was lower for late sown crop. Sandhu *et al.* (2013) also observed similar results in early-transplanted rice crop, where both cultivars exhibited the highest heat unit (HTU) accumulation by the transplanting method. This observation is consistent with the findings reported by Hundal *et al.* (2005) and Kaur *et al.* (2024) in rice crop.

Accumulated photo-thermal units (PTU)

The accumulation of photo-thermal units for two rice varieties i.e. PR 126 and PR 128 during *kharif* 2021 and *kharif* 2022 are presented in Table 7 and Table 8. Varieties sown directly on 20th May and 30th May have accumulated less number of PTUs compared to varieties transplanted on 20th June and 30th June. Variety PR 126 diretly sown on 20th May and 30th May accumulated 33828.0°C day hr of PTUs and 32966.4°C day hr of PTUs during 2021. However same variety directly sown on 20th May and 30th May during 2022 accumulated 35204.6°C day hr of PTUs and 33700.4°C day hr of PTUs respectively. But variety PR 128 directly sown on 20th May accumulated 38315.0°C day hr of PTUs and 39332.5°C day hr of PTUs during 2021 and 2022 respectively. Same variety directly sown on 30th May accumulated 37212.5°C day hr and 37772.4°C day hr of PTUs during 2021 and 2022.

Table 7. Photo-thermal units (°C day hr) accumulation of transplanted and direct seeded variety PR 126 during *kharif* 2021 and 2022

Phenological stages	PTR				DSR			
	D_1		D_2		D_1		D_2	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillering	13994.3	14562.1	13993.6	14359.3	13033.9	13683.5	13432.4	13768.5
Maximum tillering	22428.6	23460.1	22151.5	23355.6	21903.5	22943.3	21580.4	22522.5
Panicle initiation	24332.6	25399.1	24068.9	24970.1	23216.4	24003.5	23278.6	24167.5
Flowering	28378.4	29423.9	27602.9	28426.6	27298.4	27846.7	26888.7	27354.7
Soft dough	30121.0	31303.2	28842.8	30439.2	29149.7	30506.2	28593.1	29436.7
Hard dough	32457.1	34022.8	31317.1	32763.4	31595.0	32839.2	30615.3	31611.6
Maturity	34456.9	36014.7	33420.5	34758.0	33828.0	35204.6	32966.4	33700.4

Where, PTR – Puddled transplanted rice; DSR- Direct seeded rice; D_1 (PTR) - 20th June transplanting; D_2 (PTR) - 30th June transplanting; D_1 (DSR)- 20th May sowing; D_2 (DSR)- 30th May sowing

Table 8. Photo-thermal units (°C day hr) accumulation of transplanted and direct seeded variety PR 128 during *kharif* 2021 and 2022

Phenological stages	PTR				DSR			
	D_1		D_2		D_1		D_2	
	2021	2022	2021	2022	2021	2022	2021	2022
Tillering	14680.9	15779.5	14632.1	15488.8	13660.0	14562.1	14309.6	14631.5
Maximum tillering	24621.1	24845.2	24068.9	24970.1	24903.8	25399.1	24546.2	24437.4
Panicle initiation	27051.0	27846.7	26397.5	27354.7	27298.4	27846.7	26888.7	27354.7
Flowering	30598.6	31303.2	29704.9	30439.2	30355.1	31039.6	29477.3	30218.4
Soft dough	32457.1	34022.8	31317.1	32328.0	31595.0	32572.9	30837.4	31611.6
Hard dough	35034.1	36577.0	34069.1	35180.0	35034.1	36014.7	33850.0	34968.4
Maturity	38915.0	39832.5	37537.5	37972.1	38319.9	39349.2	37212.5	37272.1

Where, PTR – Puddled transplanted rice; DSR- Direct seeded rice; D_1 (PTR) - 20th June transplanting; D_2 (PTR) - 30th June transplanting; D_1 (DSR)- 20th May sowing; D_2 (DSR)- 30th May sowing

The results revealed that crop varieties sown on 20th May accumulated more PTUs as compared to 30th May sown crop during both the rice growing seasons of 2021 and 2022. According to Dar *et al*. (2018), varieties exhibiting delayed maturity, signifying a prolonged duration to reach maturity, were associated with higher number of PTUs. Similarly, directly sown crop exhibiting early maturity accumulated less PTU compared to transplanted rice varieties in *kharif* 2021 and 2022. The highest photo-thermal units (PTUs) were accumulated under the early transplanting date, aligning with the observed outcomes as reported by Sandhu *et al*. (2013).

Conclusions

During both the seasons (*kharif* 2021 and 2022) variety PR 128 took more number of days to reach physiological maturity compared to the variety PR 126. Rice varieties grown under DSR method had taken less number of days to reach physiological maturity compared to PTR method, in both the years (*kharif* 2021 and 2022). Rice verities sown on 30th May and transplanted on 30th June reached physiological maturity early compared to varieties sown on 20th May and transplanted on 20th June. Variety PR 128 accumulated higher GDDs than variety PR 126, with 2900.5 and 2568.5°C day for 20th June transplanting in 2021 and 2022. For 30th June transplanting, variety PR 126 accumulated 2514.0°C day, and variety PR 128 accumulated 2847.0°C day, while both varieties had lower GDDs in direct sowing methods, with PR 126 accumulated 2516.0°C day and 2475.2°C day GDDs in crop sown on 20th May and 30th May in 2021 and similar trends were observed in 2022. Similar pattern of PTUs and HTUs was also found. Variety PR 128 consistently showed higher AHTUs compared to PR 126, especially with a notable difference in the 20th June transplanting. Direct sowing on 20th May and 30th May resulted in lower AHTUs for both varieties compared to varieties grown in PTR method. In *kharif* 2021 and 2022, variety PR 128 consistently surpassed variety PR 126 in PTUs, particularly evident in direct sowing on 20th May, showcasing varietal differences in thermal accumulation across different sowing dates.

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