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Thermal time requirements for phenological development of rice cultivars differing in maturity duration

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Abstract

Despite decades of thermal time research in cereals, precise growing degree day (GDD) requirements for individual rice growth stages remain poorly quantified for many widely grown cultivars. This research determined thermal time requirements from transplanting through maturity for three rice cultivars of contrasting duration IR64 (early), Swarna (medium), and BPT 5204 (late) grown across six planting dates at Cornell University, Ithaca, USA, during 2021 and 2022. Thermal time from transplanting to heading ranged from 987 °C·day (IR64) to 1,438 °C·day (BPT 5204), with a base temperature of 10 °C. A linear thermal time model predicted heading date with $r^2 = 0.91$ and RMSE of 2.8 days across all cultivar-date combinations. The grain-filling phase required 580–714 °C·day depending on cultivar, accounting for 35–38 percent of total thermal time to maturity.

Keywords: Thermal time, growing degree days, rice phenology, heading, grain filling, base temperature, cultivar maturity, planting date, crop modeling, *Oryza sativa*.

Introduction

Calendar-based crop scheduling assumes that development rates are constant over time, yet rice phenology is driven primarily by temperature accumulation rather than calendar days ^[1]. Growing degree days (GDD) provide a more physiologically meaningful metric for predicting when a crop will reach key developmental stages, enabling better management of planting windows, irrigation scheduling, and harvest timing ^[2, 3].

The thermal time concept assumes that development rate is linearly proportional to temperature above a base threshold (Tbase), with the sum of daily effective temperatures predicting stage transitions ^[4]. While Tbase for rice is commonly assumed at 10 °C, some authors have reported values between 8 and 12 °C depending on cultivar and growth phase ^[5]. Cultivar-specific thermal time constants remain lacking for many popular varieties.

This research quantified thermal time requirements for three widely grown rice cultivars across six planting dates to evaluate the stability of GDD constants and the predictive accuracy of a simple linear thermal time model.

Research area description

The experiment was conducted at the Cornell University Experimental Rice Facility at Musgrave Research Farm, Aurora, New York (42.73°N, 76.66°E, elevation 253 m). The soil was a Lima silt loam with pH 6.2 and organic carbon 1.51 percent. Although this location is outside the traditional rice belt, controlled flooding and the temperate summer provided a range of thermal environments across planting dates, which is ideal for thermal time calibration.

Experimental design

A split-plot design with planting date as main plot and cultivar as subplot was used, with three replications. Six planting dates spanned May 10 to July 1 at 10-day intervals in both 2021 and 2022, creating a range of temperature regimes during each growth phase. Subplot size was 4 × 3 m. Seedlings (21 days old) were transplanted at 20 × 15 cm spacing into flooded paddies. Fertilization was 120-60-40 kg N-P₂O₅-K₂O/ha. Temperature was recorded hourly using dataloggers (HOBO U23-001) at canopy height.

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Material and Methods

Material

Three rice cultivars representing distinct maturity groups were used: IR64 (early, ~105 days), Swarna (medium, ~125 days), and BPT 5204 (late, ~140 days). Daily maximum and minimum temperatures from the field dataloggers were used to calculate GDD. Phenological observations were recorded every 2 days on 10 tagged plants per subplot: tillering onset, panicle initiation, heading (50% panicle emergence), flowering, and physiological maturity.

Methods: Daily GDD was calculated as: $GDD = [(T_{max} + T_{min}) / 2] - T_{base}$, with T_{base} optimized iteratively from 7 to 13 °C in 0.5 °C steps by minimizing the coefficient of variation (CV) of cumulative GDD to heading across all planting dates within each cultivar [6]. The model was validated by leave-one-out cross-validation across the 36 cultivar × date × year combinations. Grain filling duration was defined as heading to physiological maturity. RMSE and r^2 were used as model performance metrics. Data were analyzed in R 4.3.1.

Results

Table 1: Optimized base temperature and thermal time requirements (°C·day) for key phenological stages of three rice cultivars

Cultivar	Tbase (°C)	Tillering	Pan. Init.	Heading	Maturity	Gf phase	Gf % of total
IR64	10.0	312	687	987	1,567	580	37.0
Swarna	10.5	378	814	1,213	1,867	654	35.0
BPT 5204	9.5	421	942	1,438	2,152	714	33.2

GF = grain filling. CV of thermal time to heading: IR64 = 4.7%; Swarna = 5.1%; BPT 5204 = 4.3%

Optimized Tbase ranged from 9.5 °C (BPT 5204) to 10.5 °C (Swarna), close to the commonly assumed 10°C (Table 1). Thermal time to heading varied by 451 °C·day between the earliest and latest cultivar. The grain-filling phase accounted for

33–37 percent of total thermal time to maturity, with early cultivars allocating proportionally more thermal time to grain fill.

Table 2: Thermal time model validation: predicted vs observed days to heading across planting dates

Cultivar	R ²	Rmse (days)	Mean bias (days)	Max error (days)
IR64	0.93	2.4	+0.3	4.1
Swarna	0.89	3.1	-0.7	5.2
BPT 5204	0.92	2.7	+0.4	4.8
All combined	0.91	2.8	+0.1	5.2

Leave-one-out cross-validation across 36 cultivar × date × year combinations

The thermal time model predicted heading date with an overall r^2 of 0.91 and RMSE of 2.8 days (Table 2). Mean bias was negligible (+0.1 day), though individual predictions could

deviate by up to 5.2 days, primarily for the July 1 planting when photoperiod effects compounded temperature responses.

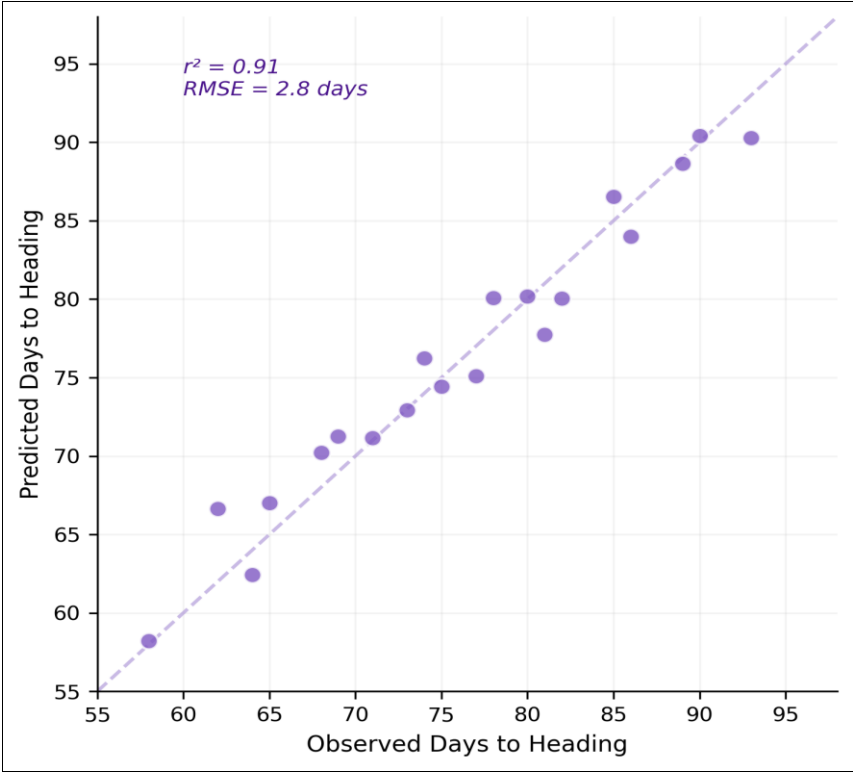


Fig 1: Observed versus predicted days to heading for three rice cultivars across six planting dates and two years (n = 36). Dashed line = 1:1 reference

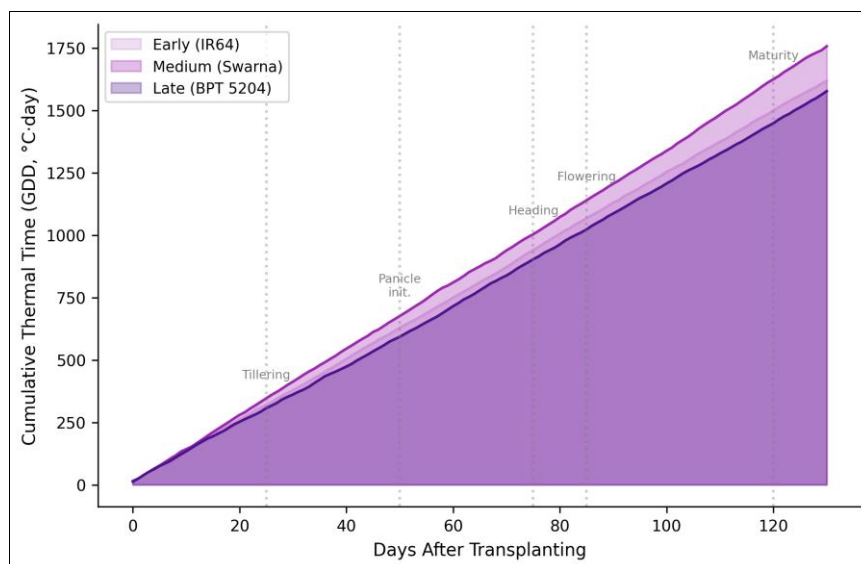


Fig 2: Cumulative thermal time accumulation (GDD, °C·day) from transplanting through maturity for three rice cultivars of contrasting duration, with key phenological stage markers

Limitations

The linear GDD model does not account for photoperiod sensitivity, which contributed to larger errors at the latest planting date. The optimized Tbase values are specific to the temperature range encountered at this site (15–34 °C) and may differ under tropical conditions with higher night temperatures. Only three cultivars were tested, and modern hybrid rice may behave differently. The two-year calibration dataset is adequate for initial parameterization but would benefit from additional years for robust validation.

Discussion

The 2.8-day RMSE for heading prediction compares favorably with more complex crop simulation models that typically achieve 3 to 5 days for rice heading [7, 8]. The near-constant Tbase of approximately 10 °C across cultivars supports the practical convention used in most rice models, though the slight variation (9.5–10.5 °C) suggests that cultivar-specific calibration improves precision [9].

The grain-filling phase consuming 33–37 percent of total thermal time highlights the importance of post-heading temperature conditions for yield formation. Early cultivars like IR64 allocated proportionally more thermal resource to grain fill, which may partly explain their yield stability across environments [10, 11]. The largest model errors occurred at late planting, where declining photoperiod likely delayed heading beyond what temperature alone would predict, consistent with known photoperiod sensitivity in indica rice [12].

Conclusion

Thermal time requirements from transplanting to heading ranged from 987 to 1,438 °C·day across early, medium, and late rice cultivars. A linear GDD model with cultivar-specific Tbase predicted heading with 2.8-day accuracy. Grain filling required 580–714 °C·day, representing one-third of total crop duration. These thermal time constants can improve planting date recommendations, harvest scheduling, and crop insurance assessments for rice. Incorporating photoperiod corrections would further improve predictions for late-season plantings.

References

1. Yoshida S. Fundamentals of rice crop science. Los Baños: International Rice Research Institute; 1981. p. 1-269.
2. Trudgill DL, Honek A, Li D, Van Straalen NM. Thermal

- time concepts and utility. *Ann Appl Biol.* 2005;146(1):1-14.
3. Ritchie JT, NeSmith DS. Temperature and crop development. In: Hanks J, Ritchie JT, editors. *Modeling plant and soil systems.* Madison: ASA-CSSA-SSSA; 1991. p. 5-29.
4. McMaster GS, Wilhelm WW. Growing degree-days: One equation, two interpretations. *Agric For Meteorol.* 1997;87(4):291-300.
5. Gao L, Jin Z, Huang Y, Zhang L. Rice clock model a computer model to simulate rice development. *Agric For Meteorol.* 1992;60(1-2):1-16.
6. Yang S, Logan J, Coffey DL. Mathematical formulae for calculating the base temperature for growing degree days. *Agric For Meteorol.* 1995;74(1-2):61-74.
7. Bouman BAM, van Keulen H, van Laar HH, Rabbinge R. The School of de Wit crop growth simulation models: A pedigree and historical overview. *Agric Syst.* 1996;52(2-3):171-198.
8. Kropff MJ, van Laar HH, Matthews RB. ORYZA1: An ecophysiological model for irrigated rice production. Wageningen: SARP Research Proceedings; 1994. p. 1-110.
9. Summerfield RJ, Collinson ST, Ellis RH, Roberts EH, de Vries FWTP. Photothermal responses of flowering in rice (*Oryza sativa*). *Ann Bot.* 1992;69(2):101-112.
10. Dingkuhn M, Miezian KM. Climatic determinants of irrigated rice performance in the Sahel II. Photoperiod and temperature responses of flowering. *Agric Syst.* 1995;48(4):411-433.
11. Vergara BS, Chang TT. The flowering response of the rice plant to photoperiod: A review of the literature. 4th ed. Los Baños: International Rice Research Institute; 1985. p. 1-61.
12. Yin X, Kropff MJ, Horie T, Nakagawa H, Centeno HGS, Zhu D, Goudriaan J. A model for photothermal responses of flowering in rice I. Model description and parameterization. *Field Crops Res.* 1997;51(3):189-200.
13. Angus JF, Mackenzie DH, Morton R, Schafer CA. Phasic development in field crops II. Thermal and photoperiodic responses of spring wheat. *Field Crops Res.* 1981;4:269-283.
14. Confalonieri R, Bregaglio S, Acutis M. A proposal of an indicator for quantifying model robustness based on the relationship between variability of errors and of explored conditions. *Ecol Model.* 2010;221(6):960-964.