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Research paper

Optimizing wet season planting time for rice varieties in tropical Lowlands based on Thermal time and Radiation use efficiency

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ABSTRACT

Rice production stability is essential to maintain Indonesia's food security, yet it is increasingly affected by climate variability. This study quantified thermal time as growing degree days (GDD) and radiation use efficiency (RUE) to evaluate rice performance across wet-season planting windows and to identify a suitable planting period for tropical lowland ecosystems. The field investigation was carried out in Sidoarjo, East Java, Indonesia, during the 2023–2024 wet season using three representative varieties: Pandan Wangi, Inpari 32, and Intani 602. Rice was transplanted at three planting periods representing early (November), mid (January), and late (March) wet season planting. The experiment applied a randomized block design with two factors with combine analyzed. Data were analyzed using analysis of variance and regression. The results indicated that planting time significantly affected all yield components. The hybrid Intani 602 achieved the highest panicle number, grain weight, and grain yield (7.56 to 9.54 t ha⁻¹), demonstrating superior adaptability and physiological performance. Regression analysis showed a significant negative relationship between GDD and grain yield and a positive relationship between RUE and grain yield. The findings emphasize the importance of matching variety selection with planting time to enhance productivity and resilience under tropical climates. Developing suitable agroclimatic-based planting calendars is recommended to support sustainable rice production systems.

Keywords: Climate variability, GDD, Genotype performance, Planting season, Lowland, RUE

Rice (*Oryza sativa* L.) serves as the principal staple crop for much of the world's population, with its greatest reliance found in Southeast Asian countries such as Indonesia. Nevertheless, fluctuations in climatic factors, particularly temperature, solar radiation, and rainfall, continue to constrain rice productivity because these variables exert direct effects on crop development and yield formation. (Yin *et al.*, 2021). In addition to cultivation practice (variety selection, irrigation, planting systems, spacing, and fertilization), rice production is also highly influenced by environmental and climatic factors, including light duration, rainfall, temperature, and humidity (Salgotra & Chauhan, 2023). Variations in light environment are also critical, as reduced sunlight intensity can substantially alter rice growth and yield formation (Garima & Sandhu, 2023).

The performance of rice is not only determined by its genetic potential and cultivation practices but also by the environmental conditions prevailing during each growth phase. Previous research

has shown that temperature and solar radiation are among the most influential climatic factors affecting rice productivity (Xu *et al.*, 2021). Nevertheless, many studies have been restricted to a single growing season or have emphasized agronomic yield traits without analyzing the underlying physiological efficiency that drives productivity. In particular, the combined evaluation of radiation use efficiency (RUE) and thermal time expressed as growing degree days (GDD) as indicators of genotype × environment interaction remains insufficiently explored in tropical lowland ecosystems. This knowledge gap limits the ability to formulate precise planting recommendations under changing climate conditions (Fu *et al.*, 2021).

The physiological mechanisms by which rice varieties adapt to different planting seasons under these conditions are not fully understood. Understanding such mechanisms is essential for improving planting calendar precision and supporting climate-resilient rice production systems (Wang *et al.*, 2019). To address

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Fig. 1: Weather parameters during 2023-24 (Tn: minimum temperature, °C; Tx: maximum temperature, °C; Tavg: average temperature, °C; RR: rainfall, mm; SS: sunshine duration, hours).

this limitation, the present study employs two physiological parameters, RUE and GDD as key indicators of environmental response (Suryanto *et al.*, 2018). RUE quantifies the capacity of a crop to convert intercepted solar energy into biomass, while GDD reflects the cumulative thermal time required for developmental progress. Recent work has similarly demonstrated the utility of agrometeorological indices, including thermal-time accumulation and efficiency metrics, for interpreting rice growth and yield responses under contrasting management environments (Kaur *et al.*, 2024).

In the tropical lowlands of East Java, wet season rice is usually transplanted between late November and early January following the onset of the rainy season, while farmers often extend planting into March when water is still available. These early, mid, and late wet season planting periods expose the crop to contrasting temperature, radiation, and rainfall conditions within a single season. A comparative evaluation of different varieties across three wet season planting periods in tropical lowland irrigated rice fields can therefore provide essential insights into varietal × planting period suitability. The distinctive contribution of this research lies in its integrated assessment of radiation and thermal efficiency across variety types and planting windows, generating evidence that links physiological efficiency with yield stability and supports the development of adaptive varietal recommendations and agroclimatic planting calendars for climate resilient rice production systems.

MATERIAL AND METHODS

Experiment design

The study was conducted under field conditions in Sidoarjo, East Java, Indonesia, located at coordinates 07°30.717' S and 112°38.608' E, with an average elevation of 5 meters above sea level. The experimental period spanned from November 2023

to July 2024. At the experimental site, the soil was characterized as alluvial. Pre planting soil analysis of the topsoil indicated the following characteristics: pH 6.80, total nitrogen (N) 0.14%, available phosphorus P_2O_5 67.03 ppm, and exchangeable potassium (K-dd) 1.09 me/100 g.

The experiment was arranged in a randomized block design (RBD) with two treatment factors: rice varieties and planting period. The varieties evaluated included Pandan Wangi (V1, a local aromatic variety with a growth duration of approximately 155 days from transplanting to physiological maturity), Inpari 32 (V2, an improved inbred variety, around 120 days), and Intani 602 (V3, a commercial hybrid variety, about 114 days). Three planting periods were tested to represent the main wet-season planting windows in the study area: PT1 (early rainy season, transplanted on 7 November 2023), PT2 (mid rainy season, transplanted on 9 January 2024), and PT3 (late rainy season, transplanted on 5 March 2024). Daily weather data for the experimental period were obtained from the Juanda Meteorological Station operated by the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG Juanda, Sidoarjo), which is located close to the experimental fields. The dataset included daily maximum and minimum air temperature (°C), relative humidity (%), rainfall (mm), and sunshine duration ($h \text{ day}^{-1}$) and was used to describe the atmospheric conditions experienced by the crop under each planting period (Fig. 1).

Rice seedlings were transplanted at a spacing of 25×25 cm, with three seedlings per hill. Fourteen days old seedlings were raised in a dry-bed nursery before transplanting. Each experimental plot measured 4×4 m (16 m^2). Standard agronomic practices, including fertilization, weed management, pest and disease control, were applied uniformly across all treatments to maintain experimental uniformity.

Table 1: Effect of planting time on growth duration (days).

Parameter	November (PT1)						March (PT3)						F-test Significance			
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	PT	V	PT*V	LSD
Before heading (d)	70	a 63	b 63	b 75	a 68	b 63	c 66	a 63	b 60	c	13.63**	4.37*	3.47*	1.00		
After heading (d)	50	a 49	ab 48	b 51	a 51	a 49	b 50	a 42	b 41	b	11.25**	38.2**	3.3*	1.47		
Total growth duration (d)	120	a 112	b 111	b 126	a 119	b 112	c 115	a 104	b 101	c	20.26**	91.1**	4.42*	1.89		

Table 2: Comparative analysis of yield and associated traits of rice varieties across environmental conditions.

Parameter	November (PT1)			January (PT2)			March (PT3)			F-test Significance				
	V1	V2	V3	V1	V2	V3	V1	V2	V3	PT	V	PT*V	LSD	
Number of panicles	23.6	a 19.6	b 22.3	ab 16.3	b 18.3	ab 21.3	a 21.3	a 21.0	a 22.3	a	13.63**	4.37*	3.47*	3.03
Number of grains per panicle	124.8	b 130.0	b 187.0	a 116.3	b 121.3	b 159.3	a 134.0	b 154.0	b 252.0	a	11.25**	38.2**	3.3*	34.85
Grains weight per panicle (g)	3.90	b 4.12	b 6.57	a 3.10	b 3.50	b 4.83	a 3.77	b 4.00	b 7.33	a	20.26**	91.1**	4.42*	0.81
Grains yield (ton ha ⁻¹)	6.53	b 8.76	a 8.77	a 5.38	b 6.01	b 7.56	a 6.49	b 7.04	b 9.54	a	5.74*	35.59**	3.44*	1.11

* V1 = Pandan Wangi, V2 = Inpari 32, V3 = Intani 602. Within each row, means followed by different letters differ significantly at $p \leq 0.05$ (LSD test). “***”, “**” and “ns” indicate F-test significance at $p \leq 0.01$, $p \leq 0.05$ and non-significant, respectively.

Observations on grain yield and its components

Observations were made on several agronomic and yield related traits, including the number of panicles per hill, the number of grains per panicle, grain weight per panicle (g), and grains yield (t ha⁻¹). Heading date was defined as the day when approximately 50% of hills within a plot showed visible panicle emergence. Harvest age (physiological maturity) was recorded as days after transplanting when most panicles had turned yellow and grains were fully hardened. In parallel, environmental parameters were monitored to evaluate the physiological response of the plants to prevailing climatic conditions, specifically the growing degree days (GDD) and radiation use efficiency (RUE).

$$\text{GDD} = \Sigma (\text{Tmean} - \text{T}_b),$$

Where daily Tmean was derived from minimum (Tmin) and maximum temperatures (Tmax). When Tmean was below Tb, daily GDD was set to zero, and temperature was capped at an upper threshold to avoid overestimation (Cruz-González *et al.*, 2025). A base temperature (Tb) of 10°C was used for rice, consistent with the biological zero temperature reported for rice (Ji *et al.*, 2024). The radiation use efficiency (RUE) was calculated as;

$$\text{RUE} = \frac{\Delta \text{W.K}}{\text{I.t.PAR}} \times 100\%$$

Where ΔW : Difference in plant dry weight (g) per m² at one time period (t), K: Coefficient heat of combustion (4,000 cal g⁻¹), I: Daily solar radiation intensity (cal m⁻² day⁻¹) was estimated from observed sunshine duration using the Angstrom-Prescott model, $I = (a + b \cdot n/N) \text{Ra}$, where n is the actual bright sunshine duration (h day⁻¹), $N = (24/\pi) \cdot \omega_s$, where $\omega_s = \arccos(-\tan\phi \cdot \tan\delta)$, ϕ is latitude (radians), and δ is solar declination as a function of day of year (J

(h day⁻¹), Ra is extraterrestrial radiation (cal m⁻² day⁻¹), and a (0.25) and b (0.50) are empirical coefficients for humid tropical lowlands, t: specific time period (days), PAR is the constant fraction of global solar radiation that is photosynthetically active, taken as 0.45 (Allen *et al.*, 1998 and Wahyudi *et al.*, 2024).

Analysis

The analysis of variance (ANOVA), was performed using the Statistical Tool for Agricultural Research (STAR, version 2.0.1; 2013–2020). Mean separation was carried out using the least significant difference (LSD) test at the 5% level when treatment effects were significant. Linear regression modeling and graphical visualization were performed using RStudio (version 4.4.1).

RESULTS AND DISCUSSION

Rice growth duration and phenological phases

Rice growth duration was significantly influenced by planting time, variety, and their interaction (Table 1). The pre-heading phase lasted 60–75 days and the post-heading phase 41–51 days, resulting in a total crop duration of 101–126 days. The January planting consistently extended crop duration across varieties, with Pandan Wangi exhibiting the longest duration at 126 days. In contrast, the March planting shortened the season to 101–115 days, mainly due to a reduced pre-heading period and a pronounced shortening of the post-heading phase in Inpari 32 and Intani 602. Jayapriya *et al.*, (2016), reported that shifts in planting time modify the thermal accumulation required to reach key developmental stages, supporting the phenological sensitivity observed in this study. Across planting windows, Pandan Wangi remained the latest-maturing variety, whereas Intani 602 matured earliest, particularly under the March planting. Recent evidence further demonstrates that

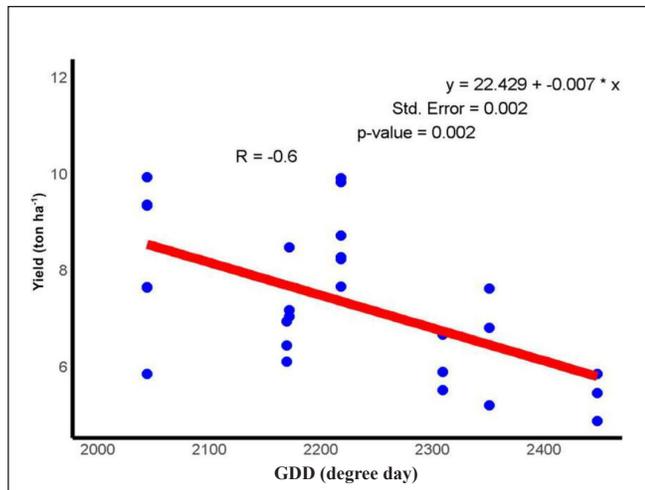


Fig. 2: Regression patterns showing the response of rice yield to Growth Degree Days (GDD)

accumulated thermal time and radiation use metrics are informative for interpreting rice growth and yield responses under contrasting management environments (Kaur *et al.*, 2024).

Yield and yield components

A significant interaction between rice varieties and planting periods was observed for key yield attributes, including panicle number, grains per panicle, grain weight per panicle, and overall grain yield (Table 2). These findings confirm that synchronization between genotype characteristics and environmental timing plays a crucial role in determining rice productivity in tropical lowland ecosystems (He *et al.*, 2024). During the first planting time (PT1), the local variety Pandan Wangi produced the highest panicle number followed by Intani 602 and Inpari 32. In the second planting (PT2), Intani 602 showed the best performance, whereas differences among varieties became less pronounced in the third planting time (PT3). This result indicates that late planting tends to reduce genotypic variation. Similar seasonal responses were reported by Horai *et al.*, (2013), who found that cooler early seasons stimulated panicle initiation, while excessive heat during vegetative growth limited tillering activity.

Grain weight per panicle and grain yield followed a similar trend. Intani 602 achieved the highest grain weight and yield, while Pandan Wangi and Inpari 32 produced lower but more stable yields across seasons. These results highlight the hybrid's strong adaptability and high radiation use efficiency during the grain filling phase (Yin *et al.*, 2021). Grain yield per hectare indicated that Intani 602 consistently achieved high productivity, ranging from 7.56 to 9.54 t ha⁻¹, with statistically significant differences observed under the second and third planting times. This yield stability demonstrates the variety's adaptive capacity to environmental variability, including abiotic stress factors such as high temperature and fluctuating radiation (He *et al.*, 2024). These results support the conclusions of Ceotto *et al.*, (2013), who emphasized the importance of physiological resilience and energy use efficiency in sustaining yield under tropical conditions.

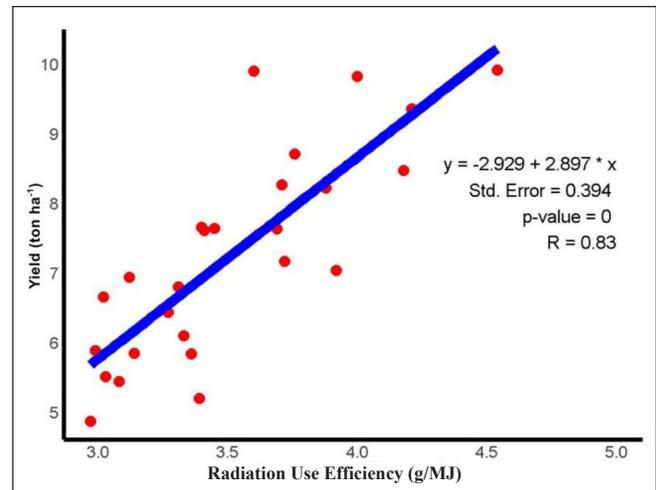


Fig. 3: Regression patterns showing the response of rice yield to radiation use efficiency (RUE).

Yield response to thermal time and radiation use efficiency

Regression analysis showed a significant negative correlation between thermal time expressed as growing degree days (GDD) and grain yield per hectare, with GDD explaining approximately 33 percent of the observed variation in yield ($R^2 = 0.33$; $p = 0.002$) (Fig. 2). This finding suggests that higher cumulative thermal exposure during the growth period tends to reduce yield, primarily due to heat induced stress during critical physiological phases such as flowering and grain filling (Ji *et al.*, 2024). Yield reduction caused by elevated temperatures has been reported across rice growing ecosystems, including both tropical and subtropical regions, primarily through mechanisms involving reduced grain fertility and impaired grain filling (Zhou *et al.*, 2021). The GDD based thermal model also indicated that temperatures exceeding the optimal physiological threshold accelerate phenological development and reduce the plant's economic yield index. Excess heat shortens the total growth duration, decreases the proportion of effective spikelets, and lowers grain filling efficiency (Ceotto *et al.*, 2013).

In contrast, RUE exhibited a significant positive correlation with grain yield (Fig. 3). An increase of one unit in RUE was associated with an approximate yield gain of 3.03 t ha⁻¹, explaining up to 58% of the yield variation ($R^2 = 0.58$; $p = 0.044$). This result highlights the central role of physiological efficiency in converting intercepted radiation into economic biomass. Similarly, Liu *et al.*, (2020), demonstrated that hybrid rice yield gains were driven more by high RUE than by increases in intercepted photosynthetically active radiation (IPAR). Further studies by Ji *et al.*, (2024) and Zhou *et al.*, (2021), also found strong positive associations between high RUE and improved grain filling, particularly under optimized planting and nutrient management regimes.

CONCLUSION

This study demonstrates that thermal time and radiation use efficiency jointly regulate rice productivity across wet-season planting periods in tropical lowlands. Higher cumulative thermal

exposure was associated with reduced grain yield, whereas higher radiation use efficiency enhanced productivity and yield stability. Local varieties such as Pandan Wangi performed better under early planting conditions characterized by moderate temperatures, while the hybrid Intani 602 exhibited superior yield and physiological efficiency under mid-season planting. Based on these findings, early to mid-wet-season transplanting is identified as the most suitable planting window for tropical lowland rice ecosystems, ensuring an optimal balance between thermal accumulation and radiation utilization. These results provide practical guidance for developing adaptive agroclimatic planting calendars and climate-resilient rice production strategies.

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Data Availability: The data supporting the findings of this study are not publicly available because the author does not have permission to distribute them.

Author contribution: **M. Muharram:** Data curation, formal analysis, investigation, validation, visualization, and writing of the original draft; **A. Suryanto:** Conceptualization, methodology, and supervision of the research; **Sudiarso:** Formal analysis, visualization, and writing-review and editing; **A. S. Karyawati:** Formal analysis, visualization, and writing-review and editing.

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REFERENCES

- Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements* (FAO Irrigation and Drainage Paper No. 56). Food and Agriculture Organization of the United Nations.
- Ceotto, E., Di Candilo, M., Castelli, F., Badeck, F. W., Rizza, F., Soave, C., Volta, A., Villani, G., & Marletto, V. (2013). Comparing solar radiation interception and use efficiency for the energy crops giant reed (*Arundo donax* L.) and sweet sorghum (*Sorghum bicolor* L. Moench). *Field Crops Research*, *149*, 159–166. <https://doi.org/10.1016/j.fcr.2013.05.002>
- Cruz-González, A., Arteaga-Ramírez, R., Monterroso-Rivas, A. I., Sánchez-Cohen, I., Soria-Ruiz, J., & Quevedo-Nolasco, A. (2025). Climate change impacts on the accumulation of growing degree days for corn in central Mexico. *Journal of Agrometeorology*, *27*(1), 38–42. <https://doi.org/10.54386/jam.v27i1.2783>
- Fu, Y., Qiang, Zhong, X. Hua, Zeng, J. Huan, Liang, K. Ming, Pan, J. Feng, Xin, Y. Feng, Liu, Y. Zhuo, Hu, X. Yu, Peng, B. Lin, Chen, R. Bing, Hu, R., & Huang, N. Rong. (2021). Improving grain yield, nitrogen use efficiency and radiation use efficiency by dense planting, with delayed and reduced nitrogen application, in double cropping rice in South China. *Journal of Integrative Agriculture*, *20*(2), 565–580. [https://doi.org/10.1016/S2095-3119\(20\)63380-9](https://doi.org/10.1016/S2095-3119(20)63380-9)
- Garima, & Sandhu, S. S. (2023). Phenology, growth and productivity of rice (*Oryza sativa* L.) under reduced sunlight intensity and foliar nitrogen application. *Journal of Agrometeorology*, *25*(1), 98–104. <https://doi.org/10.54386/jam.v25i1.1847>
- He, A., Li, J., Long, J., Ai, Z., Zhang, P., & Guo, X. (2024). Spatial and Temporal Variations of Climate Resources during the Growing Season of Early-Season Rice in Hunan Province. *Agriculture (Switzerland)*, *14*(9). <https://doi.org/10.3390/agriculture14091514>
- Horai, K., Ishii, A., Mae, T., & Shimono, H. (2013). Effects of early planting on growth and yield of rice cultivars under a cool climate. *Field Crops Research*, *144*, 11–18. <https://doi.org/10.1016/j.fcr.2012.12.016>
- Jayapriya, S., V. Ravichandran, & P. Boominathan. (2016). Heat unit requirements of different rice genotypes at Coimbatore. *Journal of Agrometeorology*, *18*(2), 326–329. <https://doi.org/10.54386/jam.v18i2.962>
- Ji, Y., Xu, Y., Sun, X., Hassan, M. A., Zhou, Y., Zou, H., & Li, Z. (2024). Optimization of sowing dates for enhanced rice yield: insights from field experiments in the middle and lower reaches of the Yangtze River, China. *BMC Plant Biology*, *24*(1), 1011. <https://doi.org/10.1186/s12870-024-05729-7>
- Kaur, K., Gill, K. K., Singh, P., & Sandhu, S. S. (2024). Growth performance and agrometeorological indices of rice under different establishment methods. *Journal of Agrometeorology*, *26*(2), 155–162. <https://doi.org/10.54386/jam.v26i2.2338>
- Liu, K., Yang, R., Deng, J., Huang, L., Wei, Z., Ma, G., Tian, X., & Zhang, Y. (2020). High radiation use efficiency improves yield in the recently developed elite hybrid rice Y-liangyou 900. *Field Crops Research*, *253*. <https://doi.org/10.1016/j.fcr.2020.105111>

fcf.2020.107804

- Salgotra, R. K., & Chauhan, B. S. (2023). Ecophysiological Responses of Rice (*Oryza sativa* L.) to Drought and High Temperature. *Agronomy*, *13*(7), 1–20. <https://doi.org/10.3390/agronomy13071877>
- Suryanto, A., Maghfoer, M. D., & Kartinaty, T. (2018). Radiation use efficiency on the different varieties and the number of seedlings of rice (*Oryza sativa* L.). *Agrivita*, *40*(3), 536–543. <https://doi.org/10.17503/agrivita.v40i3.1851>
- Wahyudi, M. I., Suryanto, A., Sugito, Y., Sugiharto, A. N., & Hamid, A. (2024). Impact of Integrated Nutrient Management Based on Silicon to Morpho-Physiological Changes on Maize: Enhancing Light Interception and Radiation use Efficiency. *Journal of Global Innovations in Agricultural Sciences*, *12*(3), 779–790. <https://doi.org/10.22194/JGIAS/24.1346>
- Wang, Y., Wang, L., Zhou, J., Hu, S., Chen, H., Xiang, J., Zhang, Y., Zeng, Y., Shi, Q., Zhu, D., & Zhang, Y. (2019). Research Progress on Heat Stress of Rice at Flowering Stage. In *Rice Science* (Vol. 26, Issue 1, pp. 1–10). Elsevier B.V. <https://doi.org/10.1016/j.rsci.2018.06.009>
- Xu, Y., Chu, C., & Yao, S. (2021). The impact of high-temperature stress on rice: Challenges and solutions. *Crop Journal*, *9*(5), 963–976. <https://doi.org/10.1016/j.cj.2021.02.011>
- Yin, M., Liu, S., Zheng, X., Chu, G., Xu, C., Zhang, X., Wang, D., & Chen, S. (2021). Solar radiation-use characteristics of indica/japonica hybrid rice (*Oryza sativa* L.) in the late season in southeast China. *Crop Journal*, *9*(2), 427–439. <https://doi.org/10.1016/j.cj.2020.06.010>
- Zhou, N. Bing, Zhang, Jun, Fang, S. Liang, Wei, H. Yan, & Zhang, H. Cheng. (2021). Effects of temperature and solar radiation on yield of good eating-quality rice in the lower reaches of the Huai River Basin, China. *Journal of Integrative Agriculture*, *20*(7), 1762–1774. [https://doi.org/10.1016/S2095-3119\(20\)63561-4](https://doi.org/10.1016/S2095-3119(20)63561-4)