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Optimizing Rice Sowing Dates for High Yield and Climate Adaptation in Central China

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Abstract: Optimizing the sowing date of rice can change the seasonal patterns and distributions of climate factors during the crop growing season, making it one of the most effective ways to adapt to climate change and achieve high yield. A four–year field experiment (2018–2021) was conducted at Jingzhou Agricultural Meteorological Experiment Station, central China, with four different sowing dates (SD) each year, late April (SD1), early May (SD2), mid–May (SD3) and late May (SD4). Dry matter accumulation, grain yield and climate conditions were observed across sowing dates. Our findings revealed that delaying the sowing date from early May to mid or late May could increase grain yield by 5.6% to 8.6%. However, sowing too early could increase heat stress, decrease the net effective accumulated temperature, inhibit rice growth, and reduce grain yield. On the other hand, sowing too late could increase the risk of low temperatures after flowering. From the perspective of increasing net effective accumulated temperature, reducing heat stress and low temperature after flowering, mid to late May was the most favorable sowing date to ensure high yield. It is suggested that optimizing rice sowing dates can effectively avoid the threat of heat stress and better match thermal resources, thereby increasing rice productivity.

Keywords: rice; sowing dates; thermal resource; grain yield; dry matter accumulation; heat stress

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1. Introduction

As the largest rice (*Oryza sativa* L.) producing and consuming country, China's rice production has accounted for about 37% of the global rice production [1]. Rice is the most important grain crop in China, which accounts for about 26% and 32% of total crop area and production, respectively [2]. During the past 30 years, rice yield has increased by around 9.3% [3], while continued yield improvement is still needed to ensure food security. The main rice growing systems in China include single–cropping rice, double–cropping rice, rice–wheat, or rapeseed rotation. In central China, rice is often sown in early May. Central China accounts for nearly 24% of China's rice production [2], making it an important and typical rice cultivation area.

The most significant and uncontrollable factor influencing crop yield has been assumed to be climate [4,5]. Previous studies have documented that increases in temperatures have accelerated rice phenology development, thus decreasing crop yield [6–9]. Furthermore, many research works have also emphasized the compound climate risk that occurs during the rice reproductive stage, such as heading, flowering, and early grain filling stage, which would normally cause a great loss in yield [10–12]. High temperature during flowering is well known to cause spikelet sterility and reduce yield in rice [13], and temperature at grain filling is a significant factor influencing spikelet fertility, 1000–grain weight [14], and rice quality [15]. The maximum, optimum, and base temperature of rice anthesis phases were approximately 37 °C, 25 °C and 15 °C, respectively, while the maximum and base temperature of rice grain filling stage were nearly 30 °C and 20 °C [8]. Different rice varieties had different temperature thresholds. Welch and Vincent [16] found that increasing maximum temperature (T_{max}) improves rice yield. However, Pattanayak and Kumar [4] showed that T_{max} was the primary source of yield reduction, especially during the reproductive stage, and the T_{max} played a larger role in reducing rice yield than minimum temperature (T_{min}). The response of rice yield to changes in T_{min} was insignificant, and the temperature effects varied by rice–growth stage after statistically analyzing 30 years of weather and yield data in China [17]. An increase in average daily temperature may shorten crop growth and thus reduce crop yields [18]. In central China, the main climate resource that restricts rice production is heat resources. If sown too early, it will generally encounter heat stress from heading to grain filling, and if sown too late, it will also cause low temperatures after flowering. Therefore, an appropriate sowing date is crucial for grain yield in central China.

Increasing crop production adaptation to climate change is one of the most effective ways to ensure global food security. Regulating the sowing date has been proposed as the most efficient and cost–effective method of adjusting the distribution and patterns of climate factors during the crop growing season, thereby mitigating the negative climate impacts on rice production in China [6]. Choosing the best sowing date to maximize yield is the simplest and least expensive adaptation for farmers. As a result, it would be crucial to change the patterns of climate factors to coincide with rice growth.

Some researchers suggested that adjusting the rice sowing date in Sichuan province could improve dry matter accumulation and grain yield [19]. This is owing to higher solar radiation and lower temperature during the growing season, which contributed to higher dry matter accumulation pre– and post–anthesis and a greater number of panicles. Tu and Jiang [20] investigated the rice responses to temperature and solar radiation variations and suggested that delaying the sowing date could stabilize and improve rice yield and resource use efficiency in central China. A similar study has been reported in India that the delay of the sowing date increased the amount of dry matter and nitrogen uptake at anthesis, which increased the grain yield of rice [21]. Overall, adjusting the sowing date to synchronize crop growth stages with optimal climate factors appears to be a practical and eco–friendly approach to maintaining high grain yield, while mitigating negative climate impacts. Therefore, it is important to adjust the original rice sowing date in order to make better use of climatic factors and avoid the occurrence of extreme events that cause yield decline. From 2018 to 2021, a four–year field experiment was conducted with different rice sowing dates, and the responses of rice growth and variations in climate resources were synchronously observed to investigate the most suitable sowing date.

2. Materials and Methods

2.1. Experimental Site and Design

Field experiments were conducted from 2018 to 2021 at the Jingzhou Agrometeorological Experiment Station (30°21′ N, 112°09′ E), Hubei Province, China. The experimental site is located in the center of Jianghan plain, which has a subtropical monsoon climate with annual precipitation of 1100–1300 mm and a mean annual temperature of 15.9–16.6 °C. The soil is classified as gleyic paddy soil after years of rice cultivation, with a medium loam texture, and the soil nutrient characteristics are shown in Table 1. The main meteorological elements for 2018 to 2021 were collected from Jingzhou agrometeorological experiment station.

Table 1. Soil nutrient characteristics in the experiment field.

Total nitrogen 2.18 g/kg	Total phosphorus 0.49 g/kg	Total potassium 3.49 g/kg
Alkali hydrolyzed nitrogen 78.4 mg/kg	Available phosphorus 59.4 mg/kg	Available potassium 132.4 mg/kg
Electrical conductivity 2.2 mS/cm	pH 7.2	Organic matter 26.7 g/kg

The rice variety of Fengliangyouxiang 1 (FLYX 1) was chosen owing to its high quality and high yield. It is one of the most ordinary hybrid rice varieties planted in central China. The detailed sowing and transplanting dates for each year are shown in Table 2. Treatments were arranged in a randomized complete block design with four replicates, each area is 20 m^2 (4 m $\times$ 5 m). For rice seedlings with different sowing dates, Pre–germinated seeds were sown in a seedbed. Thirty–day–old seedlings were transplanted to the field, Transplanting was conducted at a hill spacing of 20 cm $\times$ 18 cm with two seedlings per hill. N fertilizer was applied at the basal, tillering, and panicle initiation stages in a ratio of 5:2:3: 90, 36, and 54 kg N ha^{-1} respectively. Phosphorus (80 kg ha^{-1}) was applied and incorporated into all subplots on the day before transplantation. Potassium (100 kg ha^{-1}) was split equally between the basal and panicle initiation stages. The N, P, and K sources were urea, calcium superphosphate, and potassium chloride, respectively. Crop management followed the standard cultural practices.

Table 2. Sowing dates and dates of crop growth stages from 2018 to 2021.

Year	Treatment Code	Sowing Date	Transplanting Date	Jointing Date	Heading Date	Maturity Date
2018	SD1	21 April	26 May	1 July	20 July	28 August
	SD2	6 May	11 June	16 July	5 August	12 September
	SD3	16 May	21 June	25 July	14 August	28 September
	SD4	26 May	1 July	4 August	24 August	9 October
2019	SD1	21 April	26 May	1 July	30 July	9 September
	SD2	6 May	10 June	12 July	8 August	18 September
	SD3	16 May	20 June	22 July	18 August	30 September
	SD4	26 May	30 June	30 July	29 August	15 October
2020	SD1	26 April	27 May	3 July	28 July	3 September
	SD2	6 May	8 June	7 July	6 August	10 September
	SD3	16 May	13 June	15 July	14 August	18 September
	SD4	26 May	24 June	30 July	28 August	1 October
2021	SD1	26 April	25 May	6 July	4 August	4 September
	SD2	11 May	9 June	17 July	14 August	14 September
	SD3	21 May	19 June	24 July	24 August	23 September
	SD4	31 May	29 June	6 August	1 September	8 October

Note: SD1 is 15 days earlier than the normal sowing date, and due to the COVID–19 pandemic, it was only 10 days earlier in 2020. SD2 is the normal sowing date. SD3 is 10 days later than SD2. SD4 is 20 days later than SD2.

2.2. Plant Sampling and Analysis

At the jointing, heading, and maturity stage, aboveground biomass was measured. Twenty–five representative plants were taken from each plot at each sowing date, and plant samples were first dried in an oven at 105 °C for 30 min, then dried at 70 °C to constant weight, and weighted to obtain aboveground biomass. At maturity stage, panicle number, spikelet number per panicle, spikelet fertility, and 1000–grain weight were measured in the fifth plot. The whole samples were collected, and divided into four parts as replications, for grain yield and panicle number (excluding plants at plot borders). Two planting pits of rice plants were chosen to observe spikelet number per panicle, filled and empty grains to calculate the spikelet fertility (seed setting rate, %) and 1000–grain weight.

The dry matter accumulation rate (DMAR, kg·ha^{-1}·d^{-1}) at different growth stages of rice was calculated by Formula (1).

$$\text{DMAR} = (W_b - W_a)/D \tag{1}$$

where W_b is the dry matter weight of the next growth period, W_a is the dry matter weight of the previous period, and D is the duration of a growth period of rice (days).

2.3. Thermal Resource

The net effective accumulated temperature (A_{en}), hot accumulated temperature (H_{ht}) and cold accumulated temperature (H_{ct}) were analyzed at the jointing to heading (J–H), heading to maturity (H–M), and whole growing stage in each sowing date, respectively. The stages of J–H and H–M were regarded to be the most critical for kernel setting in this study. A_{en} was calculated by accumulating mean daily temperature between 12 °C (B, biological zero point) and 27 °C (B_h, biological upper limit temperature). Usually, there are different temperature thresholds at different growth stages of rice. In light of agricultural practice in Jianghan Plain, Hubei, China. This study adopted the high–temperature threshold as 30 °C at J–H stage and 28 °C at H–M stage, and the low temperature threshold as 20 °C at the two stages. The hot accumulated temperature (H_{ht}) was calculated by accumulating mean daily temperature above 30 °C during J–H and 28 °C during H–M [10], while the cold accumulated temperature (H_{ct}) was calculated by the accumulating mean daily temperature above 20 °C [8]. A_{en}, H_{ht}, and H_{ct} are calculated by the following formulas.

$$A_{en} = \sum(T - B) - (T - B_h) \tag{2}$$

$$H_{ht} = \sum(T - 30(\text{or } 28)) \tag{3}$$

$$H_{ct} = \sum(T - 20) \tag{4}$$

where A_{en} is the net effective accumulated temperature, T is average temperature, B is biological zero point, B_h is biological upper limit temperature, H_{ht} is the hot accumulated temperature, and H_{ct} is the cold accumulated temperature. In Formula (2), while $T \leq B$, then $T - B = 0$; similarly, while $T \leq B_h$, then $T - B_h = 0$.

2.4. Statistics Analysis

The data were analyzed using the statistical program Excel 2019 and SPSS 23.0. Data are presented as mean ± standard error. A one–way analysis of variance (ANOVA), followed by LSD (Least Significant Difference) test was used to compare different factors among four sowing dates. The changing trend of climate variables at different sowing dates was determined by correlation analysis between climate variables and the days of the year in which each sowing date was located. Regression analysis was used to determine the relationship between grain yield components and effective accumulated temperature or harmful accumulated temperature.

3. Results

3.1. Grain Yield and Yield Components

In the four–year experiment, the grain yield was 7382.1 to 10,693.9 kg·ha^{-1} evenly, the year with the lowest grain yield was 2020, which may be due to higher rainfall year within 2020. Grain yield increased with sowing date delay in all four years, and slightly decreased in SD4. Compared with SD1, the four–year average yield of SD2, SD3, and SD4 increased by 7.6%, 15.5%, and 12.7%, respectively. The yield of SD3 and SD4 was more than that in SD2 and increased by 5.6~8.6% (Table 3). This indicated that proper delay of the sowing date is beneficial in increasing rice yield.

Table 3. Grain yield and its components under different sowing dates.

Year	Sowing Date	Panicle Number m^{-2}	Spikelet Number Panicle^{-1}	Spikelet Fertility %	1000–Grain Weight g	Grain Yield kg·ha^{-1}
2018	SD1	217.3 ± 4.4c	200.7 ± 2.7c	83.1 ± 1.6b	24.6 ± 0.2b	9152.8 ± 244.7c
	SD2	257.1 ± 5.2b	219.0 ± 4.9c	82.2 ± 0.7b	24.9 ± 0.1a	10,547.9 ± 262.8b
	SD3	292.4 ± 6.0a	251.5 ± 5.8a	89.6 ± 1.6a	25.3 ± 0.2a	11,790.1 ± 567.1a
	SD4	233.7 ± 4.8b	236.4 ± 4.4b	87.7 ± 2.2a	25.1 ± 0.1a	11,284.8 ± 172.1a
2019	SD1	181.6 ± 2.2c	240.7 ± 10.3b	77.5 ± 1.4b	24.4 ± 0.1b	9716.0 ± 16.7b
	SD2	191.3 ± 1.2b	239.2 ± 1.4b	86.0 ± 0.3a	24.0 ± 0.1b	9765.5 ± 118.5b
	SD3	202.6 ± 2.7a	276.7 ± 6.8a	86.7 ± 1.2a	25.5 ± 0.1a	10,578.5 ± 59.9a
	SD4	190.0 ± 2.3b	244.9 ± 6.2b	91.5 ± 0.3a	25.4 ± 0.2a	10,449.5 ± 90.5a
2020	SD1	140.1 ± 2.9b	216.5 ± 10.8b	83.4 ± 0.3b	25.4 ± 0.5c	6857.3 ± 218.3b
	SD2	147.6 ± 3.5b	216.4 ± 1.4b	85.4 ± 0.8b	25.9 ± 0.6b	7179.0 ± 221.7b
	SD3	157.2 ± 0.9a	247.6 ± 10.6a	90.0 ± 0.7a	26.7 ± 0.4a	7990.9 ± 415.4a
	SD4	144.1 ± 3.7b	238.7 ± 7.7a	87.8 ± 1.1b	26.2 ± 0.3b	7501.3 ± 303.3b
2021	SD1	201.7 ± 5.9b	212.3 ± 10.3b	87.3 ± 0.6b	26.8 ± 0.1a	8813.4 ± 294.4b
	SD2	205.5 ± 3.5b	215.9 ± 1.4b	91.2 ± 0.7a	26.8 ± 0.1a	9876.1 ± 162.4b
	SD3	224.6 ± 3.7a	229.6 ± 6.8a	91.1 ± 0.9a	27.0 ± 0.1a	10,519.6 ± 581.9a
	SD4	202.1 ± 5.1b	219.7 ± 6.2b	89.4 ± 1.0a	26.9 ± 0.1a	10,346.8 ± 420.9a

Note: Data in the table are mean ± standard error. Lower cases after numerical values express the significance of the difference in LSD test ($p < 0.05$).

Among the yield components, SD3 almost had the most panicle number, spikelet number, spikelet fertility, and 1000–grain weight, and these were primarily influenced by climatic variables during J–H and H–M stages, respectively. There were significant differences between sowing dates in spikelet number per panicle and spikelet fertility rate in sowing dates, and the significance in spikelet fertility and 1000–grain weight were not obvious. The yield components of SD3 and SD4 were both greater than SD2.

3.2. Dry Matter Accumulation Rate (DMAR)

During the four–year field experiment, the Dry matter accumulation rate (DMAR) at different sowing dates increased rapidly at first and then decreased (Figure 1). The DMAR of SD2 and SD3 were generally larger than that of SD1 and SD4, and the maximum DMAR in J–H and H–M stages both occurred in SD3, except for the J–H stage in 2019, with high reproducibility of the four–year experiment. Compared with SD1, the DMAR of SD4 was usually larger, except for 2019. DMAR of SD3 differed significantly from other sowing dates ($p < 0.05$) in both J–H and H–M stage. Compared with SD2 (normal sowing date), DMAR of SD1 and SD4 decreased by 51.7% and 2.4% in J–H, and increased by 19.9% at that of SD3. Similarly in H–M, the DMAR of SD1 and SD4 decreased by 12.8% and 3.6% compared with SD2 and increased by 8.7% evenly at that of SD3.

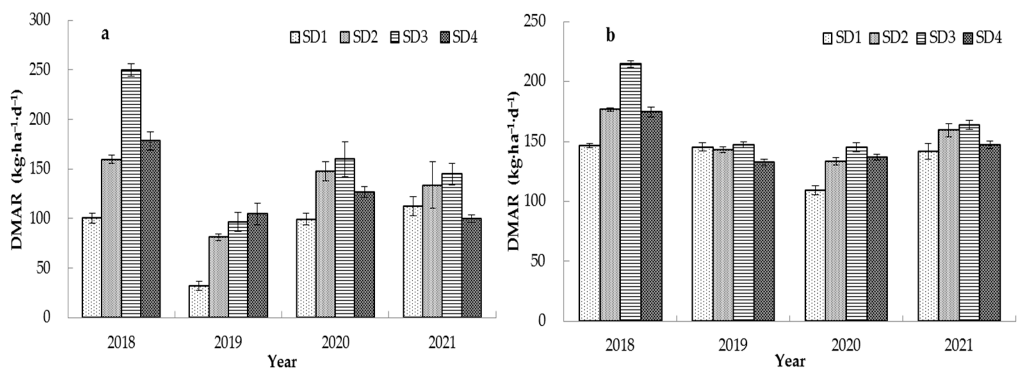

Figure 1. DMAR of different sowing dates from 2018 to 2021. (**a**) J–H stage, (**b**) H–M stage.

The error bars represent the standard error. Different letters on the error bars express the significance of the difference of the LSD test at $p < 0.05$).

3.3. Thermal Resource

The monthly precipitation and temperature of the rice growing stage from 2018 to 2021 were shown in Figure 2. In the four years, July and August were the hottest months, which were the stage of heat stress in rice. Late September and October were the stages of low temperature after flowering. The total precipitation of the rice growing stage in 2018, 2019 and 2021 was 652.9 mm, 647.2 mm, and 712.0 mm, respectively, but in 2020, it was 70% higher than the average of the other three years, reached 1141.6 mm. The variation in monthly precipitation was relatively large too. Generally, there was more precipitation in the early stage of rice growth (April–July), and less in the later stage (August–October). But in 2020, the monthly precipitation in September and October were still very high, occurred an autumn flood.

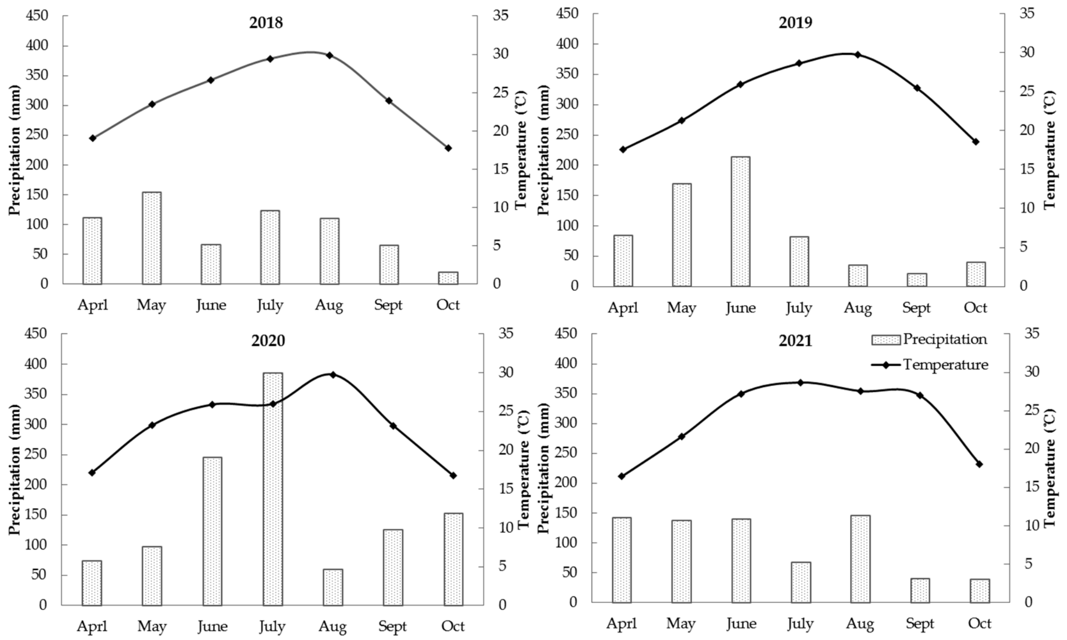

Figure 2. Monthly precipitation and temperature from 2018 to 2021.

Thermal resources differ greatly at different sowing dates (Figure 3). Heat stress and low temperature after flowering generally occurred during the jointing to maturity stage, which had the greatest impact on grain yield. The H_{ht} and H_{ct} in the J–H and H–M stage of 16 sowing dates were shown in Figure 3a,b. In the J–H stage, the variation in H_{ht} was generally between 0–20 °C·d, and there was no obvious regularity of increasing or decreasing with the postponement of the sowing date. But in the H–M stage, the downward trend was very obvious, and they had the same performance in four years of experiments. Therefore, delaying the sowing date could significantly reduce the heat stress. On the contrary, low temperatures after flowering only occurred in the H–M stage. From 2018 to 2021, low temperature after flowering occurred every year in SD4, and in SD3 of 2018, the highest H_{ct} could reach to 20 °C·d, which means that the low temperature after flowering could not be ignored while delaying the sowing date.

The A_{en} that removing H_{ht} and H_{ct} can objectively evaluate the thermal resource during rice growth. In Figure 3c, it was shown that, appropriately delaying the sowing date increased the thermal resource of rice growth, especially the beneficial portion of the heat that promotes rice growth. Among them, The A_{en} of SD4 was the highest, followed by SD4.

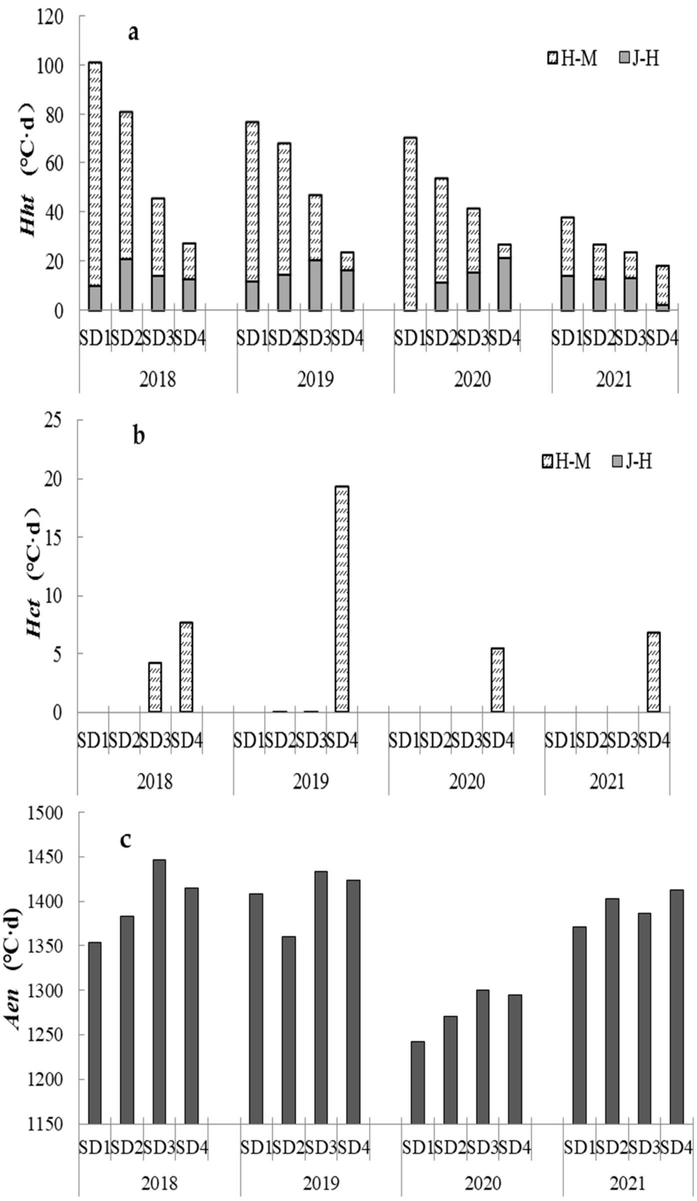

Figure 3. H_{ht}, H_{ct}, and A_{en} of different sowing dates from 2018 to 2021. (**a**) H_{ht} at J–H and H–M stage; (**b**) H_{ct} at J–H and H–M stage; (**c**) A_{en} at the whole stages.

3.4. Relationship between Grain Yield and Thermal Resource

The regression method was used to examine the relationship between rice yield (DMAR, grain yield, panicle number, spikelet number, spikelet fertility, and 1000–grain weight) and heat qualification (A_{en}, $H_{ht,}$ and H_{ct}) in the four–year experiment (Figure 4). The results revealed that, heat qualification, especially heat qualification in J–H and H–M stages, was closely related to the biomass and grain yield. Among them, A_{en} had the promoting effect on DMAR, grain yield, panicle number, and spikelet number, and H_{ht} had the inhibition effect on spikelet fertility and 1000–grain weight. Due to the lower frequency and intensity of low temperature after flowering, compared to heat stress, there was no significant regression significance of negative effect between H_{ct} and grain yield.

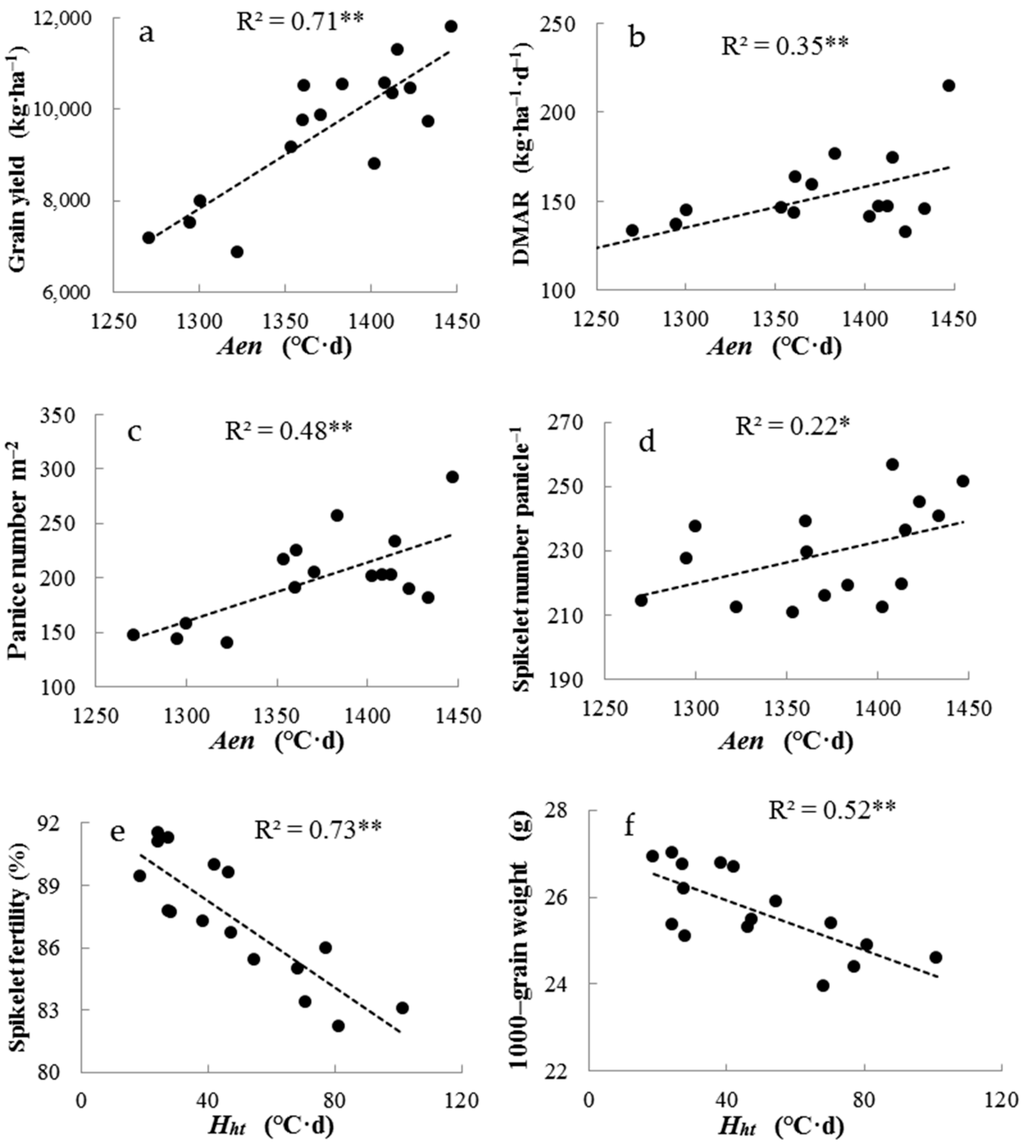

Figure 4. Relationship between A_{en} and grain yield (**a**), DMAR (**b**), panicle number (**c**) and spikelet number (**d**), and the relationship between H_{ht} and spikelet fertility (**e**) and 1000–grain weight (**f**) in different sowing dates from 2018 to 2021. * and ** indicate significance of the difference at $p < 0.05$ and $p < 0.01$, respectively. R^2 represents the determination coefficient of this regression equation.

4. Discussion

Rice (*Oryza sativa* L.) is mainly planted in tropical and subtropical regions with sufficient rainfall, where temperature stress, especially heat stress, is the main factor threatening rice production [22]. Moore estimated that global warming is exclusively responsible for 4.2% yield loss in rice during 1961–2017 [23], and this is expected to worsen by the end of the 21st century under continuous warming [24]. Alam estimated that an increase in temperature of 1 °C causes a reduction in paddy yield of between 3.44% and 0.03% according to the season [25]. Our four–year experiment has also confirmed that, compared to the average temperature of 28.1 °C during the rice growing season, rice yield was 1.2% lower than that of 27.4 °C. In central China, for double–season rice, cold stress mainly occurred during the vegetative period of early rice and the reproductive period of late rice [26,27]; but for single–season rice, it mainly occurred after flowering, and the impact on rice is much smaller than heat stress. In our experiment, cold stress often occurred in SD3 and SD4, but did not occur in SD1 and SD2. In the future, climate change is most likely towards increasing heat stress and decreasing cold stress [24], cold stress could be reduced to a small intensity but heat stress would be getting severer [28]. Therefore, adaptations are urgently needed to minimize the latent negative effects of rice heat stress in central China.

The sensitivity to heat stress varies greatly among different stages of rice. The optimal temperature in the tillering stage was 28.4 °C, which was highest than that in other stages [8]. At the flowering and grain filling stage, 21.7 to 26.7 °C of average temperature is optimal for grain filling, while higher than 27 °C would lead to a reduction of grain yield due to a decrease in grain weight [29]. Matsui observed that high temperatures (>35 °C) during flowering would cause sterility in rice spikelets, decrease florets fertility, and negatively affect rice reproductive growth [30,31]. A similar study in central China indicated that, when the average daily temperature in the vegetative stage exceeded 26.0 °C, and it was lower than 27 °C in the grain–filling stage, the actual grain yields were higher than average [32]. In our study, we used 30 °C during the J–H stage and 28 °C during the H–M stage. This is because considering that the current rice varieties have stronger high–temperature resistance.

DMAR is a sensitive index of heat stress. Previous research has shown that when the temperature exceeds the optimal growth temperature, it negatively affects the accumulation of dry matter [8]. An increase in the temperature significantly reduced dry matter accumulation, especially during the panicle initiation and heading stages [33]. The anthesis and ripening stages of rice are the most temperature sensitive [8]. Our research found that, adequate heat during the concurrent vegetative–reproductive growth stage (J–H) and reproductive growth stage (H–M) can promote the accumulation of dry matter, but excessive heat stress is detrimental, mainly because it reduces the net photosynthetic rate and reduced carbon assimilation capacity [34] and enhances respiration [34].

Optimization of sowing dates is an important way to improve resource use efficiency and adapt to ongoing climate change [35]. In our study, with the delay of the sowing dates, the temperature from heading to the maturity stage decreased, whereas the relatively higher temperature would not be beneficial to grain yield, as excessive temperature may cause poor grain filling around the anthesis stage [8,36–38]. H_{ht} and H_{ct} may reflect the degree of heat stress and low temperature after flowering suffered by rice at different sowing dates. The possibility of heat stress to rice during the key growth stage decreased as the sowing date delayed, while the possibility of low temperature after flowering increased. It should be noted that, due to the impact of climate change, the cold stress in central China will continue to show a decreasing trend in the future, and the probability of low temperature after flowering will further decrease. Therefore, perhaps in the near future, the rice planting date in the region can be postponed even more.

Besides the impact of heat, waterlogging is another important climate factor that threatens rice production in central China. For example, in a four–year experiment, the rice yield in 2020 was 10% lower than the average yield in the other three years, which is 60.3–76.4% higher than the precipitation during the rice growing season. According to nationwide observations in China, rice yield reductions due to extreme rainfall were comparable to those induced by extreme heat over the last two decades, reaching 7.6 ± 0.9% [39]. In the future, yield penalties caused by waterlogging increase from 3–11% historically to 10–20% by 2080 [40]. Therefore, the risk of waterlogging must also be prevented in central China.

5. Conclusions

Our study found that delaying the sowing date of rice in the Jianghan plain can rationally use solar–thermal resources to achieve maximum rice productivity. Sowing rice in mid–May to late May could result in the highest yield. Abundant solar–thermal resources of the early growth stage increase the production potential, while avoiding heat stress during the flowering and maturity stages of rice. In light of climate change, the sowing date should be reasonably scheduled to allow rice to reach the anthesis and ripening stages under the best heat conditions, and then improve the efficiency of the photosynthetic substances production and heat–light resources utilization. As a result, low temperatures after flowering can be ignored in Jianghan plain under the suitable late sowing conditions (no later than late May) for rice. To offset the negative effects of climate change and ultimately achieve high and stable rice yield in central China, the sowing date and other management measures (e.g., breeding high–temperature resistant rice varieties, improving rice water and fertilizer management, etc.) should be comprehensively in the future.

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