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THE EFFECTS OF RISING TEMPERATURES ON PHENOLOGY AND PRODUCTIVITY OF RICE CROP IN CHINA- A REVIEW STUDY

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ABSTRACT: This review study explores the effects of rising temperatures on rice phenology and productivity in China-an issue of growing concern amid accelerating climate change. As one of the world's most essential staple crops, rice is particularly sensitive to temperature fluctuations, especially in regions where optimal growing conditions are being disrupted by warming trends. The primary aim of this review is to synthesize existing knowledge on how increasing temperatures influence the various developmental stages of rice-germination, tillering, flowering, and maturity and their cumulative impact on yield. Drawing on research conducted between 2015 and 2025, the paper highlights a clear correlation between elevated temperatures and shifts in rice phenology. Higher temperatures have been shown to speed up plant growth, shorten the vegetative stages, and trigger earlier flowering. However, heat stress during critical phases especially flowering and grain filling stages has a detrimental effect on yields. This impact is most pronounced in China's southern and eastern regions, where temperature increases are occurring more rapidly than in the north. The review also examines adaptation strategies aimed at mitigating these adverse effects. These include the development of heat-tolerant rice varieties, adjustments in sowing dates, improvements in irrigation infrastructure, and enhanced pest management practices. Despite progress, significant challenges remain, particularly in vulnerable areas where farmers have limited adaptive capacity. Furthermore, the study underscores the need for more region-specific and integrated research to better understand how temperature interacts with other environmental variables such as soil moisture, atmospheric CO_2 levels, and extreme weather events. These factors may compound the negative effects of heat on rice yield. In conclusion, while rising temperatures pose a serious threat to rice cultivation in China, science-based adaptation strategies supported by continued research and cooperative policymaking offer a viable pathway to sustaining rice production in the face of climate change.

Key words: Rice yield, global warming, China, heat stress, rice phenology, climate change.

INTRODUCTION

According to the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), the global average surface temperature increased by approximately 0.85°C between 1880 and 2012, with a noticeable upward trend continuing in recent decades. These climatic shifts have had widespread implications for global agricultural systems, raising growing concerns about the potential negative impacts of climate change on future crop productivity (**Pachauri and Meyer, 2014**).

China is the world's leading producer, consumer, and importer of rice, with over 80% of its population depending on this staple for daily nutrition (**Chen *et al*., 2017**). Ensuring high rice yields is therefore critical for maintaining both national and global food security. Between 2012 and 2016, China allocated the rice acreage has an average of 30.23 million hectares annually to rice cultivation, representing approximately

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26.9% of the global sown area of 112.45 million hectares. During the same period, the country produced an average of 205.9 million tons of rice annually, accounting for 33.9% of the global rice output (**Alexandratos and Bruinsma, 2012**). Notably, rice yield in China have doubled over the past three decades (**IPCC, 2013**), a trend that may be partially attributed to climatic factors such as temperature fluctuations and solar radiation (**Bongaarts, 2019**).

However, climate change poses a growing threat to rice production in China. According to the **China Climate Change Blue Book (2018)**, published by the China Meteorological Administration, China has experienced a 1.6°C rise in average surface temperature between 1951 and 2017 surpassing the global average for the same period. Additionally, the frequency and intensity of extreme weather events, including heat waves and cold spells, have increased. These climatic changes are likely to have more profound impacts on rice cultivation in China than in many other countries (**Tao and Zhang, 2013; Zhao *et al*., 2017**).

China's rice cultivation spans a wide geographic area, from the Yunnan-Guizhou Plateau to the eastern coastal delta, and from Heilongjiang's Mohe in the north to Hainan in the south. This extensive range leads to considerable spatial and temporal variation in the climatic conditions during the rice-growing season (**Tao *et al*., 2013; Chen *et al*., 2017**). Moreover, China employs diverse rice production systems—such as southern double-cropping rice (SD), Yangtze River Basin rice (YRB), medium-season rice (MR), and northern single-cropping rice covering nearly all global rice cultivation models. As a result, the effects of climate change on rice phenology and yield are expected to vary significantly depending on the specific cropping system and regional context (**Guo *et al*., 2020; Zhang *et al*., 2020)**.

Given the scale and complexity of rice production in China, as well as the accelerating pace of climate change, there is a pressing need to scientifically assess its potential impacts on rice growth and yield. Such assessments will help guide the development of targeted adaptation strategies and provide a theoretical foundation for ensuring long-term food security under changing climatic conditions.

Rising global temperatures are projected to shorten the duration of the rice growing season, while exposure to extreme heat during critical developmental stages—such as the tillering phase can induce physiological stress, ultimately leading to reduced grain yields (**Prasad *et al*., 2006**). In addition to temperature, other environmental factors such as solar radiation and atmospheric CO_2 concentrations also play a crucial role in influencing rice productivity (**Tao *et al*., 2013; Houma *et al*., 2021**). For instance, **Arunrat *et al*. (2022)** found that in the lower northern region of Thailand, rice yield in irrigated systems are expected to increase under the moderate emission scenario (SSP245). However, under the high emission scenario (SSP585), yields are projected to decline by 6.0% for the first rice crop and by 17.7% for the second crop in the mid- to long-term future. Similarly, in India, rice production is anticipated to increase under the low-emission scenario (RCP2.6) across most agro-ecological zones; however, these potential gains are likely to diminish over time, with climate change having a net negative effect on yields by the 2080s (**Gupta and Mishra, 2019**).

Chen *et al.* (2020) estimated that rice yield could decline by approximately 2.55% and 2.48% under the RCP4.5 and RCP8.5 climate scenarios, respectively, for the period between 2005 and 2050 compared to the baseline period of 1960 to 2004, even after considering the potential mitigating effect of CO_2 fertilization. In contrast, **Zhang *et al*. (2019)** suggested that future climate change may have a positive impact on rice yields in the Northeast China Plain. Furthermore, **Zhang *et al*. (2023)** reported divergent trends in southern China, where early rice yield was projected to increase while late rice yield was expected to decline. These studies collectively emphasize the pronounced regional variability in the response of rice production to climate change, reflecting how differing local climatic conditions can lead to heterogeneous effects on agricultural output.

Objectives

a. Examine the impact of rising temperatures on rice growth stages across various regions of China.

b. Evaluate the effects of temperature increase on rice yield including regional variations.

c. Review and recommend climate-resilient farming practices to mitigate the adverse effects of rising temperatures.

d. Summarize findings from previous studies on temperature-induced changes in rice phenology and productivity.

e. Analyze regional climatic differences in temperature impact and identify the most vulnerable areas for rice production.

Research Problems

a. Uncertain Temperature Thresholds for Rice Growth: Identifying exact temperature limits that significantly affect rice phenology and yield is challenging, as these thresholds vary by region, variety, and growth stage.

b. Limited Knowledge of Long-Term Temperature Trends: The cumulative effects of long-term temperature changes on rice cultivation remain unclear, requiring differentiation between short-term weather fluctuations and sustained climate shifts.

c. Regional Variability in Temperature Effects: Diverse geographic, soil, irrigation, and management conditions across China lead to varied impacts of rising temperatures on rice, complicating the formulation of universal conclusions.

d. Complex Interactions with Other Environmental Factors: The combined influence of temperature, precipitation, humidity, and CO_2 on rice productivity needs further investigation.

e. Insufficient Data on Extreme Heat Events: The effects of sudden, extreme temperature spikes during key rice growth stages are under-researched despite their potential significance.

Temporal, Spatial, and Thematic Limits of the Study

Temporal limits

a. Time Frame for Data: This review will focus on research and data collected up to 2025, emphasizing studies from the past decade (2015–2025) to ensure the most current insights.

b. Long-Term vs. Short-Term Effects: Both short-term impacts (such as annual weather variations) and long-term effects (including decadal trends and climate projections) of rising temperatures on rice productivity will be examined.

Spatial Limits

The study will primarily focus on rice growing regions within China, covering diverse climatic zones including: Temperate regions: Northeastern and Northern China, Subtropical regions: Southern and Southeastern China and Tropical regions: Southern areas such as Hainan Island. While the emphasis is on China, relevant comparative research from other major rice-producing countries may be included to provide broader context and insights.

Thematic Limits

a. Climate and Temperature Variables: The review will focus specifically on how rising temperatures influence rice growth, excluding other climate variables like precipitation, CO_2 concentration, or soil moisture, though these factors may be briefly considered in relation to temperature impacts.

b. Rice Phenology: The study will examine temperature effects on various growth stages of rice, such as germination, tillering, flowering, grains filling and maturity.

c. Rice Productivity: The review will explore changes in yield, both in terms of quantity and quality, due to increased temperature levels, including the occurrence of heat stress and its implications on grain development and overall productivity.

Methodology

Study area

The research area encompasses the main rice cultivation regions across 18 provinces and municipalities in China (Fig. 1), which represent over 95% of the nation’s total rice farming area (**NBCS, 2022**). This vast cultivation zone stretches from tropical regions near 18°N latitude to as far north as 50°N. According to **Wang *et al.* (2015),** the area is divided into five distinct rice eco-regions based on climate, cropping patterns, and geographical characteristics.

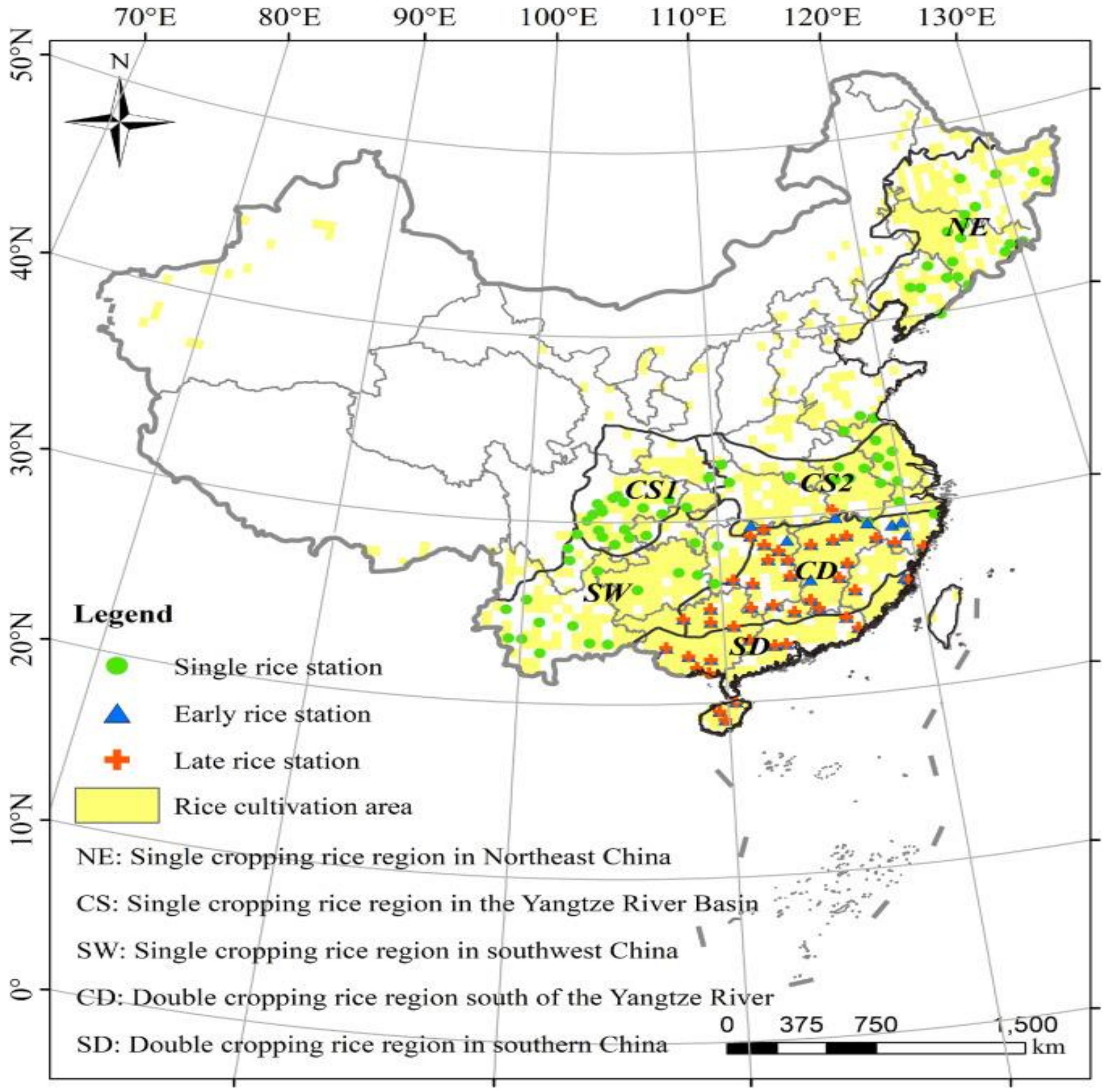

Fig. 1. Spatial distribution of rice cultivation and agri-meteorological stations in mainland of China

These include

The single-cropping rice region in Northeast China (NE); the single-cropping rice region in the Yangtze River Basin (CS), further split into CS1 (Sichuan Basin subregion in the upper reaches) and CS2 (middle-lower reaches plain subregion); the single-cropping rice region in Southwest China (SW); the double-cropping rice region south of the Yangtze River (CD); and the double-cropping rice region in southern China (SD). The favorable hydrothermal conditions in the double-cropping regions enable the cultivation of both early and late rice varieties within the same field annually.

Background Temperature and Warming Trends in Typical Rice Cultivation Systems in China

Rice cultivation in China is primarily divided into three systems: single cropping in the northern region, especially in Northeast China; medium cropping in the middle and lower Yangtze River basin; and double cropping in southern China. These systems experience markedly different climatic conditions. Based on temperature data from 1980 to 2015 (**Chen *et al*., 2020),** the recorded maximum, average, and minimum daily temperatures were 23.0°C, 18.3°C , and 13.6°C respectively, with warming rates of 0.31°C, 0.34°C, and 0.36°C per decade. Additionally, the maximum, average, and minimum temperatures were 28.0°C, 23.65°C , and 19.3°C, with corresponding warming trends of 0.29°C, 0.39°C, and 0.32°C per decade. For early rice (ER), the background temperatures averaged 23.3°C (maximum), 27.7°C (average), and 20.0°C (minimum), each rising at rates close to 0.28–0.29°C per decade.

For late rice (LR), the background temperatures were 26.3°C (average), 30.7°C (maximum), and 22.6°C (minimum), with air temperature increases of approximately 0.25°C per decade across these measures. As shown in Fig. 2, temperatures during the rice growing season have risen significantly across all three cropping systems. In southern China, the background temperatures for MR and early rice (ER) are similar. However, the post-anthesis background temperature for first-season rice in Northeast China is considerably lower than that for double rice (DR) and LR, and much lower than for MR and ER. These pronounced differences in background temperatures and warming rates across cropping systems contribute to varied climate change impacts on each system.

Response Characteristics of the Growing Season of Rice and Elevation of Yield at Temperature

Recent field warming experiments have been conducted in key rice growing regions of China to better understand the effects of increased temperatures. Between 2016 and 2020, a warming experiment took place in Harbin, Heilongjiang Province, representing the single-cropping rice system of northern China. In 2008, a nighttime warming study was carried out in Nanjing, Jiangsu Province, focusing on medium-cropping rice under both flooded and drought conditions. Additionally, from 2007 to 2011, nighttime warming experiments were conducted in Nanchang, Jiangxi, examining dual-cropping rice in southern China. These studies have provided valuable insights into the responses and adaptations of different rice growth stages and yield under varying cropping systems (**Dong *et al*., 2011; Chen *et al*., 2017; Rehmani *et al*., 2021**).

The findings showed that a 1.5°C rise in temperature significantly shortened the growth period from sowing to heading and flowering stages, while the grain-filling period for double-season rice in Heilongjiang and Nanchang was extended. Overall, although higher temperatures shortened the growth stages duration of rice. Moreover, the reproductive phase before flowering was reduced, whereas the post-flowering reproductive phase generally remained stable or did not lengthen. Similar phenological trends have been reported in long-term field studies (**Tao *et al*., 2013**).

Years of field warming studies have shown varied effects of temperature increases on rice productivity across different cropping systems (**Deng *et al*., 2017**). In Harbin, a 1.5°C temperature rise significantly boosted both biological and grain yields for single-cropping rice. In contrast, yields decreased for MR in Nanjing, while in Nanchang's double-cropping rice (DCR) system, ER yields declined and LR yield increased. Analysis of regional multi-year sowing experiments suggests that rice yield is mainly influenced by the background temperature after flowering. Higher temperatures can notably increase rice leaf area, promoting dry matter accumulation and yield formation (**Yang *et al*., 2019**).

Consequently, in regions with higher post-anthesis background temperatures, such as MR in Nanjing and early rice (ER) in Nanchang's double-cropping system, a 1.5°C temperature increase makes panicle differentiation and flowering more susceptible to heat stress. This results in lower grains setting rates and fewer grains per panicle, ultimately reducing yields. Conversely, in cooler regions like LR in Harbin's single cropping system and DR in Nanchang, the same temperature rise can increase the number of effective panicles and grains per panicle, leading to higher yield (**Chen *et al*., 2017**).

Similar warming effects have been observed through extensive site-based evaluations across China's three rice cropping systems, supported by provincial statistical data. Long-term site tests showed that a 1.0°C increase in average temperature during the rice-growing season led to a 15.3% yield increase per unit area for single cropping rice in Northeast China. However, in moderately flooded and arid regions, yield declined by 10.9%. In southern China, yield for early and late rice increased by 6.7% and 12.1%, respectively. Provincial statistics confirmed these

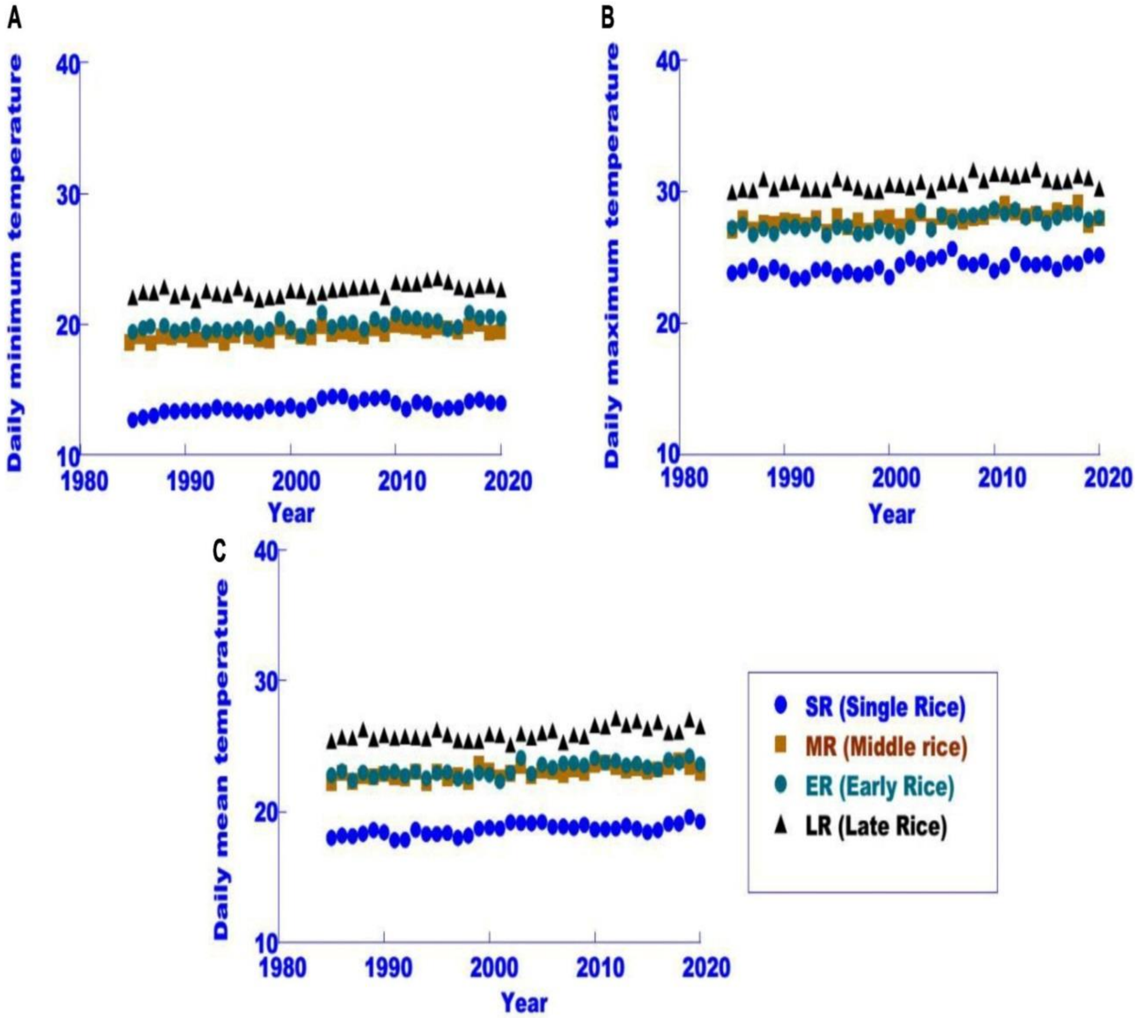

Fig. 2. Daily minimum temperature (A), maximum temperature (B), and average temperature (C) of the rice growing season in the main rice-growing regions of China during 1980–2020 (modified from Deng *et al*., 2019)

trends, reporting a 3.8% rise in single rice yields in Northeast China and a 0.6% increase for double rice under flood and drought conditions. In southern China, early and late rice yield increased by 3.7% and 8.9%, respectively. Overall, while rice yield in China's cropping systems show both positive and negative responses to warming, they have generally remained stable (**Jiang *et al*., 2021**).

Characteristics of Rice Quality Response to Climate Change

As demand for better quality of life rises, so does the need for high-quality rice. Temperature fluctuations significantly impact rice quality, particularly affecting amylose and protein levels, which are most sensitive to warming (**Siddik *et al*., 2019**). Higher temperatures reduce amylose content, enlarge starch grain size, and increase protein content. These changes make rice more fragile during processing, reduce the milling yield of brown rice, and increase grain chalkiness, negatively affecting visual quality (**Siddik *et al*., 2019**). Moreover, temperature rises alter the nutritional quality by affecting starch, storage proteins, and fatty acids. Elevated temperatures also increase rice starch's peak viscosity, hot slurry viscosity, final viscosity, disintegration value, and gelatinization temperature, while diminishing flavor quality (**Dou *et al*., 2018**).

Previous studies have shown that elevated temperatures during the rice growth period affect grain formation. Climate change disrupts rice growth dynamics, causing extreme temperature events during critical stages and altering their timing and duration (**Zhou *et al*., 2021**). An artificial climate chamber experiment (**Siddik *et al*., 2019**) identified the second week after heading as a crucial period when temperature strongly influences rice quality, with increases in gelatinization temperature and protein content, and a decrease in amylose content.

Rehmani *et al*. (2014) and Chen *et al*. (2016) conducted open-field heating experiments showing that heating after flowering reduced the visual quality of both early and late rice varieties. However, it improved the processing quality of LR and modestly enhanced the nutritional quality of both ER and LR by increasing protein content. The negative effects of extreme temperatures on rice quality mainly result from irreversible disruptions in grain filling and material accumulation during this critical phase. When average daily temperatures exceed 33°C during grain filling, both yield and quality suffer (**Siddik *et al*., 2019**). Extremely low temperatures during this stage also negatively impact rice quality. Overall, climate change tends to harm rice quality more than benefit it, emphasizing the urgent need to develop and promote adaptive rice cultivation strategies.

Impacts of Anticipated Climate Change on Rice Cultivation

Beneficial effects on rice cultivation

During the 1930s, 1950s, and 1970s, the average daily temperature during China's rice growing season was recorded as being 0.8–2.7°C, 1.7–3.4°C, and 2.3–4.1°C higher, respectively, than the temperatures observed in the early 2000s (**Lv *et al*., 2018**). The northern boundary for potential double and triple rice harvests is expected to keep moving further north, with the area suitable for triple cropping projected to reach up to 75% of the total planting area by the end of the 21st century (**Yang *et al*., 2015**). Similarly, the zones suitable for single and double cropping are also expected to shift northward. Compared to the period from 1961 to 1990, the areas suitable for single and double-cropping rice are predicted to expand by approximately 500,000 hectares and 6.2 million hectares, respectively, by the 2080s. This increase in heat availability is likely to lengthen the rice growing season and improve flexibility, enabling better adaptation strategies for climate-resilient rice production.

Negative effects on rice production

The IPCC Fifth Assessment Report highlights that climate change and extreme weather events often negatively affect crop yield (**Pachauri and Meyer, 2014**). Future temperature increases of 1–3°C are projected to almost certainly shorten the rice growing period in China (**Tao *et al*., 2008**). Specifically, with rises of 1.5°C and 2.0°C, the growth period for Drought-Resistant Rice (DCR) is expected to decrease by 4–8% and 6–10%, respectively, while Short-Cycle Rice (SCR) may experience about a 2% reduction (**Chen *et al*., 2018**). Studies combining crop models, statistical analyses, and observational data estimate that a 1% increase in temperature could lead to a 3.2% average decrease in global rice production (Zhao *et al*., 2017). By the end of the 21st century, continued warming is expected to reduce global rice production by 3.4% to 10.9%.

In China, future climate change impacts on rice yield are projected to range from a 40.2% decrease to a 6.2% increase, with an average decline of 10.6%, indicating notable spatial variation. Elevated CO_2 levels may partially offset yield losses caused by climate change; however, this compensation might not fully counterbalance the adverse effects of high temperatures in some regions and scenarios. Additionally, increased fluctuations in precipitation and temperature could lead to more frequent low-yield years (**Xiong *et al*., 2009**).

Effects of Climate Change on Rice Phenology and Yield

Numerous studies have shown that climate change significantly affects agricultural productivity (**Gupta and Mishra, 2019; Houma *et al*., 2021**). Rising temperatures generally speed up crop development, shortening the growth duration (**Asseng *et al*., 2015**).

This study indicates that rising temperatures will cause rice to flower and mature earlier, with the most significant reduction in the growing season anticipated in northeastern and certain southwestern regions of China, likely attributable to their relatively cooler climates.

These findings align with previous studies (**Tao *et al*., 2013**). A multi-model ensemble indicates that future climate change will likely reduce rice yields across most regions in China, even when accounting for CO_2 fertilization benefits.

The expected decline in rice production is mainly due to a shorter growing season that reduces photosynthetic accumulation rates, heat stress impairing photosynthesis beyond optimal temperatures, and increased plant respiratory losses. The greatest yield decreases around 10% under the SSP585 scenario are projected for central China's Yangtze River lower reaches (CS2) and southern late rice cropping areas, supporting (**Zhan *et al*., 2023**). Since temperatures in the southern region already exceed optimal levels for rice growth during the baseline period, further warming poses a serious threat to rice cultivation there.

Adjusting sowing dates is an effective adaptation strategy (**Minoli *et al*., 2022**), as it can improve water use efficiency, crop growth, and resilience to climate variability. In the CS2 and southern late rice regions, shifting sowing to cooler periods during the growing season is recommended to optimize growing conditions. Additionally, introducing heat-tolerant rice varieties in these vulnerable areas can help mitigate the impacts of extreme heat. Conversely, climate change has had positive effects in some regions such as the high latitude Northeast (NE), elevated southwestern areas (SW), and certain early rice siteswhere historically low temperatures have been alleviated, reducing cold stress and boosting yield (**Zhan *et al*., 2023**). These areas may offer opportunities to expand rice cultivation, helping secure future rice supplies.

Siddik *et al*. (2019) emphasized that extreme temperatures negatively affect photosynthesis, chlorophyll fluorescence, and dry matter accumulation, thereby reducing both rice yield and quality. The study found that Heat Stress Degree Days (HKDD) and Warm Spell Duration Index (WSDI) significantly limited yield in most regions. While the overall rise in mean growing season temperature benefited rice production in Northeast China (NE) (**Pu *et al*., 2020**), increased HKDD had a detrimental effect, likely because NE historically experienced fewer extreme heat events and current rice varieties lack sufficient heat tolerance. Thus, introducing heat-resistant varieties is essential. Beyond temperature, solar radiation (Srad) and CO_2 levels also significantly influenced rice yield variability, consistent with previous research (**Chen *et al*., 2020**). **Deng *et al*. (2015)** observed a negative correlation between solar radiation and yield. Vapor Pressure Deficit (VPD) had minimal impact in southeastern China due to adequate rainfall and irrigation, but yield in NE and Southwest (SW) was sensitive to VPD increases. The atmospheric and topographical conditions in these areas cause uneven or low precipitation, increasing drought vulnerability. Higher VPD further stresses water availability, underscoring the need to improve irrigation management during key growth stages in NE and SW to balance water supply and demand.

Responses of Different Rice Cropping Systems to Climate Change

Climate change affects single and double rice cropping systems differently. **Saud *et al.* (2022)** found that warming impacts vary due to differences in baseline temperatures and warming magnitude across systems. Focusing on the Yangtze River regions (CS and CD), which host both single and double cropping at similar latitudes, res ults showed a greater decrease in the average duration of the active planting period (ADAP) and the main development active period (MDAP) for single rice cropping system compared to double rice cropping system, supporting (**Lv *et al*., 2018**). This is likely because single rice cropping system has a longer growing season, making it more susceptible to seasonal climate variability and resulting in larger yield reductions. However, **Ding *et al*. (2019)** observed that the growing season shortened most markedly for early rice in the middle and lower Yangtze River regions compared to other rice types.

Climate change has a greater negative impact on late rice yield compared to early rice, even when accounting for CO_2 fertilization effects (**Zhang *et al*., 2023**). This is mainly due to a larger reduction in days to flowering and a smaller decrease in grain-filling duration for early rice relative to late rice. Studies show that grain-filling rate negatively correlates with its duration (**Yang *et al*., 2008**).

In contrast, the grain-filling and maturation stages of late rice are more vulnerable to higher temperatures, increasing the risk of heat stress and further reducing yields. As a result, early rice yields are expected to be more stable under future climate change compared to late rice. To mitigate these challenges, it is recommended to promote early rice cultivation and expand its planting area. Additionally, advancing the sowing date for early rice and delaying it for late rice can help optimize growing conditions.

REFERENCES

Alexandratos, N., and Bruinsma, J. (2012). World Agriculture Towards 2030 / 2050: The 2012 Revision ESA Working Paper. Rome: FAO.

Arunrat, N., N. Pumijumnong, S. Sereenonchai, U. Chareonwong and Wang C. (2020). Assessment of climate change impact on rice yield and water footprint of large-scale and individual farming in Thailand. Sci. Total Environ., 726 , Article 137864

Asseng, S., Foster I.A.N. and Turner, N.C. (2011). The impact of temperature variability on wheat yields. Glob. Change Biol., 17 (2, pp. 997-1012

Bongaarts, J. (2019). Intergovernmental panel on climate change special report on global warming of 1.5°C, Switzerland: IPCC, 2018. Popul. Dev. Rev. 45, 251–252. doi: 10.1111/ padr.12234

Chen X. , Wang L. , Niu Z. , Zhang M. , Li C. and Li J. (2020). The effects of projected climate change and extreme climate on maize and rice in the Yangtze River Basin, China. Agric. For. Meteorol. , Article 107867

Chen, J.L., Wilson, C.R., Tapley, B.D., Scanlon, B. and Guntner, A. (2016). Long-term groundwater storage change in Victoria, Australia from satellite gravity and in situ observations. *Glob. Planet. Change* 139, 56–65.

Chen, J., Tang, L., Shi, P., Yang, B., Sun, T. and Cao, W., (2017). Effects of short-term high temperature on grain quality and starch granules of rice (*Oryza sativa* L.) at post-anthesis stage. Protoplasma 254, 935–943. doi: 10.1007/s00709-016-1002-y

Chen, X., Cui, Z., Fan, M., Vitousek, P., Zhao, M., Ma, W. and Zhang, F. (2018). Sustainable development of food production in China: Challenges and potential solutions. *Global Food Security*, 17, 48–56. https:// doi.org/10.1016/j.gfs.2018.04.002

Deng, A. X., Chen, C. Q., Feng, J., Chen, J., and Zhang, W. (2019). Cropping system innovation for coping with climatic warming in China. *Crop J.* 5, 136–150. doi: 10.1016/ j.cj.2016.06.015

Ding,Y. , Wang W. , Song R. , Shao Q. , Jiao X. , and Xing W. (2017). Modeling spatial and temporal variability of the impact of climate change on rice irrigation water requirements in the middle and lower reaches of the Yangtze River, China.Agric. Water Manage., 193 , pp. 89-101

Dong, W. J., Chen, J., Zhang, B., Tian, Y., and Zhang, W. (2011). Responses of biomass growth and grain yield of midseason rice to the anticipated warming with FATI facility in east China. *Field Crops Res.* 123, 259–265. doi: 10.1016/j.eja.2014.12.008

Dou, Y., Lv, X., Chen, H., Xu, H., Zhang, Y., and Wang, M. (2018). Effects of high temperature during grain filling on rice starch properties and eating quality. *Food Chemistry*, 245, 412–418. https://doi.org /10.1016 /j.foodchem.2017.10.096

Guo, Y., Wu, W., Liu, Y., Wu, Z., Geng, X. and Zhang, Y.,(2020). Impacts of Climate and Phenology on the Yields of Early Mature Rice in China. Sustainability 12:10133. doi: 10.3390/su122310133

Gupta R. and Mishra A. (2019). Climate change induced impact and uncertainty of rice yield of agro-ecological zones of India. Agric. Syst., 173 , pp. 1-11

Houma A.A. , Kamal M.R. , Mojid M.A. , Abdullah A.F.B. and Wayayok A. (2021). Climate change impacts on rice yield of a large-scale irrigation scheme in Malaysia. Agric. Water Manage., 252 , Article 106908

IPCC (2013). Climate change 2013: the physical science basis," in Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, eds T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, *et al.* (Cambridge: Cambridge University Press), 1535.

Jiang, P., Xu, F., Zhang, L., Liu, M., Xiong, H., and Guo, X. (2021). Grain yield and N use efficiency of direct-seeded rice under different N management practices aimed to reduce N input. *Arch. Agron. Soil Sci.* 67, 1578–1590. doi: 10.1080/03650340.2020. 1800643

Long X.-X. , H. Ju, J.-D. Wang, S.-H. Gong, G.-Y. Li (2022).Impact of climate change on wheat yield and quality in the Yellow River Basin under RCP8.5 during 2020–2050.Adv. Clim. Chang. Res., 13 (3) , pp. 397-407

Lv Z. , Zhu Y. , Liu X. , Ye H. , Tian Y. and Li, F. (2018). Climate change impacts on regional rice production in China. Clim. Change, 147 (3–4) , pp. 523-537

Ministry of Ecology and Environment of the People's Republic of China. (2018). China Climate Change Blue Book (2018): Annual Report on China's Policies and Actions on Climate Change. Beijing: China Environmental Science Press.

Minoli, S., Kumar, A., and Singh, R. (2022). Adaptive agricultural practices to enhance water use efficiency under climate variability. Agricultural Water Management, 265, 107537. https://doi.org/10.1016/j.agwat.2022.107537

NBCS (2022). China Statistical Yearbook. China Statistics Press, Beijing

Pachauri, R.K. and Meyer, L.A. (2014). Climate Change 2014: Synthesis Report," in Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, (Geneva, Switzerland: IPCC), 1–151.

Pu, L., Cai, X., Zhang, G., and Liu, Q. (2020). Impacts of climate warming on rice yield and heat stress in Northeast China. Agricultural and Forest Meteorology, 280, 107814. https://doi.org/10.1016/j.agrformet.2019.107814

Prasad P.V.V. , K.J. Boote, L.H. Allen, J.E. and Sheehy, J.M.G. (2006). Thomas Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. Field Crop. Res., 95 (2–3) pp. 398-411

Rehmani, M.I.A., Ding, C., Li, G., Ata-Ul-Karim, S. T., Hadifa, A., and Bashir, M. A., (2021). Vulnerability of rice production to temperature extremes during rice reproductive stage in Yangtze River Valley, China. Journal of King Saud University. *Science* 33:101599. doi: 10.1016/j.jksus.2021.101599

Rehmani, M. I. A., Wei, G., Hussain, N., Ding, C., Li, G. and Liu, Z., (2014). Yield and quality responses of two indica rice hybrids to post-anthesis asymmetric day and night open-field warming in lower reaches of Yangtze River delta. *Field Crops Res.* 156, 231–241. doi: 10.1016/j.fcr.2013.09.019

Saud S, Wang D, Fahad S, Alharby HF, Bamagoos AA, Mjrashi A, Alabdallah NM, AlZahrani SS, AbdElgawad H, Adnan M, Sayyed RZ, Ali S and Hassan S (2022) Comprehensive Impacts of Climate Change on Rice Production and Adaptive Strategies in China. Front. Microbiol. 13:926059. doi: 10.3389/fmicb.2022.926059

Siddik, M. A., Zhang, J., Chen, J., Qian, H., Jiang, Y., Raheem, A. K., (2019). Responses of indica rice yield and quality to extreme high and low temperatures during the reproductive period. *Eur. J. Agron.* 106, 30–38. doi: 10.1016/j.eja.2019.03.004

Tao F.L., Zhang Z. , Shi W.J. , Liu Y.J. , Xiao D.P. , S. Zhang, Z. Zhu, M. Wang and Liu F.S. (2013). Single rice growth period was prolonged by cultivars shifts, but yield was damaged by climate change during 1981–2009 in China, and late rice was just opposite. Glob. Change Biol., 19 (10) , pp. 3200-3209

Tao, F.L. and Zhang, Z. (2013). Climate change, high-temperature stress, rice productivity, and water use in eastern China: a new superensemble-based probabilistic projection. J. Appl. Meteorol. Clim. 52, 531–551. doi: 10.1175/JAMC-D-12-0100.1

Wang P., Zhang Z. , Chen Y., Wei X. , Feng B. and Tao F. (2015). How much yield loss has been caused by extreme temperature stress to the irrigated rice production in China?. Clim. Change, 134 (4) , pp. 635-650

Xiong, W., Lin, E., Ju, H., and Xu, Y. (2009). Climate change and critical thresholds in China's food security. Climatic Change, 93 (3–4), 445–456. https://doi.org/10.1007/s 10584-008-9508-4

Yang W. , Peng S. , Dionisio-Sese M.L. , Laza R.C. and Visperas R.M. (2008).Grain filling duration, a crucial determinant of genotypic variation of grain yield in field-grown tropical irrigated rice. Field Crops Res., 105 (3) , pp. 221-227

Yang, T. T., Zeng, Y. H., Sun, Y. N., Zhang, J., Tan, X. and Zeng, Y., (2019). Experimental warming reduces fertilizer nitrogen use efficiency in a double rice cropping system. Plant Soil Environ., 65: 483–489. doi: 10. 17221/315/2019-PSE

Yang, X., Lin, E., Ma, S., Ju, H., Guo, L., Xiong, W. and Xu, Y. (2015). Potential impacts of climate change on cropping systems in China. Agricultural and Forest Meteorology, 203, 61–74. https://doi.org/10. 1016 /j.agrformet.2014.12.003

Zhan P., Zhu W. , Zhang T. and Li N. (2023). Regional inequalities of future climate change impact on rice (*Oryza sativa* L.) yield in China. Sci. Total Environ., 898 , Article 165495

Zhang, H., Zhou, G.S., Liu, D.L., Wang, B., Xiao, D.P. and He L. (2019). Climate-associated rice yield change in the Northeast China Plain: a simulation analysis based on CMIP5 multi-model ensemble projection. Sci. Total Environ., 666 , pp. 126-138

Zhang Z. , Li Y. , Chen X. , Wang Y. , Niu B. , Liu D.L. , He J. , Pulatov B. , Hassan I. and Meng Q. (2023). Impact of climate change and planting date shifts on growth and yields of double cropping rice in southeastern China in future. Agric. Syst., 05 , Article 103581

Zhang, Z., Yang, Z., Fahad, S., Zhang, T., Xu, W. and Cui, K., (2020). A hot-blast warming facility for simulating global warming in low-stature crop systems and its application case to assess elevated temperature effects on rice in Central China. *Plant Methods* 16:57. doi: 10.1186/s13007-020-00598-1

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B. and Huang, Y., (2017). Temperature increase reduces global yields of major crops in four independent estimates. Proc. Natl. Acad. Sci. U. S. A. 114, 9326–9331. doi: 10.1073/pnas.1701762114

Zhou, Y., Xu, L., Xu, Y., Xi, M., Tu, D. and Chen, J., (2021). A meta-analysis of the effects of global warming on rice and wheat yields in a rice–wheat rotation system. Food Energy Sec., 10:e316. doi: 10.1002/fes3.316.

آثار ارتفاع درجات الحرارة على فينولوجيا وانتاجية محصول الأرز في الصين – دراسة مرجعية

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تستهدف الدراسة المرجعية تأثير ارتفاع درجات الحرارة على فينولوجيا وانتاجية محصول الأرز في الصين، الناجم عن تغير المناخ. يُعد الأرز، باعتباره أحد أهم المحاصيل الأساسية، شديد الحساسية لتغيرات درجات الحرارة، لا سيما في مناطق زراعته والتي تتغير فيها ظروف النمو المثلى نتيجةً الاحتباس الحراري. كان الهدف الرئيسي من هذه الدراسة المرجعية هو تجميع معلومات حول كيفية تأثير ارتفاع درجات الحرارة على مراحل نمو الأرز المختلفة (الإنبات، التفريع، الإزهار، والنضج) وعلى إنتاجيته الأرز. سلطت هذه الدراسة الضوء على أهم النتائج للدراسات التي أُجريت على مدى العقد الماضي (2015-2025) والتي تؤكد على وجود علاقة وثيقة بين ارتفاع درجات الحرارة وتغير فينولوجيا الأرز. وقد ثبت أن ارتفاع درجات الحرارة يُسرّع النمو، ويُقلل من مراحل النمو الخضري، ويُسبب إزهارًا مبكرًا. ومع ذلك، فإن الإجهاد الحراري خلال المراحل الحساسة في الأرز، وخاصةً الإزهار وامتلاء الحبوب، يؤدي إلى انخفاض محصول الأرز. ويكون هذا التأثير شديدًا بشكل خاص في المناطق الجنوبية والشرقية من الصين. بالإضافة إلى ذلك، أظهرت الدراسة الحالية كيف يُمكن استخدام استراتيجيات التكيف مع تغير المناخ، مثل زراعة أصناف أرز متحملة للحرارة، تغيير مواعيد الزراعة، تحسين أنظمة الري، ممارسات مكافحة الآفات والتي يمكن أن تُساعد في التخفيف من هذه الآثار السلبية. ورغم الجهود المبذولة، لا تزال هناك تحديات في تكيف زراعة الأرز مع ارتفاع درجات الحرارة، لا سيما في المناطق الأكثر عُرضة للتغيرات المناخية. وأشارت الدراسة الراهنة أيضًا إلى الحاجة إلى أبحاث أكثر شمولاً ومخصصة لكل منطقة لفهم كيفية تفاعل درجات الحرارة مع العوامل البيئية الأخرى، مثل رطوبة التربة، ومستويات ثاني أكسيد الكربون، والظواهر الجوية الشاذة، والتي قد تُفاقم الآثار السلبية على إنتاج الأرز. يجب أن تُركّز الأبحاث المُستقبلية على تطوير نماذج أكثر تحديدًا لكل منطقة لفهم التأثير الشامل لتغيرات درجات الحرارة على إنتاجية الأرز، بما في ذلك تفاعلاتها مع العوامل البيئية الأخرى. ويتعيّن على واضعي السياسات والمزارعين العمل بشكل تعاوني لتنفيذ استراتيجيات تكيّفية لحماية إنتاج الأرز في مواجهة ارتفاع درجات الحرارة. وفي الختام، ورغم أن ارتفاع درجات الحرارة في الصين يشكل تحديات كبيرة لزراعة الأرز، فإن استراتيجيات التكيف الاستباقية والقائمة على العلم، بدعم من البحث المستمر، يمكن أن تساعد في التخفيف من هذه المخاطر وضمان استدامة زراعة الأرز في العالم مستقبلياً.

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