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PHENOPHASIC CHANGES FOR RICE VARIETIES UNDER PROJECTED CLIMATE SCENARIOS IN KERALA

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ABSTRACT

Climate change is having significant and observable impacts on both ecosystems and livelihoods, particularly in agricultural regions like Kerala. This study utilized the GFDL CM3 climate model to project future climatic conditions under RCP 4.5 and RCP 8.5 scenarios, indicating a marked temperature increase across the region. By mid- to late-century, the northern zone is expected to experience a temperature rise of 4°C to 6°C, while the southern zone may see a rise of 2°C to 4°C under both scenarios. The implications of these temperature changes on rice phenophases were examined using the CERES-DSSAT model, calibrated with data from a split-plot design experiment involving two rice varieties (Jyothi and Jaya) and five planting dates. The study focused on three key phenophases: transplanting to panicle initiation, panicle initiation to anthesis, and anthesis to physiological maturity. The results showed that under projected future climate conditions, the duration from transplanting to panicle initiation for Jyothi reduced from 31-41 days (base period) to 29-31 days, and for Jaya from 38-51 days to 37-39 days. Additionally, the duration from panicle initiation to anthesis generally decreased, except in Idukki where it increased by 2-5 days. The period from anthesis to physiological maturity also shortened, dropping from 34-41 days to 31-33 days for both varieties. The consistent reduction in the total crop duration was linked to the projected temperature increases of 1°C to 6°C, with 1°C warming accelerating rice maturity by 4-6 days. These shortened crop durations could have adverse effects on rice production.

Keywords: CERES-DSSAT, Heat stress, Planting date, Temperature stress

Climate change represents an urgent global challenge, underpinned by a substantial body of evidence. Over the past three decades, the Earth has experienced a consistent increase in surface temperatures, a trend that stands in stark contrast to the climate patterns observed prior to 1850 (Stocker *et al.*, 2013). This warming has triggered a cascade of responses across the climate system, including shifts in precipitation patterns, glacial retreat, sea-level rise, and an increase in the frequency and intensity of extreme weather events (Stocker *et al.*, 2013; Hartmann *et al.*, 2013). Such transformations have profound and widespread implications for agriculture. Among the array of globally cultivated crops, rice holds particular significance due to its extensive role in food production and consumption. India, a major contributor to the global rice market, accounts for over 20% of the world's rice production, with a substantial share of this output being generated during the monsoon season (FAOSTAT, 2018). In the fiscal year 2022-23, India achieved a historic milestone by producing 135.75 million metric tons of rice, an increase from the 129.47 million metric tons recorded in the previous year and surpassing the five-year average of 120.39 million metric tons (Statista, 2024). In the state of Kerala, rice is a fundamental staple, covering approximately 7.62% of the total cultivated land. During the 2022-23 period, paddy cultivation in Kerala spanned 1.91 lakh hectares, yielding a total of 5.59 lakh tonnes, with a productivity rate of 2,884 kg per hectare. However, rice cultivation is particularly vulnerable to climate variability, and rising temperatures pose a significant threat to both its growth and yield.

The latest report by the Intergovernmental Panel on Climate Change (IPCC) highlights a significant rise in atmospheric carbon dioxide (CO_2) levels, reaching a record 419.3 parts per million (ppm), which represents a 50% increase compared to pre-industrial levels. This alarming trend is largely driven by human activities, including fossil fuel combustion and deforestation. The global mean climate is governed by its energy budget, a delicate equilibrium between the solar energy absorbed and the energy radiated back into space. As global temperatures rise from +1.5°C to +4°C above pre-industrial levels, extreme temperature events, particularly the hottest-day temperatures, are projected to intensify, especially in mid-latitude and semi-arid regions (IPCC, 2023). The composition of the atmosphere plays a pivotal role in maintaining this balance by influencing the radiative fluxes at the

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Earth's surface. Human-induced changes, such as the emission of greenhouse gases (GHGs), aerosols, and modifications to land use and land cover (LULC), have disrupted this balance, driving contemporary climate change (Krishnan *et al.*, 2020). Global Climate Models (GCMs) are indispensable tools for understanding climate change, as they simulate various greenhouse gas emission scenarios that help elucidate potential future climate patterns (Chou, 2014). These models simulate different pathways of radiative forcing through Representative Concentration Pathways (RCPs), specifically RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5, with radiative forcing values of 2.6, 4.5, 6, and 8.5 W/m^2, respectively. The outcomes of these simulations depend on the projected levels of greenhouse gas emissions in the coming decades (Zhai, 2019). In India, projections indicate a significant increase in mean surface air temperatures by the end of the 21st century (2070-2099). Under RCP 2.6, the temperature is expected to rise by 0.24-1.33°C, while under RCP 4.5, it could increase by 0.41-2.44°C, and under RCP 8.5, by 0.45-4.44°C (Sanjay *et al.*, 2020). Such temperature changes are poised to have detrimental impacts on livelihoods and ecosystems, possibly undermining recent technological advancements aimed at mitigating these effects. Scientific observations confirm that climate change is occurring globally, affecting all regions and components of the climate system. Since pre-industrial times, the global average surface temperature has increased by approximately 1°C due to anthropogenic forcing (Allen *et al.*, 2018).

Temperature is a critical environmental factor that governs the growth and development of crops (Slafer and Rawson, 1994). Consequently, the agricultural sector is particularly vulnerable to climate change, given its scale and sensitivity to weather patterns, leading to significant economic repercussions (Mendelsohn, 2009). Challinor *et al.* (2014) noted that if both temperate and tropical regions experience a warming of 2°C, the combined production of staple crops such as wheat, rice, and maize is likely to decline. Rice, in particular, requires optimal temperature conditions between 20°C and 40°C, and temperature extremes can adversely affect its growth and yield. Yoshida *et al.* (1981) emphasized that rice production in tropical regions is highly sensitive to climatic changes. Studies have also shown that higher temperatures result in a reduced growing season for rice, ultimately leading to yield reductions (Matthews *et al.*, 1997; Ullah, 2017). This paper aims to assess the impact of projected climate change scenarios, specifically RCP 4.5 and RCP 8.5, on the duration of rice cultivation.

MATERIALS AND METHODS

Study area

Kerala, located in the southwest region of India, spans between 8°18' and 12°48' N latitude and 74°52' and 77°22' E longitude. Covering a total geographical area of 38,863 sq. km (Ajithkumar, 2015), the state is administratively divided into 14 districts. For the purpose of this study, weather data from each district were analyzed, and the entire state was categorized into five distinct agro-climatic zones: the Northern zone, Central zone, High-range zone, Problematic zone, and Southern zone (Plate 1). The Northern zone comprises the districts of Kasargod, Kannur, Kozhikode, and Malappuram. The Central zone includes the districts of Palakkad, Thrissur, and Ernakulam. The Problematic zone encompasses Alappuzha and Kottayam. The High-range zone is represented by the districts of Wayanad and Idukki, while the Southern zone consists of Thiruvananthapuram, Kollam, and Pathanamthitta. Notably, Wayanad district was excluded from the analysis due to the absence of rice cultivation during the *virippu* (*kharif*) season.

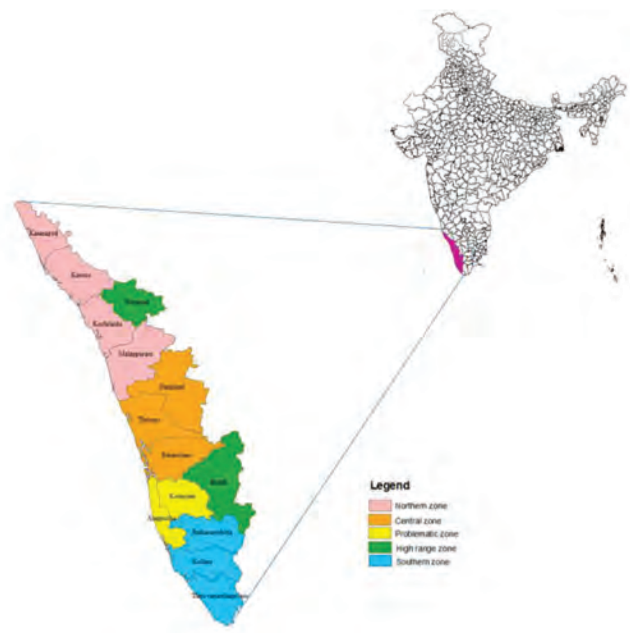

Plate 1. Study area: Kerala

Weather data

To assess climate change in Kerala, gridded data were collected from the India Meteorological Department (IMD) for all 13 districts from 1980 to 2020, specifically focusing on the *kharif* rice planting period. The weather parameters analyzed included solar radiation, rainfall, maximum temperature, and minimum temperature. To project future climate changes in Kerala, two climate scenarios were utilized: RCP 4.5

(a stabilization pathway) and RCP 8.5 (a high emission pathway), as outlined in the Intergovernmental Panel on Climate Change's fifth assessment report (AR5). Under the RCP 4.5 scenario, greenhouse gas emissions are expected to peak around 2040, followed by a decline, representing a trajectory often described as the "stabilization pathway." In contrast, the RCP 8.5 scenario assumes a continuous increase in emissions throughout the 21st century, defining it as a "high emission pathway" (van Vuuren *et al.*, 2011). These pathways offer valuable insights into the range of future climate scenarios, contingent on global greenhouse gas management, which is why both RCPs were selected for this study. Future climate conditions were projected using data from various Global Climate Models (GCMs), including CCSM4, HadCM2, and GFDL CM3. Among these, the GFDL CM3 model was deemed the most accurate for Kerala following bias correction, as demonstrated by Venkat (2017). The GFDL CM3, developed by the Geophysical Fluid Dynamics Laboratory, is a coupled general circulation model that integrates the atmosphere, ocean, land surface, and sea ice. This model was specifically designed to address complex climate change challenges, such as aerosol-cloud interactions, climate-chemistry dynamics, and stratosphere-troposphere coupling (Donner, 2011). This study compared the baseline period (1980-2020) with projected future climate simulations for the mid-century (2021-2050) and end-of-century (2051-2080) periods across the 13 districts of Kerala.

Table 1. Geographical coordinates of districts in Kerala

Sr. No.	District	Latitude	Longitude
1	Thiruvananthapuram	8.61	77.02
2	Kollam	8.96	76.88
3	Pathanamthitta	9.28	76.93
4	Alappuzha	9.42	76.45
5	Kottayam	9.64	76.65
6	Idukki	9.88	77.03
7	Eranakulam	10.06	76.47
8	Thrissur	10.47	76.32
9	Palakkad	10.79	76.56
10	Malappuram	11.13	76.16
11	Kozhikode	11.48	75.83
12	Kannur	12.00	75.53
13	Kasaragode	12.46	75.15
14	Wayanad	11.71	76.10

Experimental data

The experiment was conducted during the 2020 *kharif* season and involved five distinct planting dates and two rice varieties: Jaya and Jyothi. Jaya is a medium-duration variety with a growth period of 130 days and is a cross between *Taichung (Native) 1* and *T-141*. It is typically cultivated under irrigated conditions across India during both the *kharif* and *rabi* seasons. In contrast, Jyothi is a short-duration variety with a growth period of 110-115 days and is well-adapted to wetlands, making it suitable for year-round cultivation in Kerala. Jyothi was developed through a cross between *PTB-10* and *IR 8*. The experimental design employed was a split-plot design, where the main plot treatment consisted of five planting dates: June 5th, June 20th, July 5th, July 20th, and August 5th. The sub-plot treatment included the two rice varieties, Jaya and Jyothi, allowing for a comprehensive analysis of the interaction between planting dates and rice variety on crop growth and yield.

Crop simulation model

The DSSAT's CERES-Rice model was employed to investigate the impact of climate change on the duration of rice cultivation. This model was calibrated and evaluated using data collected from the field experiment. The CERES-Rice model is part of the Decision Support System for Agrotechnology Transfer (DSSAT), a comprehensive tool developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). DSSAT was created through collaboration among an international network of scientists to facilitate the application of crop models within an integrated system. The initial motivation for developing DSSAT was to combine information on soil properties, weather conditions, and crop management practices to enhance decision-making processes for transferring agricultural production technologies across regions with varying soil and climatic conditions (IBSNAT, 1993). Vysakh *et al.* (2016) demonstrated the application of the CERES-Rice model to simulate rice phenology and yield. They calibrated the model's genetic coefficients through 6000 iterations and validated its performance against field experimental data. The genetic coefficients used for simulating the phenophases are presented in Table 2.

The duration of rice growth was predicted using the calibrated genetic coefficients in the DSSAT CERES model, under climate change scenarios based on Representative Concentration Pathways (RCP) 4.5 and 8.5. This analysis was conducted for 13 districts in Kerala.

RESULTS AND DISCUSSION

Changes in maximum temperature during the *kharif* season

The analysis reveals that maximum temperatures are projected to increase substantially in future scenarios compared to the base period. Under the RCP 4.5 scenario, northern districts in Kerala, such as Kasargod,

Table 2. Genetic coefficients of Jyothi and Jaya varieties of rice

Variety	P1	P2R	P5	P2O	G1	G2	G3	G4	PHINT
Jaya	557.0	60.3	465.4	10.4	57.0	0.0286	1.10	1.10	81.0
Jyothi	551.0	22.3	444.0	11.4	50.4	0.0256	1.10	1.10	82.0

Kannur, Kozhikode, and Malappuram, are expected to experience a temperature rise of 4°C by mid-century, with further warming to 5°C by the end of the 21st century (Table 2). In the central districts of Palakkad, Thrissur, and Ernakulam, temperature increases of 3.5°C by mid-century and 4.5°C by the century's end are anticipated. In the problem area zone, comprising Alappuzha and Kottayam, temperature increases of 2°C and 3°C are projected by mid-century and the end of the 21st century, respectively. In contrast, the southern districts of Kollam, Pathanamthitta, and Thiruvananthapuram are expected to see a more modest temperature rise of 1-2°C under future scenarios. A unique pattern is anticipated in Idukki, where temperatures are expected to decrease by 0.9°C by mid-century, followed by a slight increase of 0.2°C by the end of the 21st century. Similarly, under the RCP 8.5 scenario, temperatures are projected to rise significantly across the state. By the end of the century, the northern zone may experience an increase of 6°C (Ajithkumar and Riya, 2022). In the central zone, a temperature increase of 5°C is expected, while the problem area zone may experience a 4°C warming. the northern and central zones of Kerala are expected to undergo more pronounced temperature changes compared to the southern zone (Table 3).

Changes in minimum temperature during the *kharif* season

The analysis indicates that minimum temperatures are projected to rise across Kerala, irrespective of the concentration pathways. Under the RCP 4.5 scenario, minimum temperatures in the northern and central zones are expected to increase by 6-7°C in future scenarios. In the problem area zones, a temperature rise of nearly 4°C is anticipated, while the southern zone is projected to experience a warming of 3-4°C. A similar pattern is observed under the RCP 8.5 scenario, with minimum temperatures expected to increase by approximately 7°C in the northern zone and by 5-6°C in the central zone. In the problem area zones, a temperature rise of nearly 5°C is predicted, while the southern zone may see a warming of 3-4°C. However, Idukki, which falls within the high-range zone, exhibits a distinct pattern. Under the RCP 4.5 scenario, the minimum temperature in Idukki is expected to decrease by 0.2°C by mid-century, followed by increases of 0.6°C and 1.6°C by the end of the 21st century under RCP 4.5 and RCP 8.5, respectively (Table 4). Overall, the model predicts an increase in minimum temperatures throughout Kerala, with the most significant warming expected in the northern and central zones, compared to the southern zone.

Table 3. Changes in maximum temperature during *kharif* season: Base period vs. future scenarios under RCP 4.5 and RCP 8.5

District	Base Period temperature (°C)	RCP 4.5		RCP 8.5	
		Mid-century temperature (°C)	End-century temperature (°C)	Mid-century temperature (°C)	End-century temperature (°C)
Kasargod	26.5	30.8(4.3)	31.7(5.2)	31.0(4.5)	33.0(6.5)
Kannur	26.6	31.0(4.4)	31.9(5.3)	31.2(4.6)	33.1(6.5)
Kozhikode	26.7	31.0(4.3)	31.9(5.2)	31.2(4.5)	33.2(6.5)
Malappuram	27.1	31.0(3.9)	32.0(4.9)	31.2(4.1)	33.3(6.2)
Palakkad	27.7	31.1(3.4)	32.1(4.4)	31.3(3.6)	32.2(4.5)
Thrissur	28.9	31.8(2.9)	32.9(4.0)	31.4(2.5)	33.1(4.2)
Ernakulam	28.6	30.5(1.9)	32.0(3.4)	31.3(2.7)	33.2(4.6)
Idukki	29.6	28.7(-0.9)	29.7(0.1)	28.9(-0.7)	31.1(1.5)
Alappuzha	29.4	31.0(1.6)	31.9(2.5)	31.2(1.8)	33.1(3.7)
Kottayam	29.4	31.3(1.9)	32.2(2.8)	31.5(2.1)	33.4(4.0)
Pathanamthitta	30.4	32.1(1.7)	33.0(2.6)	32.2(1.8)	34.4(4.0)
Kollam	30.7	31.2(0.5)	32.1(1.4)	31.4(0.7)	33.5(2.8)
Thiruvananthapuram	31.2	31.9(0.7)	32.8(1.6)	32.1(0.9)	33.1(1.9)

Table 4. Changes in minimum temperature during *kharif* season: Base period vs. future scenarios under RCP 4.5 and RCP 8.5

District	Base Period temperature (°C)	RCP 4.5		RCP 8.5	
		Mid-century temperature (°C)	End-century temperature (°C)	Mid-century temperature (°C)	End-century temperature (°C)
Kasargod	20.1	25.7(5.6)	26.3 (6.2)	25.8 (5.7)	27.3 (7.2)
Kannur	19.9	25.8(5.9)	26.4 (6.5)	25.9 (6.0)	27.4 (7.5)
Kozhikode	19.6	25.6(6.0)	26.3 (6.7)	25.7 (6.1)	27.3 (7.7)
Malappuram	19.6	25.4(5.8)	26.1(6.5)	25.5 (5.9)	27.1 (7.5)
Palakkad	20.2	25.5 (5.3)	26.2 (6.0)	25.6 (5.4)	27.2 (7.0)
Thrissur	22.2	25.6 (3.4)	26.3 (4.1)	25.8 (3.6)	27.3 (5.1)
Ernakulam	21.2	25.7 (4.5)	26.4 (5.2)	25.8 (4.6)	27.4 (6.2)
Idukki	22.0	21.8 (-0.2)	22.5 (0.5)	21.9 (-0.1)	23.7 (1.7)
Alappuzha	22.2	25.6 (3.4)	26.3 (4.1)	25.8 (3.6)	27.3 (5.1)
Kottayam	22.2	25.8 (3.6)	26.5 (4.3)	25.9 (3.7)	27.5 (5.3)
Pathanamthitta	23.0	25.9 (2.9)	26.7 (3.7)	26.1 (3.1)	27.8 (4.8)
Kollam	23.3	25.8 (2.5)	26.5 (3.2)	25.9 (2.6)	27.6 (4.3)
Thiruvananthapuram	23.8	26.3 (2.5)	27.0 (3.2)	26.4 (2.6)	28.0 (4.2)

Thus, both maximum and minimum temperatures are expected to rise during the southwest monsoon period in Kerala. Research by Nayak *et al.* (2022) suggests a warming trend of 3-5°C across India between 2051 and 2110, compared to the reference period of 1951-2010. This temperature increase is particularly pronounced under the RCP 8.5 scenario, as indicated by the study's findings. Similarly, Kaur and Kaur (2022) observed that temperature escalation is more significant under the RCP 8.5 scenario compared to the RCP 4.5 scenario, further supporting this trend.

Impact of increase in temperature on phenophase

The entire rice growing period was divided into three phenophases, with the duration of each phenophase presented in Tables 5 and 6. There was minimal variation in temperature between the RCP 4.5 and RCP 8.5 scenarios, which may explain the lack of significant differences in the duration of each phenophase under both RCPs.

Transplanting to panicle initiation

During the base period, the time required for panicle initiation in the Jyothi rice variety ranged from 31 to 41 days. The minimum and maximum temperatures during this period were between 19 to 23°C and 26 to 31°C, respectively. As temperatures are projected to rise in future scenarios, the duration for panicle initiation is expected to decrease. Under the RCP 4.5 scenario, maximum temperatures are forecast to increase by 0.3 to 4°C, and minimum temperatures by 2.2 to 5.6°C. As a result, the time required for panicle initiation is anticipated to shorten by 30 to 31 days by mid-century, and further decrease to 29 to 30 days by the end of the 21st century across all districts, except for Idukki. In Idukki, however, the time for panicle initiation is projected to increase by 2 days by mid-century, with no further change by the century's end. A similar trend is expected under the RCP 8.5 scenario. In Idukki, the time for panicle initiation is projected to decrease by 2 days by the end of the 21st century compared to the baseline period. For the rice variety Jaya, the base period showed a panicle initiation duration ranging from 36 to 51 days. In future scenarios, this duration is expected to decrease to 37 to 39 days by mid-century and 36 to 38 days by the end of the 21st century under both RCPs. These findings indicate a notable advancement in the time from transplanting to panicle initiation under future temperature increases, particularly in regions experiencing more pronounced warming. Similar results were reported by Das *et al.* (2020), who found that a 2-3°C temperature rise reduced the vegetative period by 10 days. This accelerated growth could have significant implications for rice crop management and timing, highlighting the need for adaptation strategies to address the challenges posed by changing climatic conditions.

Panicle initiation to anthesis

For the Jyothi rice variety, the period from panicle initiation to anthesis ranged from 32 to 40 days during the base period, with maximum and minimum temperatures between 27°C and 32°C. As temperatures are projected to rise in future scenarios (mid and end of

Table 5. Days to each phenophase of Jyothi under RCP 4.5 and 8.5: Base period and future projections

Districts	Base period			Mid century			End century		
RCP 4.5	**T- PI***	**PI-A**	**A-PM**	**T- PI**	**PI-A**	**A-PM**	**T- PI**	**PI-A**	**A-PM**
Kasargod (KSG)	41	40	42	31	32	33	30	31	33
Kannur (KNR)	41	40	42	31	32	32	30	31	33
Kozhikode (KZK)	41	40	43	31	32	32	30	31	32
Malappuram (MLP)	40	39	42	31	32	32	30	32	32
Palakkad (PLK)	39	38	41	31	32	32	30	31	33
Thrissur (TSR)	38	37	40	31	32	33	32	31	34
Ernakulam (EKM)	36	36	38	31	32	32	30	20	43
Idukki (IDK)	34	32	39	36	37	39	34	35	37
Alappuzha (ALP)	34	34	37	31	32	33	30	31	33
Kottayam (KTM)	34	33	37	30	31	33	29	31	32
Pathanamthitta (PTA)	33	33	36	30	31	32	29	31	32
Kollam (KLM)	32	32	36	30	31	32	29	31	31
Thiruvananthapuram (TVM)	31	32	34	30	31	32	29	30	31
RCP 8.5	**T- PI**	**PI-A**	**A-PM**	**T- PI**	**PI-A**	**A-PM**	**T- PI**	**PI-A**	**A-PM**
Kasargod (KSG)	41	40	41	34	32	34	29	31	33
Kannur (KNR)	41	40	41	31	32	32	29	31	32
Kozhikode (KZK)	41	40	42	31	32	32	29	31	32
Malappuram (MLP)	40	39	42	31	32	33	29	31	32
Palakkad (PLK)	39	38	41	31	32	33	29	31	33
Thrissur (TSR)	38	37	40	31	32	33	29	31	33
Ernakulam (EKM)	36	36	38	29	31	32	29	31	32
Idukki (IDK)03	34	32	39	36	36	38	32	40	29
Alappuzha (ALP)	34	34	36	31	31	32	29	24	38
Kottayam (KTM)	34	33	37	30	31	33	29	30	32
Pathanamthitta (PTA)	33	33	36	30	31	32	29	31	32
Kollam (KLM)	32	32	35	30	31	32	29	30	32
Thiruvananthapuram (TVM)	31	32	34	30	31	32	29	30	31

*T-PI: Transplanting to panicle initiation, PI- A: Panicle initiation to anthesis, A-PM: Anthesis to physiological maturity

the 21st century) under both RCPs, this growth stage is expected to shorten, with the duration reduced to 31 to 32 days. However, in the high-range zone of Idukki, an opposite trend is expected, where a temperature decrease of 1°C is projected. As a result, the duration from panicle initiation to anthesis, which was 32 days during the base period, is expected to increase to 35-40 days by mid and end-century under future climatic conditions. Similarly, for the Jaya rice variety, the base period showed the panicle initiation to anthesis duration ranging from 33 to 40 days. In future scenarios, this period is projected to decrease to 31-32 days, indicating a faster progression from panicle initiation to anthesis. In Idukki, however, the period from panicle initiation to anthesis is expected to increase from 34 days to 36-38 days under the projected climate scenarios. These findings highlight the complex and region-specific responses of rice growth stages to future climate changes, highlighting the need for localized adaptation strategies.

Anthesis to physiological maturity

The duration from anthesis to physiological maturity showed a significant negative correlation with temperature. This period was prolonged in both rice varieties in the northern zone, where temperatures are lower compared to the southern zone. In the northern zone, maximum temperatures ranged from 27°C to 29°C, while in the southern zone, they ranged from 28°C to 30°C. In Jyothi, this period ranged from 42 to 34 days, and in Jaya, it ranged from 43 to 36 days. Under future climate scenarios (mid and end of the 21st century) for

Table 6. Days to each phenophase of Jaya under RCP 4.5 and 8.5: Base period and future projections

Districts	Base period			Mid century			End century		
RCP 4.5	**T- PI***	**PI-A**	**A-PM**	**T- PI**	**PI-A**	**A-PM**	**T- PI**	**PI-A**	**A-PM**
Kasargod (KSG)	51	39	43	39	32	35	38	32	34
Kannur (KNR)	51	40	43	38	32	35	38	32	34
Kozhikode (KZK)	51	40	45	39	32	34	38	32	34
Malappuram (MLP)	49	40	45	39	32	35	38	32	33
Palakkad (PLK)	47	38	42	38	32	35	37	32	34
Thrissur (TSR)	39	38	41	38	32	35	37	32	34
Ernakulam (EKM)	44	36	40	38	32	35	37	32	33
Idukki (IDK)	43	34	39	45	38	40	42	36	40
Alappuzha (ALP)	42	34	39	38	32	34	37	32	33
Kottayam (KTM)	42	34	38	37	32	33	37	32	33
Pathanamthitta (PTA)	40	33	37	37	32	34	36	32	34
Kollam (KLM)	39	33	36	37	32	34	36	31	33
Thiruvananthapuram (TVM)	38	33	36	37	28	37	36	31	33
RCP 8.5	**T- PI**	**PI-A**	**A-PM**	**T- PI**	**PI-A**	**A-PM**	**T- PI**	**PI-A**	**A-PM**
Kasargod (KSG)	51	39	43	39	32	35	37	31	34
Kannur (KNR)	51	40	43	38	32	35	37	31	33
Kozhikode (KZK)	51	40	45	38	32	34	37	31	33
Malappuram (MLP)	49	40	45	39	33	34	37	32	34
Palakkad (PLK)	47	38	42	38	32	35	37	31	33
Thrissur (TSR)	39	38	41	38	32	35	36	31	34
Ernakulam (EKM)	44	36	40	38	32	35	36	31	33
Idukki (IDK)	43	34	39	44	37	41	40	35	37
Alappuzha (ALP)	42	34	39	38	32	34	36	31	34
Kottayam (KTM)	42	34	38	37	32	33	36	31	33
Pathanamthitta (PTA)	40	33	37	37	32	34	36	31	32
Kollam (KLM)	39	33	36	37	32	34	36	31	33
Thiruvananthapuram (TVM)	38	33	36	37	31	34	36	31	32

*T-PI: Transplanting to panicle initiation, PI- A: Panicle initiation to anthesis, A-PM: Anthesis to physiological maturity

both RCPs, the duration is projected to decrease to 31-33 days in Jyothi and 33-35 days in Jaya. In the future, under the RCP 4.5 scenario, the maximum and minimum temperatures are expected to increase by up to 3°C and 6°C, respectively, by mid-century. By the end of the century, the temperature increase is expected to follow a similar trend. Under the RCP 8.5 scenario, by the end of the century, the minimum temperature is projected to increase by 7°C, and the maximum temperature by 5°C. This rise in temperature is anticipated to accelerate the maturity process of rice, consistent with findings from Geethalakshmi *et al.* (2017) and Liu *et al.* (2017), which indicate that higher temperatures shorten the maturity period of rice. Notably, there was minimal difference in temperature between the RCP 4.5 and RCP 8.5 scenarios, which may explain the minimal variation in the duration of this growth stage under both scenarios.

4.3. Impact on the total duration of rice

To assess the impact of temperature increases on the total duration of rice growth, we examined the duration of two rice varieties, Jaya and Jyothi, during the base period and under simulated future climate scenarios. The duration of these varieties during the base period and in future conditions is presented in Tables 7 and 8, respectively. Our findings highlight the complex relationship between temperature and rice growth duration. The results are consistent with the conclusions of Saseendran *et al.* (2000) and Zhang *et al.* (2013), which emphasize the significant role of temperature fluctuations in crop maturation. It is essential to interpret these findings within the context of agricultural practices and climate change adaptation. These insights shed light on potential challenges for rice

Table 7. Changes in duration (days) of Jyothi under RCP 4.5 and 8.5: Base period vs. future scenarios

Districts	Base period	RCP 4.5		RCP 8.5	
		Mid-century	End of century	Mid-century	End of century
Kasargod (KSG)	122	96	94	96	92
Kannur (KNR)	122	95	94	95	92
Kozhikode (KZK)	124	95	94	95	92
Malappuram (MLP)	122	95	94	95	93
Palakkad (PLK)	117	95	95	95	92
Thrissur (TSR)	115	95	97	96	92
Ernakulam (EKM)	109	95	93	92	92
Idukki (IDK)	105	112	107	110	101
Alappuzha (ALP)	104	96	94	94	91
Kottayam (KTM)	104	94	92	94	91
Pathanamthitta (PTA)	101	93	92	93	91
Kollam (KLM)	99	93	91	93	91
Thiruvananthapuram (TVM)	97	93	91	92	90

Table 8. Changes in duration (days) of Jaya under RCP 4.5 and 8.5: Base period vs. future scenarios

Districts	Base period	RCP 4.5		RCP 8.5	
		Mid-century	End of century	Mid-century	End of century
Kasargod (KSG)	134	106	104	106	102
Kannur (KNR)	134	105	104	105	101
Kozhikode (KZK)	136	105	104	105	101
Malappuram (MLP)	134	106	103	105	102
Palakkad (PLK)	127	106	103	105	101
Thrissur (TSR)	117	105	103	105	101
Ernakulam (EKM)	120	105	102	104	100
Idukki (IDK)	115	123	118	122	111
Alappuzha (ALP)	115	104	102	103	101
Kottayam (KTM)	115	103	102	103	100
Pathanamthitta (PTA)	110	103	102	103	100
Kollam (KLM)	109	103	101	103	99
Thiruvananthapuram (TVM)	107	102	100	102	98

production and offer valuable information for developing strategies aimed at ensuring sustainable rice cultivation in a changing climate.

Focusing on the Jyothi rice variety, during the base period, the crop duration ranged from 97 to 124 days. However, future simulations project a contraction in this duration, reducing it to 90 to 100 days. In the northern zone (comprising Kasargod, Kannur, Kozhikode, and Malappuram), the crop duration initially ranged from 122 to 124 days but is expected to decrease to 95 days by mid-century. Under both the stabilization (RCP 4.5) and high-emission (RCP 8.5) scenarios, a temperature increase of 4.5°C is anticipated, further shortening the maturity period to 94 days under RCP 4.5 and 92 days under RCP 8.5 by the end of the century. In the central zone, Jyothi's crop duration is projected to decrease to 95 days in future simulations, with a more pronounced reduction to 92 days under the RCP 8.5 scenario by the century's end. In the southern and problem areas, a projected 2°C temperature rise is expected to reduce the crop duration from 100 days to 93 days by mid-century. By the end of the century, with a further 3°C increase, the duration is expected to shorten to 91 days. On the other hand, in the high-range zone, a reverse trend is predicted, with a slight temperature decrease of 0.8°C under RCP 4.5 and 0.6°C under RCP 8.5 by mid-century. This cooling effect is projected to extend the duration of Jyothi by approximately 7 days under both

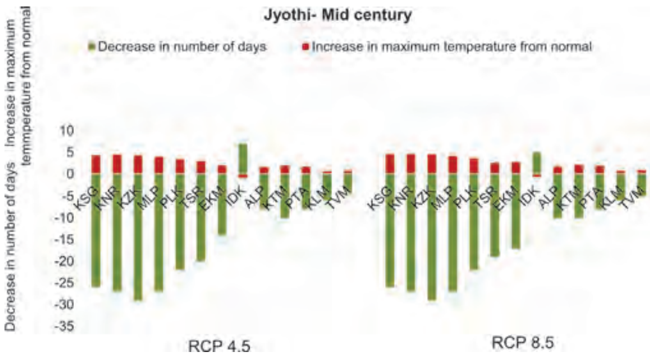

Fig. 1. Deviation from normal maximum temperature and changes in number of days from transplanting to maturity during mid-century in Jyothi

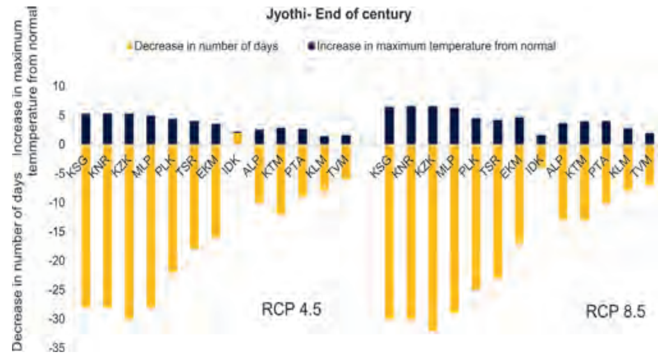

Fig. 2. Deviation from normal maximum temperature and changes in number of days from transplanting to maturity during end of the century in Jyothi

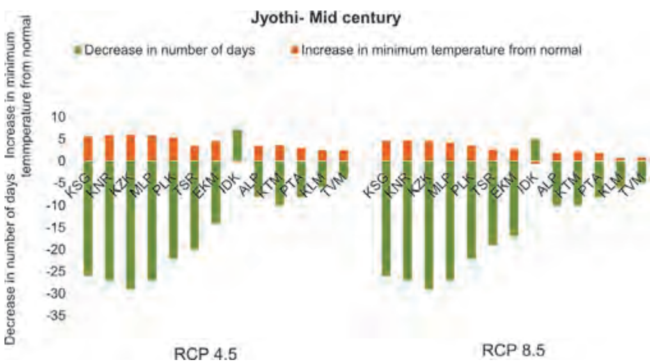

Fig. 3. Deviation from normal minimum temperature and changes number of days from transplanting to maturity during Mid-century in Jyothi

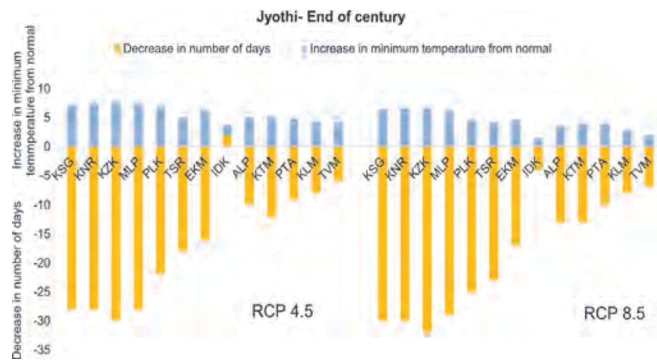

Fig. 4. Deviation from normal minimum temperature and changes in number of days from transplanting to maturity during mid-century in Jyothi

scenarios (Fig. 1 and 2). A clear negative correlation between temperature and crop duration is evident, as a mere 1°C increase in temperature accelerates maturity by 6-7 days. This observation aligns with Ziska *et al.* (1997), who found that a 4°C temperature rise led to faster rice crop maturation. Interestingly, seasonal variations also influence crop maturation: during dry seasons, maturity is hastened by six days, while in wet seasons, it is advanced by five days. This warming trend has significant implications for rice cultivation. Elevated temperatures shorten each phenological stage, leading to a decrease in overall crop duration (Ahmad *et al.*, 2019). Moreover, increased temperatures can reduce the grain-filling period, leading to incomplete grain filling and limited starch accumulation, which in turn reduces grain yield (Ren *et al.*, 2023).

Parallel outcomes were observed for the Jaya rice variety. The established duration for Jaya, ranging from 107 to 136 days, was notably shortened in future simulations, with the crop duration predicted to reduce to 90-100 days. During the base period, in the northern zone of Kerala, Jaya had a 134 day crop duration. However, by mid-century, this duration is expected to decline to 106 days under both the RCP 4.5 and RCP 8.5 scenarios, reflecting a 4°C temperature rise compared to the baseline. By the end of the century, the duration further contracts to 101-104 days, corresponding to a 5-6°C temperature increase. In the central zone, which includes districts like Palakkad and Thrissur, where temperatures are projected to rise by 3°C, the crop duration decreases from 120 days to 105-106 days. Similarly, in the Ernakulam district, a 2°C temperature increase is expected to reduce Jaya's duration from 120 to 105 days. By the end of the century, a 4°C temperature rise will further reduce Jaya's duration to 100 days. In the southern and problematic zones, the base period saw a duration of 110-115 days for Jaya, which is expected to decrease to 103 days by mid-century, due to a 2°C temperature increase. By the end of the century, with an additional 2-3°C rise in temperature, Jaya's maturity period is projected to shorten further to 100 days. On the other side, in the high-range zone, where a temperature decrease is expected, the crop duration of Jaya is projected to increase by 8 days under both RCP scenarios. However, under RCP 8.5, by the century's end, a projected 1.5°C temperature rise will result in a 4-day reduction in Jaya's duration compared to the baseline (Fig. 4 and 5). It is important

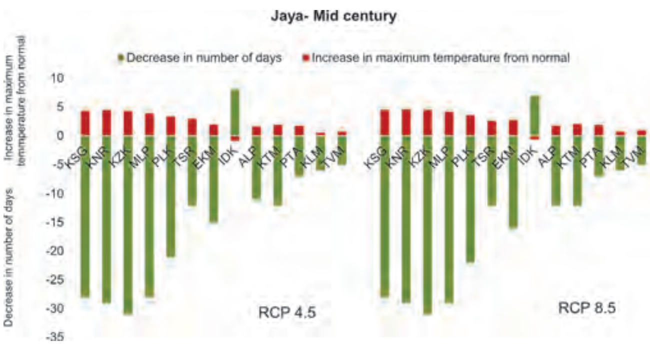

Fig. 5. Deviation from normal maximum temperature and changes in number of days from transplanting to maturity during mid-century in Jaya

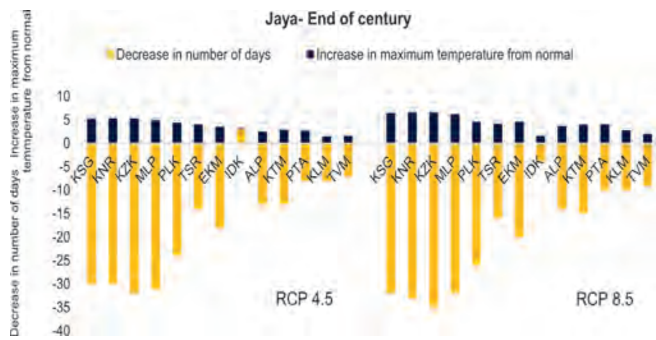

Fig. 6. Deviation from normal maximum temperature and changes in number of days from transplanting to maturity during end of the century in Jaya

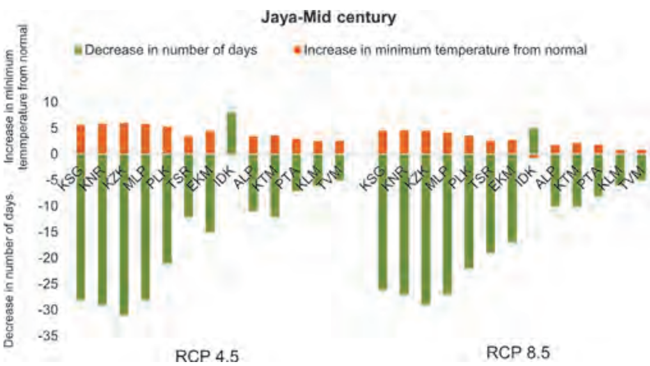

Fig. 7. Deviation from normal minimum temperature and changes in number of days from transplanting to maturity during mid-century in Jaya

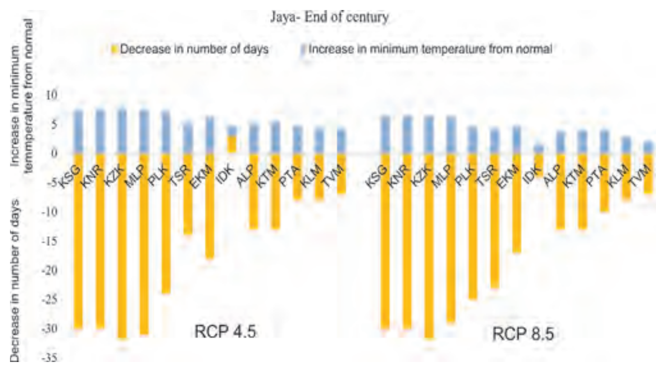

Fig. 8. Deviation from normal minimum temperature and changes in number of days from transplanting to maturity during end of the century in Jaya

to note that the shortening of the crop maturity period, due to reduced time for biomass accumulation during the vegetative phase, would result in a reduction in rice yield (Yao *et al.*, 2007). An increase in temperature can hasten crop senescence, thus shortening the overall crop duration and impairing grain filling, as observed in wheat (Lobell *et al.*, 2012). A similar trend was found in rice, where a decrease in the grain-filling stage could potentially reduce rice yield (Lyman *et al.*, 2013).

CONCLUSION

In conclusion, the rising temperatures in Kerala are projected to significantly impact rice growth and yield, primarily by reducing the overall crop duration. The acceleration of growth stages, driven by the rapid accumulation of Growing Degree Days (GDD), leads to shorter phenophase durations. Among the various zones in Kerala, the northern zone is expected to experience the greatest temperature increase, resulting in the most considerable reduction in crop duration. On the other hand, the high-range zone, such as Idukki, is projected to experience a slight temperature decrease, extending the crop duration by 8 days under both the RCP 4.5 and RCP 8.5 pathways. These findings highlight the importance of understanding regional temperature trends and their effects on crop development. By recognizing these changes, farmers can make informed decisions on crop management, such as adjusting planting schedules and adopting practices that enhance yield stability. Ultimately, this knowledge will enable better adaptation to regional temperature variations, ensuring more reliable rice production outcomes in the face of climate change.

LITERATURE CITED

Ahmad S, Abbas G, Ahmed M, Fatima Z, Anjum M A, Rasul G, Khan M A and Hoogenboom G 2019. Climate warming and management impact on the change of phenology of the rice-wheat cropping system in Punjab, Pakistan. *Field Crops Res* **230**: 46-61.

Ajithkumar B, Rao V U M, Sreekala P, Chandrasekhar Vishnu and Sekhar E 2015 Agroclimatic Atlas of Kerala. https://www.researchgate.net/publication/341788375_Agroclimatic_Atlas_of_Kerala

Allen M R, Dube O P, Solecki W, Aragón-Durand F, Cramer W, Humphreys S, Kainuma M, Kala J, Mahowald N, Mulugetta Y, Perez R, Wairiu M and Zickfeld K 2018. Framing and Context. In: Global Warming of 1.5°C. An

IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global GHG emissions pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte V, P Zhai, H O Pörtner, D Roberts, J Skea, P R Shukla, A Pirani, W Moufouma-Okia C Péan, R Pidcock, S Connors, J B R Matthews, Y Chen, X Zhou, M I Gomis, E Lonnoy, T Maycock, M Tignor and T Waterfield (eds.) https://www.ipcc.ch/sr15/

Ajithkumar B and Riya K R 2022. Temperature variation in Kerala: Present and future. *Int J Environ Clim Change* **12**(12): 1185-95.

Challinor A J, Watson J, Lobell D B, Howden S M, Smith D R, Chhetri N 2014. A meta-analysis of crop yield under climate change and adaptation. *Nat Clim Chang* **4**: 287-91.

Chou S C, Lyra A, Mourão C, Dereczynski C, Pilotto I, Gomes J, Bustamante J, Tavares P, Silva A, Rodrigues D and Campos D 2014. Assessment of climate change over South America under RCP 4.5 and 8.5 downscaling scenarios. *American J Clim Change* **3**(05): 512. doi:10.4236/ajcc.2014.35043

Das P, Deka R L, Goswami J and Barua S 2020. Effect of elevated CO_2 and temperature on growth and yield of winter rice under Jorhat condition. *J Agrometeorol* **22**(2): 109-15.

Donner L J, Wyman B L, Hemler R S, Horowitz L W, Ming Y, Zhao M, Golaz J C, Ginoux P, Lin S J, Schwarzkopf M D and Austin J 2011. The dynamical core, physical parameterizations, and basic simulation characteristics of the atmospheric component AM3 of the GFDL global coupled model CM3. *J Clim* **24**(13): 3484-3519. https://doi.org/10.1175/2011JCLI3955.1

FAOSTAT, 2018 FAOSTAT. Available at: http://www.fao.org/faostat/en/data/QCL/metadata. Accessed 4 Nov, 2023.

Geethalakshmi V, Bhuvaneswari K, Lakshmanan A and Sekhar N U 2017. Assessment of climate change impact on rice using controlled environment chamber in Tamil Nadu, India. *Curr Sci* **112**(10): 2066-72.

Hartmann D L, Tank A M K, Rusticucci M, Alexander L V, Brönnimann S, Charabi Y A R, Dentener F J, Dlugokencky E J, Easterling D R, Kaplan A and Soden B J 2013. Observations: Atmosphere and Surface. In: Climate Change 2013 - The Physical Science Basis, *Working group I contribution to the fifth assessment report of the intergovernmental panel on climate change* (pp. 159-254). Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.008

IPCC [Intergovernmental Panel on Climate Change] 2023 Climate Change 2023: Synthesis Report-Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland

International Benchmark Sites Network for Agrotechnology Transfer 1993. The IBSNAT Decade. Department of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, Hawaii

Kaur J and Kaur P 2022. A critical assessment of changes in climate predicted by four GCMs under different RCP scenarios in Punjab (India). *MAUSAM* **73**(4): 749-62.

Krishnan R, Sanjay J, Gnanaseelan C, Mujumdar M, Kulkarni A and Chakraborty S 2020. Assessment of climate change over the Indian region: A report of the Ministry of Earth Sciences (MOES), Government of India (p. 226). SpringerNature, Singapore. https://doi.org/10.1007/978-981-15-4327-2

Liu S, Waqas M A, Wang S H, Xiong X Y and Wan Y F 2017. Effects of increased levels of atmospheric CO_2 and high temperatures on rice growth and quality. PLoSOne. **12**(11): e0187724. journal.pone.0187724

Lobell D B, Sibley A and Ortiz-Monasterio J I 2012. Extreme heat effects on wheat senescence in India. *Nature Climate Change* **2**: 186-89.

Lyman N B, Jagadish K S V, Nalley L L, Dixon B L and Siebenmorgen T 2013. Neglecting rice milling yield and quality underestimates economic losses from high-temperature stress. PLoS One **8:** e72157

Matthews R B, Kropff M J, Horie T and Bachelet D 1997. Simulating the impact of climate change on rice production in Asia and evaluating options for adaptation. *Agric Sys* **54**: 399-425. https://doi.org/10.1016/S0308-521X(95)00060-I

Mendelsohn R 2009. The impact of climate change on agriculture in developing countries. J *Nat Res Policy Res* **1**: 5-19.

Nayak S, Takemi T and Maity S 2022. Precipitation and temperature climatologies over India: A Study with AGCM large ensemble climate simulations. *Atmosphere* **13**(5): 671.

Ren H, Bao J, Gao Z, Sun D, Zheng S and Bai J 2023. How rice adapts to high temperatures. *Front Plant Sci* **14**: 1137923

Sanjay J, Revadekar J V, Ramarao M V S, Borgaonkar H, Sengupta S, Kothawale D R, Patel J, Mahesh R, Ingle S, AchutaRao K and Srivastava A K 2020. Temperature changes in India. Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India, pp. 21-45.

Saseendran S A, Singh K K, Rathore L S, Singh S V and Sinha S K 2000. Effects of climate change on rice production in the tropical humid climate of Kerala, India. *Climatic Change* **44**(4): 495-514.

Slafer G A and Rawson H M 1994. Does temperature affect final numbers of primordia in wheat? *Field Crops Res* **39**(2-3): 111-17.

Statista 2024. India: Production volume of rice 2023. Retrieved from Statista. https://www.statista.com/statistics/1140236/india-production-volume-of-rice/

Stocker T F, D Qin, G K Plattner, M Tignor, S K Allen, J Boschung, A Nauels, Y Xia, V Bex and P M Midgley (eds.)

2013. Climate change 2013-The physical science basis. *Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, pp. 33-115.

Ullah S 2017. Climate change impact on agriculture of Pakistan-A leading agent to food security. *Int J Environ Sci Nat Res* **6**(3): 76-79.

van Vuuren D P, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt G C, Kram T, Krey V, Lamarque J F and Masui T 2011. The representative concentration pathways: An overview. *Climatic Change* **109**(1): 5-31. https://doi.org/ 10.1007/s10584-011-0148-z

Venkat J 2017. Assessment of rice (*Oryza sativa* L.) production under climate change scenarios. M Sc (Ag) thesis, Kerala Agricultural University. 163p.

Vysakh A, Ajithkumar B and Rao A S 2016 Evaluation of CERES-Rice model for the selected rice varieties of Kerala. *J. Agrometeorol* **18**(1): 120.

Yao F, Xu Y and Lin E 2007. Assessing the impacts of climate change on rice yields in the main rice areas of China. *Climatic Change* **80**: 395-409.

Yoshida S, Satake T and Mackill D 1981. High-temperature Stress. International Rice Research Institute Paper No. **67**: 1-15.

Zhai Y, Huang G, Wang X, Zhou X, Lu C and Li Z 2019. Future projections of temperature changes in Ottawa, Canada through stepwise clustered downscaling of multiple GCMs under RCPs. *Climate Dynamics* **52**: 3455-70.

Zhang T Y, Huang Y and Yang X G 2013. Climate warming over the past three decades has shortened rice growth duration in China and cultivar shifts have further accelerated the process for late rice. *Glob Chang Biol* **19**: 563-70.

Ziska L H, Namuco O, Moya T and Quilang J 1997. Growth and yield response of field-grown tropical rice to increasing carbon dioxide and air temperature. *Agronomy J* **89**(1): 45-53.