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Research Article

Assessing the Impact of Climate Change on Short-duration Rice Varieties in Kerala: A Study using Weather Data and Yield Prediction Model

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ABSTRACT

Earth's climate is changing and it is evident with plenty of evidence. The study aims to determine the impact of climate changes on short-duration rice varieties in Kerala. To assess impact of climate change, the weather data from 1980 to 2020 has been collected from the India Meteorological Department (IMD) for 13 districts of Kerala and the future weather data was downloaded from the GFDL CM3 climate model under RCP 4.5 and RCP 8.5. DSSAT – CERES model has been used for predicting the rice yield for the base period (1980-2020) and future period. From the assessment of climate change, it was observed that the temperature (maximum and minimum) is expected to increase by 1 to 7°C in the future under both Representative Concentration Pathway (RCPs). An excess and large excess increase in rainfall is expected in the future under both scenarios. The yield of rice is being negatively impacted by rising temperatures. The flowering period was found to be the most sensitive period. The yield decreased by 35 to 60% in comparison to the base period when the temperature increased by more than 3°C from base period. Overall, in the future, the yield of rice is expected to decrease due to an increase in temperature.

Key words: Climate change, RCPs, Temperature, Rice

Introduction

The climate is important in determining an area's flora and fauna. Climate change affects every aspect of the environment. It may cause changes in temperature, precipitation, and other factors that impact biodiversity, directly or indirectly. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), global temperatures are expected to rise by 1.4 to 6.4°C by 2100, with an increase in atmospheric CO_2 from 600 to 1550 ppmv (IPCC, 2007). One of the main factors affecting the Earth's global mean climate is its energy budget, which is the equilibrium between the energy Earth gets from the Sun and the energy it reflects back into space. By modifying the incoming and outgoing radiative fluxes at the surface and the composition of the atmosphere changes the climate. Anthropogenic (human-caused) emissions of greenhouse gases (GHGs), aerosols, and changes in land use and land cover (LULC) are the main contributors to today's climate change (Krishnan *et al.*, 2020). The Global Climate Models (GCMs) use different greenhouse gas emission scenarios to obtain climate change information (Chou, 2014). The models take different paths to achieve four different radiative forcings, which correspond to different concentration paths of greenhouse gases, referred to as the Representative concentration pathway (RCPs)

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(Zhai, 2019). The pathways define different climate futures, all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come. Under RCP 4.5 a peak emission of greenhouse gas is expected around 2040 and then it declines hence it may be referred to as stabilizing pathway; under RCP 8.5 the emission is expected to increase continuously throughout the 21st century *i.e.* high emission pathway (Vuuren, 2011). In a study conducted by Kaur *et al.* (2022), also reported that there is a chance of increasing temperature by -0.1 to 7.2, -0.1 to 7.4, 0.3 to 7.5, 0.7 to 7.8, 1.2 to 8.1 and 1.1 to 8.0! from normal during the time periods 2031- 40, 2041-50, 2051-60, 2061-70, 2071-80 and 2081-95, respectively.

Changes in weather and climate have a significant effect on agriculture. Being an agrarian economy India's gross domestic product (GDP) is heavily reliant on the timely occurrence of the monsoon (Gadgil and Gadgil, 2006) and on other climatic parameters like temperature and solar radiation. Therefore, we cannot disregard how climate change affects crop productivity. Rice comprises a major part of cultivation also regarded as the staple food of more than half of the population. It has been cultivated for nearly 60% of the total cropped area and nearly 77% of the entire nation's food production. Hence, rice production in India can never be neglected. Weather parameters like temperature, rainfall, and solar radiation significantly influence rice production (Yoshida, 1981; Sreenivasan, 1985; Fageria, 2007). Therefore, the study focuses on the impact of the change in climate on short duration rice varieties in Kerala during *virippu* season (June to September).

Materials and Methods

Study area

Kerala is the south western state of India, positioned between 8°18' and 12°48' N latitude and 74°52' and 77°22' E longitude. The state has a total geographical area of 38,863 sq. km (Ajithkumar, 2015). Kerala has 14 districts (Fig. 1) and the study has been done by analyzing the weather data and predicting the yield for the 13 districts of Kerala. Wayanad district has not been considered since there was no rice cultivation in Wayanad during *virippu* season.

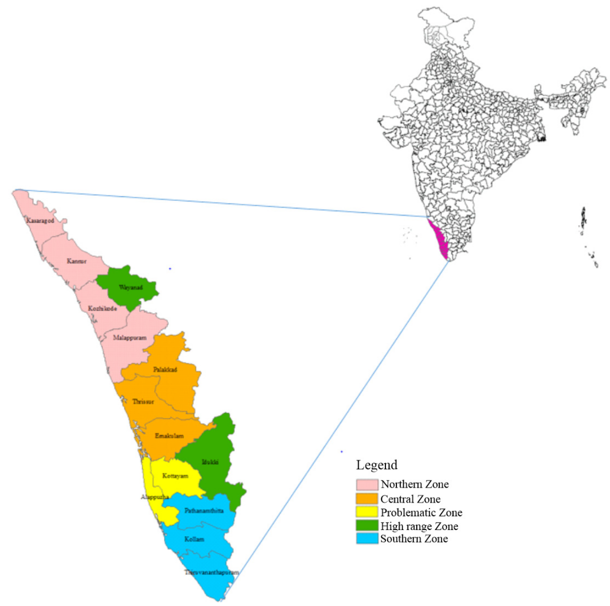

Fig. 1. Study area in Kerala state

Weather data

To study the impact of climate change on Kerala the weather data from 1980 to 2020 has been collected from the India Meteorological Department (IMD) for 13 districts of Kerala. The weather parameters collected were rainfall, maximum and minimum temperature. The future climate has been estimated from Geophysical Fluid Dynamics Laboratory's GFDL CM3 climate model. The GFDL Climate Model version 3 (CM3) is a coupled general circulation model for the atmosphere, ocean, land, and sea ice. The primary goal of CM3 was to focus on novel problems in climate change, such as aerosol-cloud interaction, chemistry and climate, and stratosphere-troposphere coupling (Donner, 2011). According to Venkat *et al.* (2017), among various climate models the GFDL-CM3 model performed well in simulating the current climate over Kerala. Hence, GFDL CM3 model has been used in this study to predict the future climate under the stabilizing pathway (RCP 4.5) and high emission pathways (RCP 8.5). To assess the future changes in the weather parameters of Kerala the climate normal (1980 to 2020) has been compared with the future scenarios *i.e.* mid-century (2021-50) and end of the 21st century (2051-80) under RCP 4.5 and 8.5 (Table 1 and 2).

Table 1. Base period and projected weather data under RCP 4.5 during the southwest monsoon

Districts	Maximum temperature (°C)			Minimum temperature (°C)			Rainfall (mm)		
	Base period	MC	EC	Base period	MC	EC	Base period	MC	EC
				Northern zone					
Kasargod	26.5	30.8	31.7	20.1	25.7	26.3	3212.6	3618.0	3451.5
Kannur	26.6	31.0	31.9	19.9	25.8	26.4	2348.1	3494.3	3229.9
Kozhikode	26.7	31.0	31.9	19.6	25.6	26.3	2021.8	3161.6	3047.3
Malappuram	27.1	31.0	32.0	19.6	25.4	26.1	1507.1	2669.1	2620.7
				Central zone					
Palakkad	27.7	31.1	32.1	20.2	25.5	26.2	1433.1	2606.4	2199.7
Thrissur	28.9	31.8	32.9	22.2	25.6	26.3	1587.2	2299.4	2411.7
Ernakulam	28.6	30.5	32.0	21.2	25.7	26.4	1818.8	2501.3	2419.9
				High range zone					
Idukki	29.6	28.7	29.7	22.0	21.8	22.5	1053.3	1502.6	1409.7
Wayanad	26.6	26.9	27.9	19.5	20.8	21.5	1486.6	2470.7	2363.9
				Problematic zone					
Alappuzha	29.4	31.0	31.9	22.2	25.6	26.3	1831.6	2321.3	2133.6
Kottayam	29.4	31.3	32.2	22.2	25.8	26.5	1698.9	2326.6	2234.6
				Southern zone					
Pathanamthitta	30.4	32.1	33.0	23.0	25.9	26.7	980.5	2027.5	2012.0
Kollam	30.7	31.2	32.1	23.3	25.8	26.5	818.5	1934.4	1846.9
Thiruvananthapuram	31.2	31.9	32.8	23.8	26.3	27.0	650.0	1083.9	1043.0

MC: Mid century EC: End of the century

Table 2. Base period and projected weather data under RCP 8.5 during the southwest monsoon

Districts	Maximum temperature (°C)			Minimum temperature (°C)			Rainfall (mm)		
	Normal	MC	EC	Normal	MC	EC	Normal	MC	EC
				Northern zone					
Kasargod	26.5	31.0	33.0	20.1	25.8	27.3	3212.6	3470.2	3359.6
Kannur	26.6	31.2	33.1	19.9	25.9	27.4	2348.1	3387.3	3141.0
Kozhikode	26.7	31.2	33.2	19.6	25.7	27.3	2021.8	3019.7	2968.7
Malappuram	27.1	31.2	33.3	19.6	25.5	27.1	1507.1	2625.7	2538.5
				Central zone					
Palakkad	27.7	31.3	32.2	20.2	25.6	27.2	1433.1	2544.2	2290.6
Thrissur	28.9	31.4	33.1	22.2	25.8	27.3	1587.2	2794.4	3007.0
Ernakulam	28.6	31.3	33.2	21.2	25.8	27.4	1818.8	2564.7	2392.5
				High range zone					
Idukki	29.6	28.9	31.1	22.0	21.9	23.7	1053.3	1471.1	1396.2
Wayanad	26.6	27.1	29.2	19.5	20.9	22.6	1486.6	2370.4	2473.0
				Problematic zone					
Alappuzha	29.4	31.2	33.1	22.2	25.8	27.3	1831.6	2206.7	2223.8
Kottayam	29.4	31.5	33.4	22.2	25.9	27.5	1698.9	2318.9	2391.1
				Southern zone					
Pathanamthitta	30.4	32.2	34.4	23.0	26.1	27.8	980.5	2070.4	1900.7
Kollam	30.7	31.4	33.5	23.3	25.9	27.6	818.5	1892.1	1766.4
Thiruvananthapuram	31.2	32.1	33.1	23.8	26.4	28.0	650.0	950.3	1110.7

MC: Mid century EC: End of the century

Rice variety used

The rice variety used in the study was Jyothi. Jyothi is a short-duration variety with a growth period of 110-115 days. It is the result of a cross between PTB-10 and IR 8. It is grown in Kerala throughout the year.

DSSAT CERES –Rice crop growth simulation model

The DSSAT's CERES-Rice model was used to study the impact of climate change on rice. The crop growth simulation models are a useful tool for simulating the growth and yields of crops according to various scenarios (Vaghef *et al*., 2013). The CERES- Rice model has been widely used to assess the impact of climate change on crop yields (Oteng-Darko, 2012; Yoon, 2020; Aswathi *et al*., 2022). According to Bhuvaneswari *et al*. (2014), rice yield was expected to decrease by 4 to 56% with a 1 to 5°C increase in temperature from normal during various planting dates, *i.e.* June 1st to July 15th in Tamil Nadu. In this study also the yield was predicted using the DSSAT CERES model for the base period and under the climate change scenarios using Representative Concentration Pathway (RCP) 4.5 and 8.5 for the 13 districts of Kerala. The future yield during different simulations *i.e*. Mid-century (2021-50) and end of the 21st century (2051-80) under both RCPs (RCP 4.5 and 8.5) has been predicted. The percentage changes in yield have been calculated by the following equations *i.e.*

Percentage deviation = (Simulated yield/ Base period yield – 1) × 100

Result and Discussion

Comparison of simulated weather data with baseline climate data during the experimental period (Kharif season)

In order to assess the effects of climate change, it was essential to compare simulated weather data under RCP 4.5 and 8.5 with the baseline climate (1980–2020) during the *viruppu* (*Kharif*) season in Kerala.

Maximum temperature

The maximum temperature is expected to increase in future scenarios when compared with the base period. Under RCP 4.5 the temperature is expected to increase by 4°C in northern districts like Kasargod, Kannur, Kozhikode and Malappuram by mid-century. The warming continues to increase and by the end of the 21st century, the temperature is expected to increase by 5° C from the base period. In districts like Palakkad, Thrissur and Ernakulam *i.e.* the central zone of Kerala, the warming is expected to increase by 3.5°C and 4.5°C from baseline by the mid and end of the 21st century, respectively. In Alappuzha and Kottayam, the problem area zone the temperature is expected to increase by 2 and 3°C in the mid and end centuries, respectively. While in southern zone districts viz. Kollam, Pathanamthitta and Thiruvananthapuram the temperature is expected to increase by 1-2°C in future scenarios. While in Idukki the temperature is expected to decrease by 0.9°C in the mid-century and then increase by 0.2°C by end of the 21st century. A similar trend is expected under RCP 8.5 where the temperature is expected to increase by 6°C by the end of the 21st century in the northern zone. By the end of the 21st century, temperature increase by 5°C and 4°C is expected by the central and problem area zone, respectively. Figures 2 and 3 shows the deviation of maximum temperature from the baseline. More deviation in temperature is seen in northern as well as in central zone of Kerala when compared with southern zone of Kerala.

Minimum temperature

The minimum temperature is expected to increase in Kerala irrespective of concentration pathways. Under RCP 4.5 the minimum temperature is expected to increase by 6–7°C in future scenarios in the northern and central zone of Kerala. In problem area zones the temperature is expected to increase nearly by 4°C in future scenarios and in southern zone the warming is expected to increase by 3–4°C in future scenarios. A similar trend has been observed by RCP 8.5. Under RCP 8.5 the minimum temperature is expected to increase approximately by 7°C in future scenarios in the northern and by 5–6°C in the central zone of Kerala. In problem area

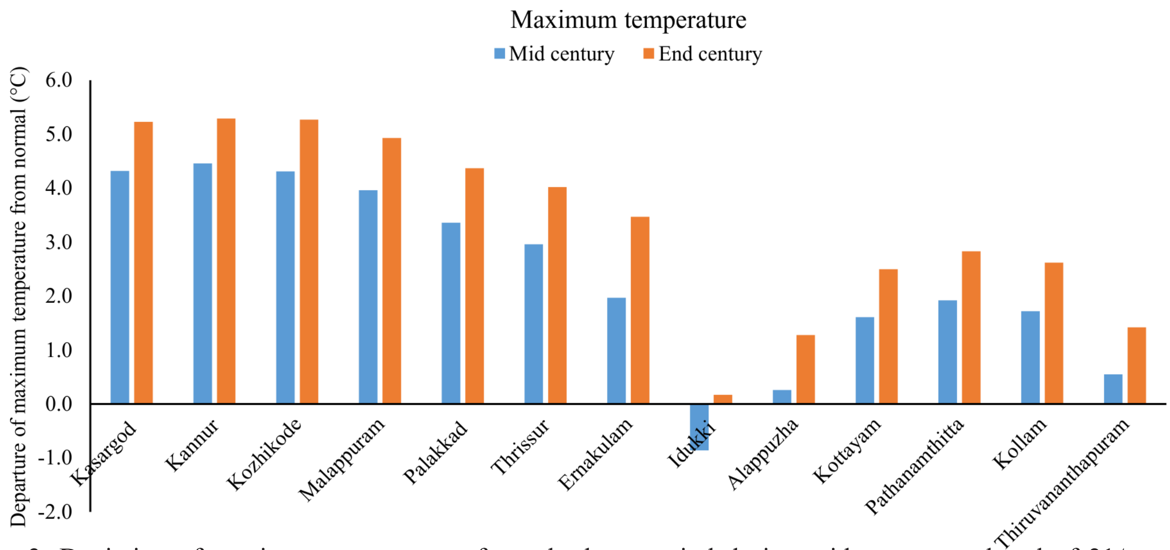

Fig. 2. Deviation of maximum temperature from the base period during mid-century and end of 21st century under RCP 4.5

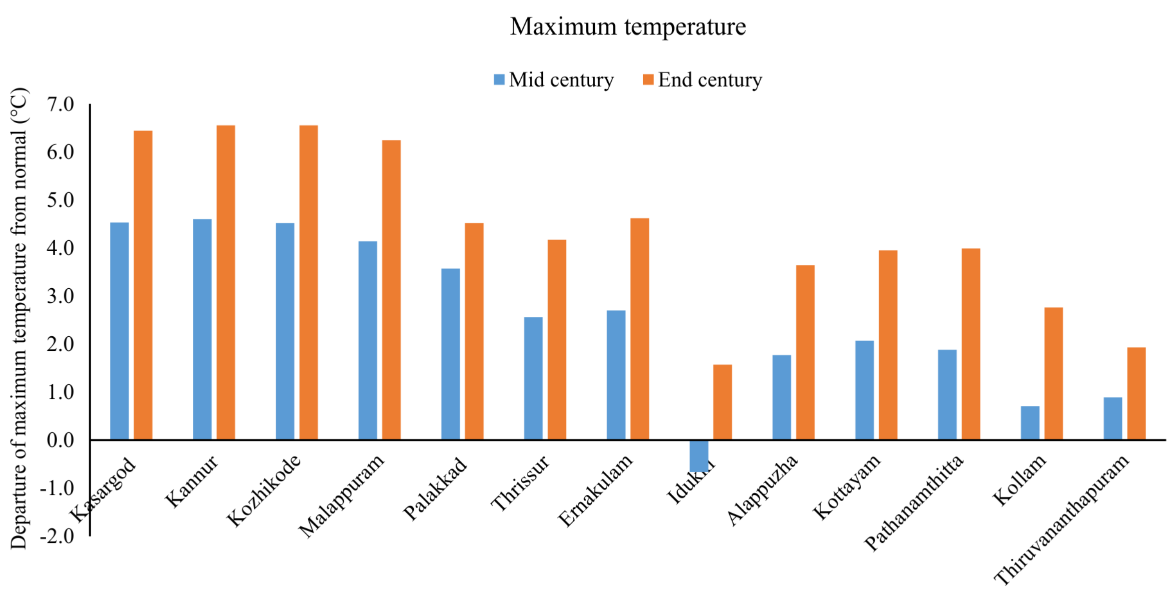

Fig. 3. Deviation of maximum temperature from the base period during mid-century and end of 21st century under RCP 8.5

zones, the temperature is expected to increase almost by 5°C in future scenarios and in southern the warming is expected to increase by 3–4°C in future scenarios. Hence, an increase in minimum temperature from the base has been predicted by the model in Kerala with an exception at Idukki (high range zone) where the minimum temperature may expect to decrease by 0.2°C in mid-century under RCP 4.5 and then the temperature is expected to increase by 0.6° C and 1.6°C by end of the 21st century under RCP 4.5 and 8.5, respectively. Similar to maximum temperature, minimum temperature is also expected to show greater positive deviation in northern and central zone when compared to the southern zone (Fig. 4 and 5).

Rainfall

An increase of rainfall from the base period is expected in future scenarios under both the RCPs, Under RCP 4.5 large excess (> 60% deviation from baseline) and excess (20–59% deviation from

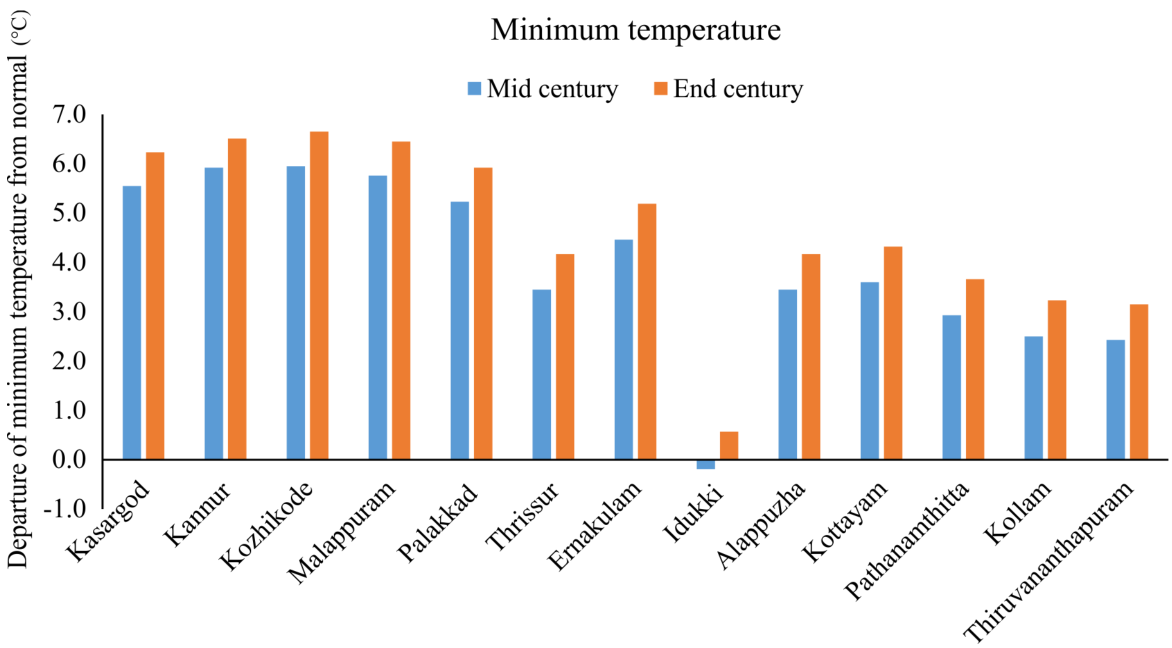

Fig. 4. Deviation of minimum temperature from base period during mid-century and end of 21st century under RCP 4.5

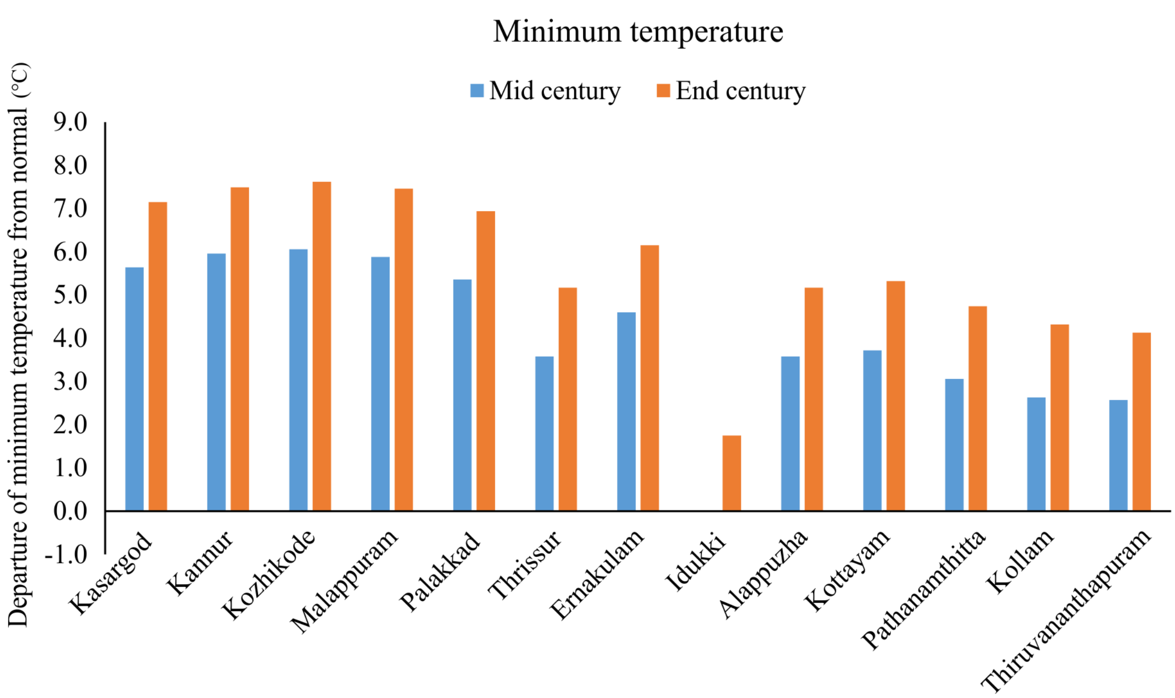

Fig. 5. Deviation of minimum temperature from base period during mid-century and end of 21st century under RCP 8.5

baseline) rainfall was expected in Kerala except in Kasargod where normal rainfall (-19 to 19% deviation from baseline) is expected in the mid and end of the 21st century. In Alappuzha, by end of the 21st century, the rainfall is expected to show a normal deviation (Fig. 6). A similar condition was observed under the RCP 8.5. Large excess and excess rainfall was expected in all districts of Kerala except in

Kasargod where normal rainfall in mid and end of the 21st century. In Alappuzha by the end of 21st century the rainfall is expected to show a normal deviation (Fig. 7). In contrast with temperature deviation, departure of rainfall is expected to be more in southern zones when compared to the other zones

Impact of climate change on rice cultivation

The yield was predicted using the DSSAT CERES model for the base period as well as for future scenarios. Two dates of planting were considered *i.e.* early planting which is considered to be between June 5th to July 5th and late plantings *i.e.* between July 5th and August 5th. In this study, the yield was expected to decrease in future scenarios. Early plantings produced a better yield during the base period while late plantings produced a higher yield in the future irrespective of concentration pathways and future scenarios (Table 3).

The yield of rice variety Jyothi during the base period and future scenarios has been shown in Table 3. In the mid-century, the projected yield changes of early plantings were by -14% (Idukki) to -60% (Kozhikode). While in the late plantings, the yield is

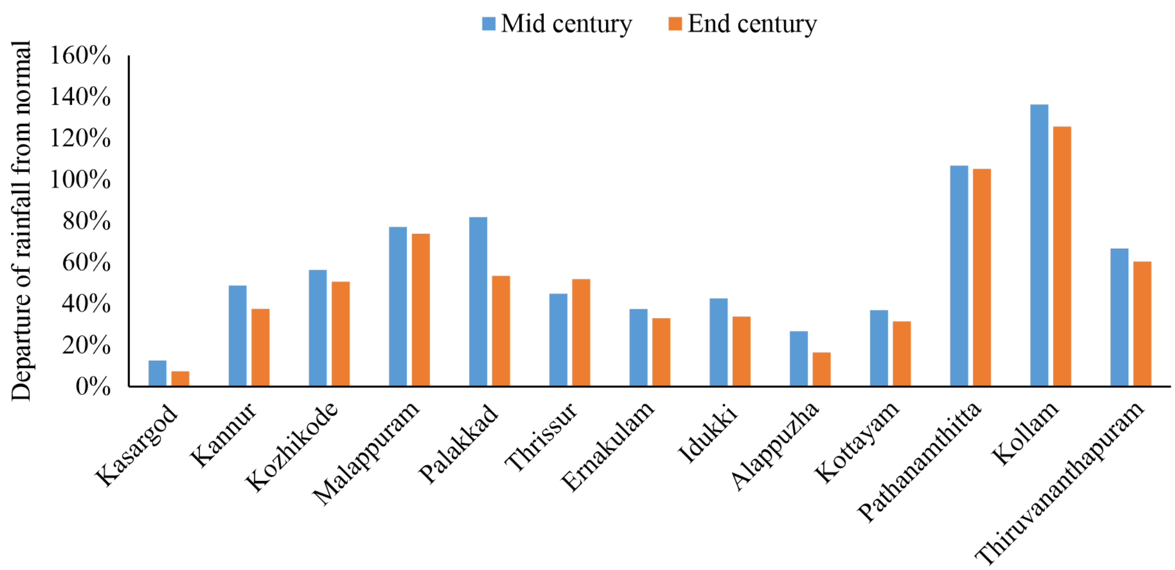

Fig. 6. Departure of rainfall from base period during mid-century and end of 21st century under RCP 4.5

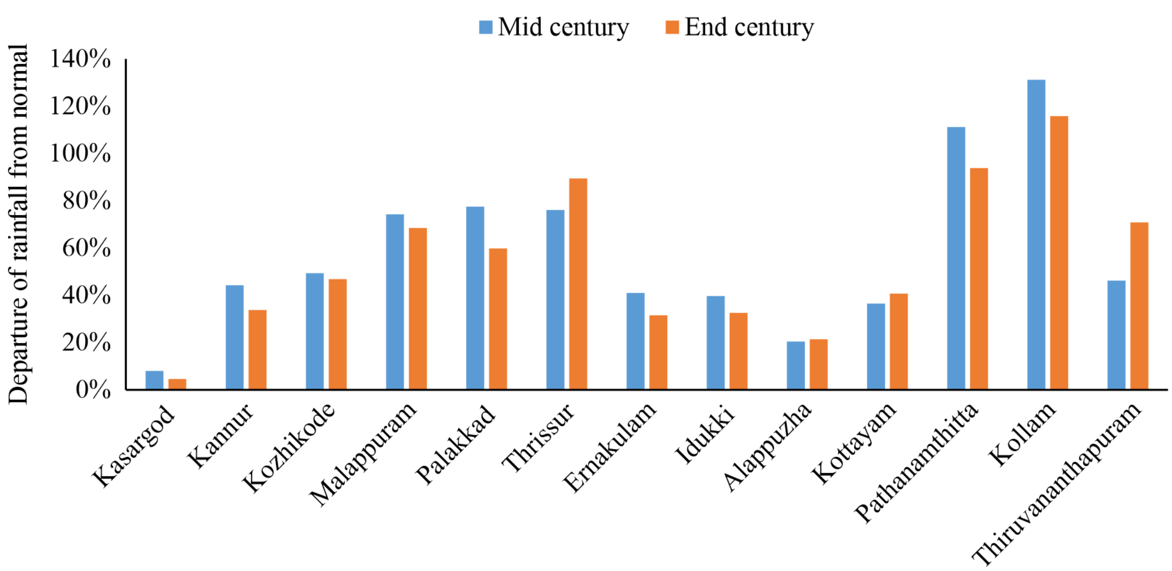

Fig. 7. Departure of rainfall from base period during mid-century and end of 21st century under RCP 4.5

Table 3. Predicted yield (kg ha^{-1})of Jyothi in the base period and under future scenarios using DSSAT model

Districts	Base yield (kg ha^{-1})		RCP 4.5				RCP 8.5			
			Mid-century		End of 21st century		Mid-century		End of 21st century	
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
Kasargod	7868.5	7549.7	4295.0	5780.3	4003.5	5791.0	4447.5	5992.3	3489.5	5082.3
Kannur	8118.5	7986.0	4035.0	5699.3	3796.0	5295.0	4180.0	5865.7	2886.0	4684.3
Kozhikode	8351.0	8192.7	3595.0	5866.7	3657.0	5620.7	3758.5	5908.0	3071.0	4665.0
Malappuram	8287.0	8120.0	4546.5	6438.0	4298.0	6188.0	4444.5	6513.3	3390.5	5054.7
Palakkad	7949.5	7772.7	4174.5	6456.0	4042.0	6384.7	4190.0	6540.3	3442.5	4846.3
Thrissur	7689.0	7539.0	4263.5	6693.3	5167.5	7350.7	4338.0	6683.7	3507.5	5077.3
Ernakulam	7266.5	7024.7	4116.0	6175.3	4034.5	5824.0	4043.5	6120.0	3349.5	4950.3
Idukki	6890.5	6827.7	5930.5	8306.7	5310.0	7752.3	5808.0	8109.0	4670.5	6783.3
Alappuzha	6692.0	6684.3	3390.5	5985.0	3106.5	5652.7	3495.0	5857.7	3151.0	4659.0
Kottayam	6697.0	6684.0	3452.5	6035.3	3248.5	5467.7	3541.5	5934.7	3001.0	4634.7
Pathanamthitta	6331.0	6377.7	3672.0	5389.7	3657.0	5138.3	3736.0	5362.3	3045.5	4406.3
Kollam	6187.5	6197.7	3154.0	5396.3	3204.0	4968.0	3160.0	5247.3	2613.5	4487.0
Thiruvananthapuram	6142.5	5907.3	3910.0	4943.3	3354.0	4314.3	2454.5	4739.7	2740.0	3409.3

expected to increase by 22% and 19% in the Idukki district under RCP 4.5 and 8.5. In other districts the projected changes in rice yield during late plantings were found to be between -10% (Kottayam and Alappuzha) to -29% (Kannur). During the mid-century, the projected yield differences between RCPs were less, probably due to factor interactions like rising temperature reducing the CO_2-induced yield gains for the higher RCP (Araya *et al.,* 2015).

By the end of 21st century, the different pathways showed differences in the simulated yield. Under the stabilizing pathway (RCP 4.5) the early planting showed a decrease in yield by -23 (Idukki) to -56 % (Kozhikode). During the same period, the late plantings showed an increase in yield by 14% in Idukki, while yield reduced by -2% to -34% in other districts. Under the high emission pathway (RCP 8.5) the projected yield was found to be lesser than the RCP 4.5. The projected changes ranged between -32% to -63% in the early planting and between -1% to -43% in the late plantings, deviation was found to be less in Idukki and high in Kozhikode, respectively.

The correlation between yield and weather parameters showed a significant negative correlation between yield and maximum temperature during the flowering period. Sridevi and Chellamuthu (2015) reported that an increase in the maximum temperature affected the floral initiation of the rice plant, which lowers the grain weight of the rice harvest. According to Abbas and Mayo (2021), an increase in minimum and maximum temperatures, particularly from panicle start to anthesis, results in a considerable drop in yield. The percentage changes in yield and the deviation of maximum temperature have been plotted in Figure 8 and 9 for the respective RCPs 4.5 and 8.5.

The figures indicate that the increase in temperature might negatively influence the yield. An increase in temperature by 1 to 2! led to a 10 to 30% reduction in the yield. A temperature increase of more than 4°C decreased the yield by more than 50% of the yield during the base period. At the same time, the yield increased by 14 to 22% as a result of the reduction in temperature by 2 to 3°C. Oh-e *et al.* (2007) reported that there is a positive correlation between the percentage of sterile spikelet and the maximum temperature during the flowering period and the grain yield is expected to decline when the mean temperature exceeded 28ºC. Yun-Ying *et al.* (2008) has reported that heat stress can cause damage to the cells during meiosis, leading to abnormalities in the anthers and pollen grains. This can result in

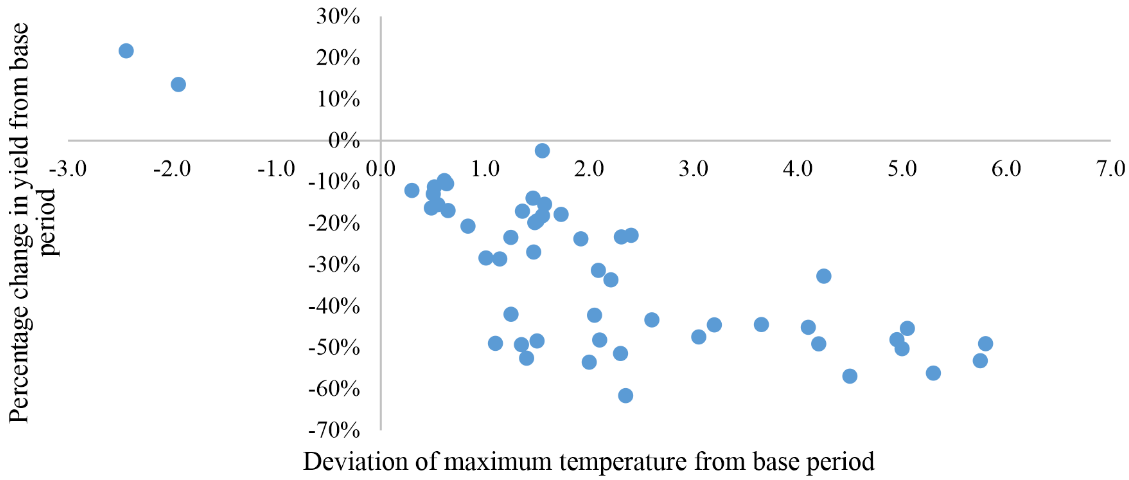

Fig. 8. Expected changes in yield due to the variation of temperature in Kerala under RCP 4.5

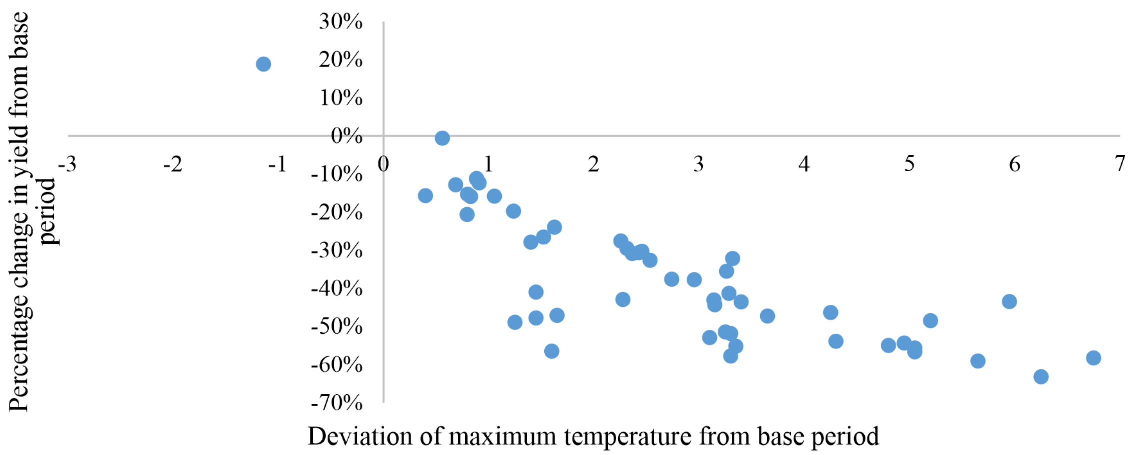

Fig. 9. Expected changes in yield due to the variation of temperature in Kerala under RCP 8.5

reduced anther dehiscence, which is the process of the anther opening up to release the pollen grains, and a decrease in pollen fertility rate and thereby have a significant impact on yield. High temperatures during the grain-filling period of crop development can have negative effects on starch synthesis in the grains, especially under nitrogen-deficient conditions (Ito *et al.*, 2009). High temperature cause accumulation of sucrose leading to decrease in carbon and nitrogen transport from the shoots to the ears through phloem. Further, heat stress may also cause high chalkiness and poor edible quality. These are mainly associated with starch synthesis in endosperm at the time of grain filling (Umemoto and Terashima, 2002; Zheng-xun *et al.*, 2005). Temperature influences the expression of SBE genes as well as the expression difference of each isoform gene during grain filling and this determine the structure of starch in rice endosperm and the quality of rice grains (Wei *et al.*, 2009b). Sandhu (2017) also reported that anthesis and grain development are the stages of rice that are most sensitive to high temperatures (heat stress). Thus, the increase in temperature may lead to a reduction in yield in the future. Additionally, the study shows that the deviation of maximum temperature from the base period during the flowering period was higher during the early plantings than the late plantings, which may be the reason for better yield in late plantings than early plantings (Fig. 10 and 11).

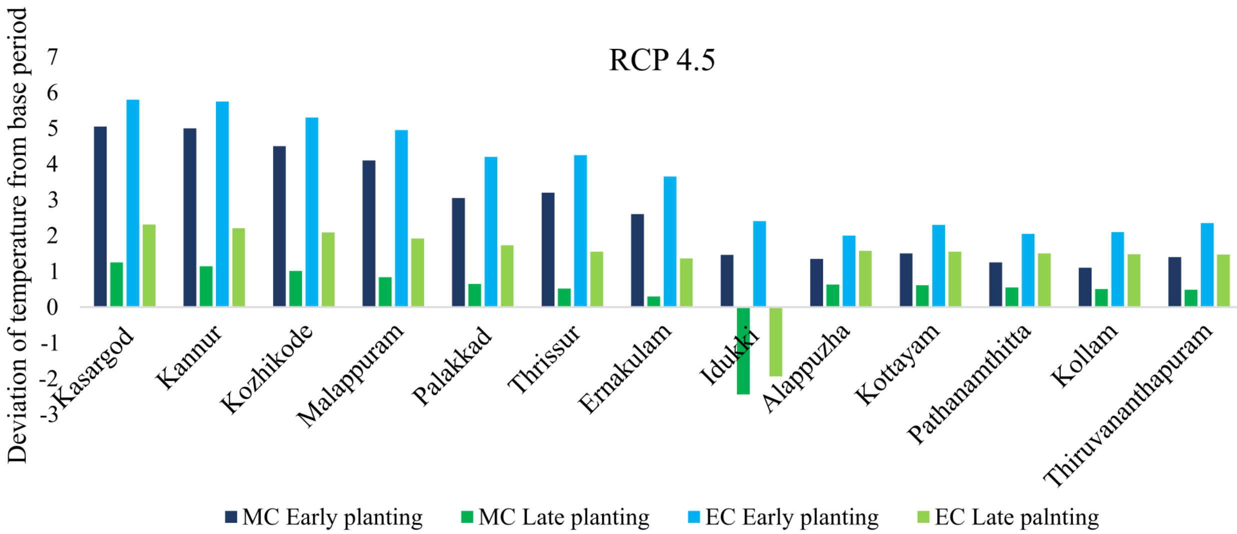

Fig. 10. Deviation of maximum temperature from the base period during the flowering period under RCP 4.5

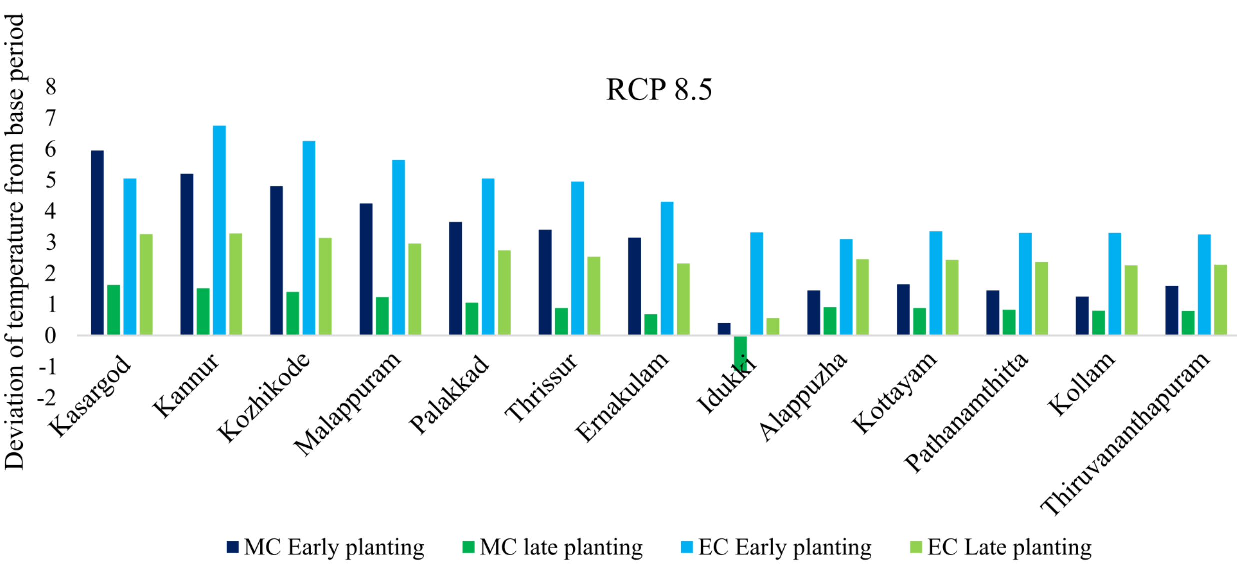

Fig. 11. Deviation of maximum temperature from the base period during the flowering period under RCP 8.5

Conclusions

The changes in atmospheric parameters are having a significant influence on rice yield. From the assessment of climate change, it was concluded that there will be an increase in temperature and rainfall in most parts of Kerala during the southwest monsoon season. As a result of these changes, the yield is expected to decrease in the future. An increase in temperature during flowering had a significant negative impact on yield. Hence, in future the rice yield is expected to decrease and when compared with the early plantings, late plantings are found to be better in future.

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