***Original Research Article***

# Phasic development of rice during the present and future climatic conditions in central zone of Kerala

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## ABSTRACT

Rice is a staple food and its demand is substantially increasing with the growth of the global population. Phenological development was found to play a significant role in the distribution of carbon among plant organs, which has an impact on rice yield. Temperature affects plant phenology, and the current rapid climate change has revived interest in understanding and modelling plant phenology response to the warming trend. Two rice varieties *viz.,* Jyothi (short duration variety) and Jaya (medium duration variety) were raised at Agriculture Research Station, Mannuthy, during the *kharif*season of 2021and phonological observations *viz.* days to 50% flowering and physiological maturity were recorded. The phenophase has been also predicted from the Info-Crop and CERES-DSSAT for both varieties during the experimental period for validation. To study the phenology changes in future conditions i.e., near (2030), mid (2050) and end (2080) century, future weather data has been downloaded from the GFDL-CM3 climate model under RCP 4.5 and RCP 8.5 scenarios. Using the projected weather data, the phenophase of both varieties has been predicted using InfoCrop and CERES- DSSAT models.During the base period, Jyothi took 71 days and Jaya took 75 days to reach 50% flowering, while the total duration was found to be101 days in Jyothiand 108 days in Jaya. In the case of 50% flowering, CERES-DSSAT predicted more accurately for Jyothiwhile InfoCrop predicted more accurately for Jaya.The prediction of physiological maturity was found to be more accurate using CERES-DSSAT in Jaya and InfoCrop in Jyothi. Validation results showed that both models can be used to predict the phenophases of rice varieties. The predicted duration during base period was compared with future duration. The days to 50% flowering is expected to reduce by 3-4 days in Jyothi and 3 daysin Jaya whereas the physiological maturity is projected to shorten by 3-6 days in Jyothi and 4-5 days in Jaya, by the end century. Results showed that the temperature rise in future can cause the considerable reduction in duration to attain 50% flowering and physiological maturity of rice varieties.

Keywords: Phenophase, Info-Crop, CERES DSSAT, Rice, 50% flowering, Physiological maturity

## 1. INTRODUCTION

Cereals are the main source of nutrition and food for populations around the world, with rice accounting for over 40% of consumption globally (Muthayya et al., [1]).Rice is the primary food source for more than half of the world's population, providing 35-80 percent of the daily caloric intake requirements of Asia's 3.3 billion people (Bandumula et al., [2]).Phenological development has been shown to have a substantial impact on carbon transportation across plant organs and thereby have a significant impact on rice yield (Guo et al., [3]). Phenophase usually refers to the start, peak, or end of a certain botanical development (Sparks and Menzel, [4]). Phenology has been defined as the study of cyclical biological events and is strongly influenced by both short and long-term variations in the weather and climate (Shen et al., [5]). In plants, this can include flowering, leaf unfolding (or budburst), seed set and dispersal, and leaf fall (Davi et al., [6]). Generally, crop phenology determines the timing and duration of critical periods for growth and development (Porter and Semenov, [7]), which are important elements of yield and agricultural productivity (Chmielewski, [8]).

The threat of global food security has increased as a result of the recent intensification of climate change, which is harming agricultural productivity (Giorgi et al., [9]). Rice (*Oryzasativa* L.), is susceptible to climate change and is highly vulnerable to it (Liu et al., [10]). Numerous researchers have studied the impact of climate change on crop phenology of rice (Ye et al., [11], Bai and Xiao, [12]). Changes in crop phenology play a key role in yield formation through regulation of the duration of biomass accumulation in various organs. Climate change would likely shorten the duration of crop growth, thus limiting production and affecting future global food security (Anwar et al., [13]). These changes can be studied using weather data under climate change scenarios. Climate change scenariosare projections of future greenhouse gas (GHG) emissions that analysts use to determine the future vulnerability to climate change (Carter et al., [14]). IPCC fifth Assessment Report (AR5) adopted four greenhouse gas concentration trajectories called Representative Concentration Pathways (RCPs). The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values.

Crop weather models help to study the impact of climate change on growth and development of crops. As crop phenology plays an important role in crop development and yield (Tao et al., [15]), the simulation of crop phenology is important in many crop simulation models (Streck et al., [16]). The Indian Institute of Agricultural Research created the generic InfoCrop-Rice model. The phenological development of rice is divided into three main stages: sowing to emergence, emergence to anthesis, and storage organ filling. The emergence to anthesis phase is further divided into three sub-phases: basic juvenile, photoperiod sensitive, and storage organ development. This model was created to simulate how soil, weather, pests, agronomic practices (such as planting, residues, irrigation, and nitrogen) and planting conditions affect crop yield and the environmental problems that go along with it. Being a user-friendly model, its goal is to enhance the usage of crop models in research and development while requiring less input (Aggarwal et al., [17]). Multiple crop models, including CERES-Rice, are included in the International Benchmark Systems Network for Agrotechnology Transfer (IBSNAT) Decision Support System for Agrotechnology Transfer (DSSAT) (Goswami and Dutta, [18]). The CERES-Rice model simulates crop growth, development, and yield, accounting for weather, genetics, soil water, carbon, and nitrogen, as well as planting, irrigation, and nitrogen fertilizer management (Ritchie et al., [19]). It has been extensively used to simulate the effects of management strategies, plant genetics, soil conditions, and weather on the development, growth, and yield of rice crops (Mall and Aggarwal, [20]). In this context, this study focuses on the duration of phenophase in rice varieties and its future changes with the aid of Info-Crop and CERES-DSSAT models.

## 2. METHODOLOGY

An experiment for "Comparison of Info-Crop and CERES-DSSAT models of rice under projected climatic conditions of Kerala" was done during 2021-2022 at the Department of Agricultural Meteorology, College of Agriculture, KAU, Vellanikkara

### 2.1 Location of the experiment

The fieldwork was carried out during the *kharif* season of 2021 at the Agricultural Research Station, Kerala Agricultural University, Mannuthy, Thrissur. The station is located at 22.0 m above mean sea level (MSL) at $10^0$ 32’ N latitude and $76^0$20’ E longitude. The area experiences a typical warm humid tropical climate. The area is benefited by both southwest and northeast monsoons.

At the study field, the soil texture was sandy loam. Table.1 demonstrates the physical properties of the soil in the experimental field.

Table 1. Physical properties of soil at the experimental field

| S.No. | Particulars | Value |
|---|---|---|
| 1 | Coarse sand (%) | 27.6 |
| 2 | Fine sand (%) | 24.2 |
| 3 | Silt (%) | 22.2 |
| 4 | Clay (%) | 26.0 |

## 2.2Varieties chosen for the study

Jyothi and Jaya, popular varieties of rice, were used in the experiment. Jyothi is a short duration and Jaya is a medium duration variety with a growing period of 115-120 days and 120-125 days respectively. Jyothi has been developed from the cross between PTB-10 and IR 8. As this is having wider adaptability, it is cultivated in all three seasons and in a wide range of field conditions. Jaya variety is developed from crossing Taichung (Native) 1 and T-141, recommended for cultivation in both *kharif* and *rabi*seasons

## 2.3Weather data used for the study

The Principle AgrometObservatory of the College of Agriculture, KAU, Vellanikkaraprovided the necessary weather information for the experiment year i.e., 2021, including the maximum temperature, minimum temperature, bright sunshine hours and rainfall. The bright sunshine hours converted to solar radiation using Decision Support System for Agrotechnology Transfer (DSSAT) weatherman. For studying the climate change impact on phenophase of rice in future, two RCPs are chosen *viz.,* RCP 4.5 and 8.5. The RCP 4.5 represents a future with relatively ambitious emission reduction with stabilized radiative forcing achieved shortly after 2100. The RCP 8.5 scenario represents a future with no policy changes to reduce emissions and it can be comparable with the SRES scenario of AIFI. The Climate Change Agriculture and Food Security (CCAFS) Institute under the CGIAR system have hosted a website for providing the downscaled projection data on a point basis (http://gismap.ciat.cgiar.org/MarkSimGCM/), through MarkSim$^{TM}$ DSSAT weather file generator. This converts the downscaled weather data from global climate models (GCMs) to DSSAT weather input file format. GFDL-CM3 was used to project or represent changes in average monthly rainfall, and minimum and maximum monthly temperature data for three-time slices *viz.,* 2030 (near century), 2050 (mid-century), and 2080 (end century).
The Principle AgrometObservatory of the College of Agriculture, KAU, Vellanikkara supplied the necessary weather information for the experiment, including the maximum temperature, minimum temperature, bright sunshine hours and rainfall. The bright sunshine hours converted to solar radiation using Decision Support System forAgrotechnology Transfer (DSSAT) weatherman.

## 2.4 Crop simulation models

The challenges posed by climate change demand an exceptional capability to predict crop responses to the environment and management. Crop growth is an extremely complex phenomenon that results from a series of complex interactions between soil, plant, and weather. Dynamic crop growth simulation is a modern technique that allows for a quantitative understanding of the impact of these and other agronomic management parameters on crop growth and productivity. Info-Crop (Information on Crop) and Decision Support System for Agrotechnology Transfer (DSSAT) are such dynamic crop simulation models which are used in the current study. Calibration is the process of making arbitrary changes to parameter/ coefficient values in a model to match data from the real experiment and was done by adjusting genetic coefficients. Calibration of genetic coefficients for Info-Crop and CERES-DSSAT model has been done with datasets including date of planting, spacing, plant density, irrigation details, leaf area, phenophases, method of harvesting, and yield details.

**2.4.1 Validation of models**

Statistical parameters like Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Bias Error (MBE), and Percent Error (PE) are used to evaluate the goodness of fit and performance of the model (AgriMetSoft, [21]).

Percent Error (PE) is calculated by using the formula: (simulated-observed)/observed*100.

Root Mean Square Error (RMSE) is the square root of the variance of the residuals. It indicates the absolute fit of the model to the data–how close the observed data points are to the model's predicted values. RMSE is a standard way to measure the error of a model in predicting quantitative data.

Formally, RMSE is defined as follows:

$$RMSE = \sqrt{[\ \Sigma(Pi - Oi)^2 / n\ ]}$$

Where Pi is the predicted value for the $i^{th}$ observation
Oi is the observed value for the $i^{th}$ observation
n is the sample size

RMSE is always non-negative, and a value of 0 (almost never achieved in practice) would indicate a perfect fit for the data. In general, a lower RMSE is better than a higher one.

Mean Absolute Error is simply, as the name suggests, the mean of the absolute errors. The absolute error is the absolute value of the difference between the forecasted value and the actual value. It measures accuracy for continuous variables and indicates how big of an error we can expect from the forecast on average.

$$MAE = \frac{1}{n} \times \sum_{i=1}^{n} (|O_i - P_i|)$$

|Oi - Pi| = the absolute errors and Σ = summation symbol

Mean bias error is primarily used to estimate the average bias in the model and to decide if any steps need to be taken to correct the model bias.

$$MBE = \frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)$$

## 3. RESULTS AND DISCUSSION

### 3.1 Comparison of observed and predicted duration during base period

Duration of each phenophase for both the selected varieties had been observed and recorded from transplanting to 50% flowering and to physiological maturity. Jyothi (short duration variety) has taken 71 days and Jaya (medium duration variety) has taken 75 days to reach 50% flowering stage. During present condition, the total crop duration was found to be 101 and 108 days for Jyothi and Jaya varieties respectively. Info-Crop and CERES models are calibrated for the duration of 50% flowering and physiological maturity stages of Jyothi (short duration variety) and Jaya (medium duration variety). For 50% flowering phenophase, it was observed that Jyothi has taken 71 days while Jaya has taken 75 days from transplanting. Jyothi and Jaya varieties simulated by using the given genetic coefficients. The Info-Crop and CERES-DSSAT model predicted duration of 50% flowering stage of Jyothi variety was 73 and 71 days respectively. For Jaya variety, both models predicted the duration of 76 days to reach flowering stage.

### 3.1.1 Validation of Info-Crop and CERES-DSSAT models

The validation for the 50% flowering prediction of both models was done. Info-Crop and CERES-DSSAT models validation results for the 50% flowering and physiological maturity of both rice varieties represented in Table 2. Info-Crop model showed Percent Error 2.8% and MAE, RMSE and MBE of 2 for Jyothi variety. CERES-DSSAT model showed 0.4 MAE, 0.6 RMSE, 0 MBE and 0% Percent Error for short duration variety viz., Jyothi. The Info-Crop and CERES-DSSAT models had 0.4 MBE and 0.5% Percent Error for the predicted duration of 50% flowering in Jaya. MAE and RMSE of 0.4 and 0.6 for Info-Crop and MAE and RMSE of 1.2 and 1.4 in case of CERES-DSSAT model was observed in Jaya variety. In case of Jyothi, CERES-DSSAT predicted more accurately while in Jaya InfoCrop predicted more accurately days to 50% flowering. Validation results revealed that both crop models are good in agreement with the observed values of 50% flowering duration of rice varieties in the central zone of Kerala.The observed crop duration from transplanting to physiological maturity was 101 and 110 days in Jyothi and Jaya respectively. The Info-Crop and CERES-DSSAT models predicted crop duration was 100 and 98 days for Jyothi while it was 103 and 109 days for Jaya variety respectively. The validation for physiological maturity stage of both the varieties was carried out for Info-Crop and CERES-DSSAT models. For Jyothi variety, Info-Crop model showed 2.4 MAE, -1.6 MBE, 2.6 RMSE and -1.6 % PE. For Jaya variety crop duration, CERES-DSSAT model had MAE of 2.8, MBE of -2.8, RMSE of 3.4 and -2.7% PE. Validation of Info-Crop rice model with 7.2 MAE, -7.2 MBE, 7.4 RMSE and -6.5% PE whereas CERES-DSSAT model with 1.8 MAE, -1 MBE, 1.8 RMSE and -0.9% PE was found for Jaya variety duration. The validation results for physiological maturity duration of short and medium duration rice varieties showed that the InfoCrop as well as CERES-DSSAT models are predicting the crop duration accurately.

Table 2. Validation results for 50% flowering and physiological maturity of rice varieties

| | Validation results for 50% flowering duration | | | | |
|---|---|---|---|---|---|
| Variety | Model | PE | MAE | RMSE | MBE |
| Jyothi | Info-Crop | 2.8 | 2 | 2 | 2 |
| | CERES-DSSAT | 0 | 0.4 | 0.6 | 0 |
| Jaya | Info-Crop | 0.5 | 0.4 | 0.6 | 0.4 |
| | CERES-DSSAT | 0.5 | 1.2 | 1.4 | 0.4 |
| | Validation results for physiological maturity duration | | | | |
| Variety | Model | PE | MAE | RMSE | MBE |
| Jyothi | Info-Crop | -1.6 | 2.4 | 2.6 | -1.6 |
| | CERES-DSSAT | -2.7 | 2.8 | 3.4 | -2.8 |
| Jaya | Info-Crop | -6.5 | 7.2 | 7.4 | -7.2 |
| | CERES-DSSAT | -0.9 | 1.8 | 1.8 | -1 |

## 3.2. Phasic development of rice varieties under future climatic conditions

The duration of 50% flowering and physiological maturity stages of Jyothi, as well as Jaya varieties, were predicted using Info-Crop and CERES-DSSAT models for the near century (2030), mid-century (2050), and end century (2080) using two scenarios viz., RCP 4.5 and RCP 8.5 of the GFDL-CM3 climate model.

Duration of 50% flowering predicted by Info-Crop model was 70, 70, and 69 days in Jyothi while it was 74, 73 and 73 days for Jaya variety, under RCP 4.5 scenario of near (2030), mid (2050), and end (2080) century respectively. Under RCP 4.5 scenario, CERES-DSSAT model predicted duration of 50% flowering for Jyothi variety was 70, 69 and 68 days whereas for Jaya variety it was 74, 74 and 73 days in the near, mid, and end century respectively. In case of transplantingto physiological maturity duration under RCP 4.5 scenario, InfoCrop model predicted 97, 96 and 94 days for Jyothi whereas 104, 101 and 102 days for Jaya variety, while CERES-DSSAT model predicted 97, 96 and 95 days for Jyothi and 107, 106 and 105 days for Jaya, in near (2030), mid (2050) and end (2080) century respectively. Days to 50% flowering under RCP 8.5 scenario, the Info-Crop model predicted 72, 70 and 69 days for Jyothi and 75, 73 and 73 days for Jaya in near (2030), mid (2050) and end (2080) century respectively. CERES-DSSAT model predicted 70, 68 and 68 days for Jyothi and 75, 74 and 73 days for Jaya, in near, mid and end century respectively. Days to physiological maturity under RCP 8.5 scenario,InfoCrop model predicted 98, 96 and 94 days for Jyothi and 106, 101 and 102 days for Jaya in near (2030), mid (2050) and end (2080) century respectively.CERES-DSSAT model predicted 98, 96 and 94 days for Jyothi and 108, 106 and 104 days for Jaya, in near, midand endcentury respectively.

### 3.3. Comparison of phasic development of rice under present condition with future climatic conditions

Info-Crop and CERES-DSSAT models showed lesser days for transplanting to 50% flowering of rice varieties under future conditions of both the scenarios compared to present condition, as shown in Table 3. The predicted duration of Jyothi variety was 73 days in Info-Crop model and 71 days in CERES-DSSAT model, for the present condition. Under RCP 4.5 scenario, Jyothi variety duration was projected to reduce by 3-4 days whereas under RCP 8.5 scenario it's duration reduced by 4-6 days by 2080s. For Jaya variety, Info-Crop and CERES-DSSAT models predicted duration for the base period was 76 days to attain 50% flowering stage. Duration of Jaya variety is projected to reduce by 3days by the end century under both the scenarios, predicted by both the Info-Crop and CERES-DSSAT models. Impact of maximum temperature on days from transplanting to 50% flowering stage under RCP 4.5 is shown in Figure 1 (a) Jyothi and (b) Jaya. The days from transplanting to 50 % flowering stage under RCP 8.5 scenario is represented in Figure 2 (a) Jyothi and (b) Jaya varieties. For both the varieties, during transplanting to 50% flowering stage, the maximum temperature from the base period is expected to rise by approximately 2°C under RCP 4.5 scenario and 3°C under RCP 8.5 scenario by the end century.Raoufi and Soufizadeh[22] simulated the impacts of climate change on phenology, growth and yield of various rice genotypes in humid sub-tropical environments using AquaCrop-Rice model. The results showed that the temperature was more influencing both the vegetative and reproductive phases. They reported that the higher temperature accelerates the flowering as well as physiological maturity stage. Shrestha et al. [23] reported that sowing, transplanting, anthesis and maturity were earlier by 5.4, 3.2, 6.2 and 4.8 days decade$^{-1}$ in Madagascar. The current study results also showed that the increase in maximum temperature during future conditions might be a major cause for the reduced duration of rice varieties.

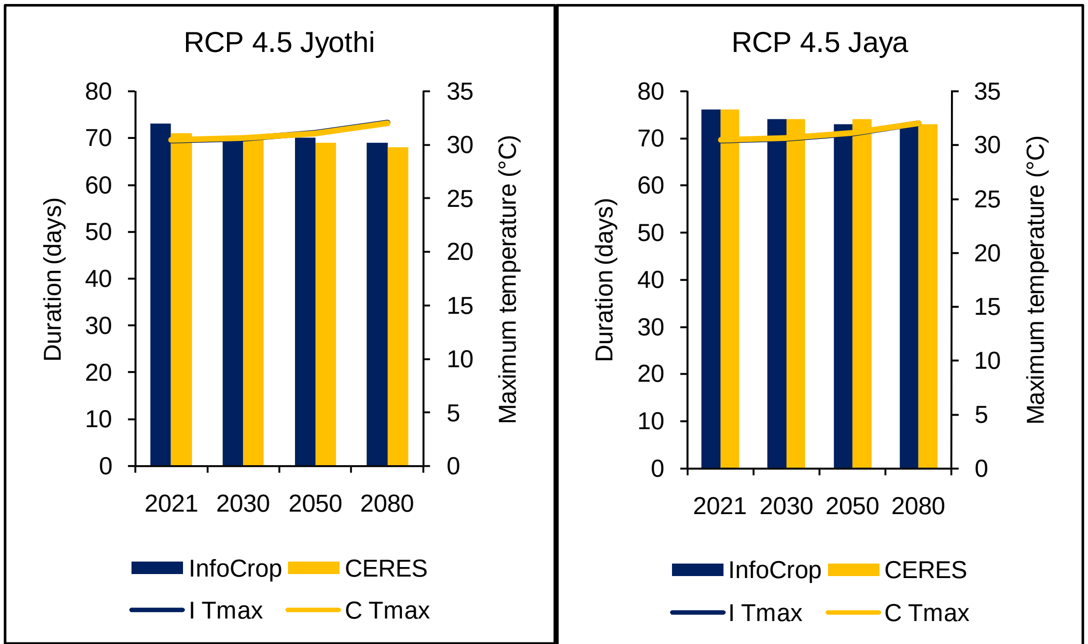
Table 3.The change in days from transplanting to 50% flowering of rice varieties from the base period to future projected climatic conditions

| Scenario | Year | Info-Crop | | CERES-DSSAT | |
|---|---|---|---|---|---|
| | | Jyothi | Jaya | Jyothi | Jaya |
| Base period | 2021 | 73 | 76 | 71 | 76 |
| RCP 4.5 | 2030 | 70 | 74 | 70 | 74 |
| | 2050 | 70 | 73 | 69 | 74 |
| | 2080 | 69 | 73 | 68 | 73 |
| RCP 8.5 | 2030 | 72 | 75 | 70 | 75 |
| | 2050 | 70 | 73 | 68 | 74 |
| | 2080 | 69 | 73 | 68 | 73 |

The predicted duration of transplanting to physiological maturity of rice varieties by InfoCrop and CERES-DSSAT models was decreased from the present to future conditions of both RCP 4.5 and 8.5 scenarios compared to base period for both Jyothi and Jaya, as shown in Table 4. Jyothi variety shown duration of 100 days in Info-Crop model and 98 days in CERES-DSSAT model, for the base period. Under RCP 4.5 scenario, Jyothi variety showed reduction of 3-6 days whereas under RCP 8.5 scenario, it's duration reduced by 2-4 days by 2080s. For the base period, Jaya variety had predicted crop duration of 103 and 109 days by InfoCrop and CERES models respectively. The crop duration of Jaya variety was projected to reduce by 1-4 days under RCP 4.5 scenario and 1-5 days under RCP 8.5 scenario by the end (2080) century. Impact of maximum temperature on physiological maturity duration of rice varieties represented in Figures 3 and 4. According to findings of Rani and Maragatham [24], compared to the ambient temperature (108 days), the time taken for plants to reach maturity at elevated temperature was less i.e., at 4°C (96 days) and at 2°C (102 days). Zhang and Tao [25] modeled the response of rice phenology to climate change and variability in different climatic zones. They found that under future climate scenarios, all the five models considered for the study, predicted the reduction in the duration of rice crop with temperature rise. Saseendran et al. [26] studied the effect of climate change on the rice crop in humid tropical humid conditions of Kerala, using CERES rice model, in which they found that the rice maturity period is projected to shorten by 8% with temperature rise in future. The current study revealed that the days to physiological maturity reduced under higher temperature conditions compared to lower temperature.

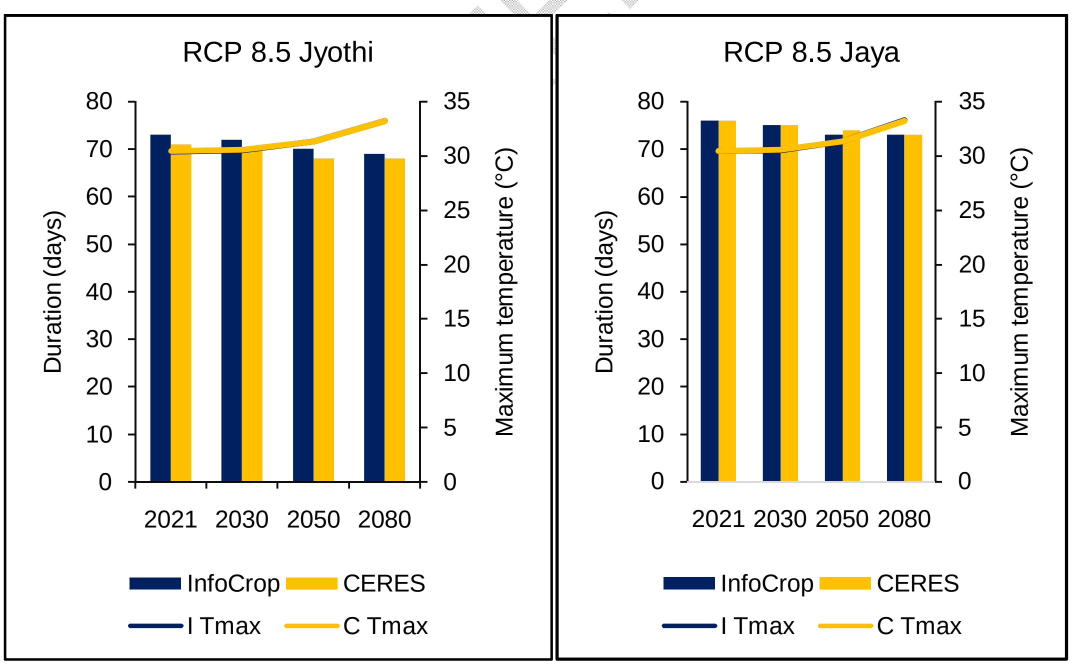
Table 4.The change in duration of transplanting to physiological maturity of rice varieties from the base period to future projected climatic conditions

| Scenario | Year | Info-Crop | | CERES-DSSAT | |
|---|---|---|---|---|---|
| | | Jyothi | Jaya | Jyothi | Jaya |
| Base period | 2021 | 100 | 103 | 98 | 109 |
| RCP 4.5 | 2030 | 97 | 104 | 97 | 107 |
| | 2050 | 96 | 101 | 96 | 106 |
| | 2080 | 94 | 102 | 95 | 105 |
| RCP 8.5 | 2030 | 98 | 106 | 98 | 108 |
| | 2050 | 96 | 101 | 96 | 106 |
| | 2080 | 94 | 102 | 94 | 104 |



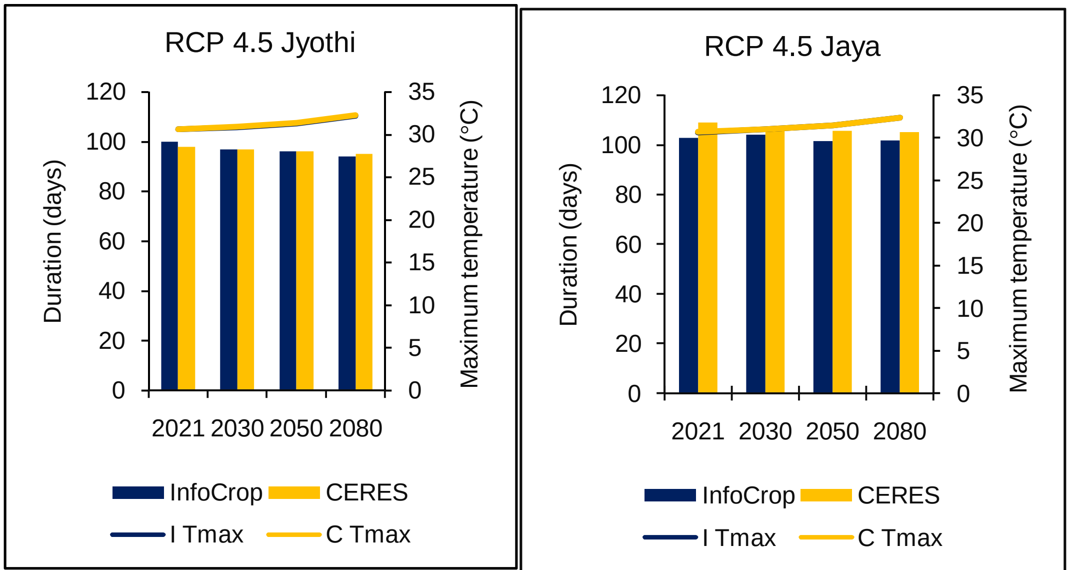

(a) (b)

Fig. 1. Impact of maximum temperature during present and future conditions under RCP 4.5 scenario on the transplanting to 50% flowering duration of (a) Jyothi - Short duration variety (b) Jaya - Medium duration variety



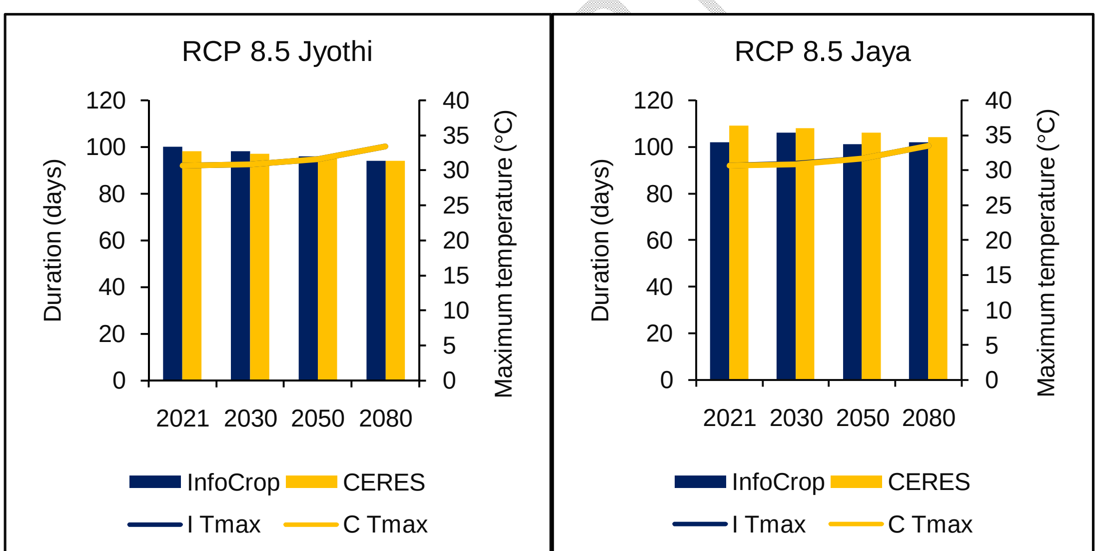

(a) (b)

Fig. 2. Impact of maximum temperature during present and future conditions under RCP 8.5 scenario on the transplanting to 50% flowering duration of (a) Jyothi - Short duration variety (b) Jaya - Medium duration variety




(a) (b)

Fig. 3. Impact of maximum temperature during present and future conditions under RCP 4.5 scenario on the duration of (a) Jyothi - Short duration variety (b) Jaya - Medium duration variety




(a) (b)

Fig. 4. Impact of maximum temperature during present and future conditions under RCP 4.5 scenario on the duration of (a) Jyothi - Short duration variety (b) Jaya - Medium duration variety

## Conclusion:

From the study, it was found that the temperature rise in future have significant impact on the duration of both 50% flowering and physiological maturity in rice varieties. The InfoCrop and CERES-DSSAT models are predicting the reduced duration from the present situation to future simulations. Both short duration as well as medium duration varieties may experience higher maximum temperature and this might have reduced the crop duration in future compared to base period.

**COMPETING INTERESTS**

AUTHORS HAVE DECLARED THAT NO COMPETING INTERESTS EXIST.

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