Climate Change

# Exploring the impact of climate change on selected local rice genotypes in the Coastal Savannah agroecological zone of Ghana

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## ABSTRACT

In Ghana, rice (Oryza sativa) is the second most significant cereal crop after maize. However, rice cultivation faces several challenges, including low yields further aggravated by climatic variability, raising substantial concerns for food security. This study aimed to evaluate the impact of climate change impact on the growth and yield of four local rice genotypes (*CRI-Amankwatia, CRI-Dartey, Ex-Baika,* and *Ex-Viono)* cultivated in the Coastal Savannah agroecological zone using the calibrated and evaluated CRES-Rice model within the Decision Support System for Agrotechnology Transfer (DSSAT). The CERES-Rice crop model within the DSSAT software was employed to predict rice yields for two planting seasons under mid-21st-century climate scenarios (2040–2069) from two Representative Concentration Pathways (RCPs 4.5 and 8.5). These predictions were compared to simulated yields from a historical period (1980–2009) using five Global Circulation Models (GCMs): CCM4, MPI-ESM-MR, HadGEM2-ES, GFDL-ESM2M, and MIROC5. The findings suggest that declining rainfall and rising temperatures due to climate change could shorten the flowering and maturity periods. Further, rice production declined in both seasons across all climate scenarios, with the most significant decline occurring during the minor (dry) season, reaching up to 28.3% under the higher emission scenario. This research constitutes the first evaluation of climate change impacts on the four indigenous rice genotypes within the Coastal Savannah agroecological zone of Ghana.

**Keywords:** Coastal Savannah, climate change, local rice, genotypes, resilience

# 1. INTRODUCTION

Agriculture is the primary food source worldwide, providing essential cereal crops such as rice, wheat, and maize. It directly sustains billions of people across the globe. In Ghana, agriculture is a cornerstone of the economy. It contributes about 20% to the GDP and employs over 40% of the labour force (Sogah et al., 2024; Nyamekye et al., 2021). The most significant food grain cultivated globally is rice. The global demand for cereals, especially rice, has increased dramatically over the past four decades due to population expansion and the resulting rise in consumption particularly, among the urban dwellers (Klutse et al., 2018).

Rice is frequently highlighted as a food security crop by the Food and Agriculture Organization (FAO) because of its nutritional, economic, and cultural significance, and its ability to support the daily dietary needs of over 3.5 billion people globally. It is essential to ensure the stability of the global food supply. Ghana consumes about 80,000 metric tonnes of rice annually, with an average of 35 kg consumed per person (MoFA, 2022). However, domestic rice production is inadequate to satisfy the growing demand, leading to substantial annual import expenditures to bridge the supply gap and avert potential food crises.

Insufficient agricultural output remains a key contributor to food insecurity. Rice production is affected by several factors, such as agronomic practices and environmental conditions. The key management practices that play a critical role encompass tillage operations, selection of cultivars, sowing density, timing of transplanting, plant density, fertilizer application strategies, chemical inputs, and irrigation management. The environmental factors include temperature, rainfall, sunlight, wind, and humidity greatly influence crop growth and yield (Halder et al., 2020).

Technological innovations in agriculture, such as enhanced crop varieties and advanced irrigation techniques, have not diminished the substantial influence of weather and climate on agricultural productivity (Mukhopadhyay and Das, 2023). Climate change represents one of the most pressing challenges confronting global agriculture, profoundly affecting food security, particularly in at-risk regions such as sub-Saharan Africa. Ghana’s Coastal Savannah agroecological zone has unique climate and soil conditions essential for supporting rice farming involving rain-fed and irrigated systems. However, rice cultivation in this area faces significant risks from climate change.

These include temperature alterations, shifts in rainfall patterns, and extreme weather phenomena (Adiku et al., 2015). Rice genotypes demonstrate varying levels of resilience when exposed to environmental stresses, including drought, salinity, and temperature fluctuations. It is crucial to understand the impact of climate change on these local rice genotypes to maintain and enhance rice production in the face of these challenges. Studies have shown that some rice genotypes may be more resilient to stress conditions, which could be essential for food security in the Coastal Savannah zone. The study assesses how climate change affects specific rice genotypes cultivated in Ghana's Coastal Savannah zone.

A Decision Support System for Agroecological Transfer (DSSAT) was employed. The DSSAT-CERES-Rice model, in conjunction with climate models, has been widely used in recent studies to assess the possible effects of climate change on future rice growth and yields (Ansari et al., 2021; Alejo, 2021; MacCarthy et al., 2017). Climate models offer forecasts of forthcoming climatic scenarios, while crop models, exemplified by DSSAT-CERES-Rice, replicate the growth and yield of crops by integrating anticipated climate variables with essential factors such as soil characteristics, management strategies, and agronomic traits (Hoogenboom et al., 2019).

This study aims to determine the rice genotypes that are most resilient for cultivation in this climate-vulnerable region by evaluating their performance under changing environmental conditions. The results will help create climate-smart farming methods essential for sustaining rice production in Ghana and other similar agroecological zones. This research represents a novel application of the DSSAT CERES-Rice model to evaluate the effects of climate change on four distinct local rice genotypes.

# 2. MATERIALS AND METHODS

### Study Area

The research was conducted at the Soil and Irrigation Research Centre (SIREC) of the University of Ghana in Kpong. This location is within the Coastal Savannah agroecological zone of the country. The research covered April to July (wet season) and September to December (dry season) of 2022 growing seasons. The wet and dry seasons are commonly referred to as the *major* and *minor* seasons, respectively, in Ghana. The site is 22 meters above mean sea level, at latitude 60 09 N and longitude 00 04 E. The terrain features gentle slopes varying from 1% to 5% (MacCarthy et al., 2020). The study zone experiences a bimodal rainfall with an average annual total between 600 and 1200 mm.

It supports two distinct cropping seasons: The wet season, which occurs from April to June, and the dry season, from September to November. The yearly average temperature is approximately 27.2 $^0$C, with 22.1 and 33.3 $^0$C being the annual minimum and maximum temperatures. The soil within the study area is identified as calcic vertisol, characterized by its dark coloration. The expansive clay soil when wet expands and gets sticky, but contracts and becomes hardened when it dries. This causes significant cracks during dry spells. The meteorological information for the field trial was collected from a standard weather station at the research facility, approximately 80 meters from the experimental field.

### Data sources for the model

The data necessary for simulating the crop model was collected from multiple references. Information regarding soil data, including soil properties, soil texture, runoff coefficient, and soil organic carbon, was acquired from the research field. Other characteristics of the soil surface information, such as slope, drainage rate, color, and moisture-retaining characteristics of the various soil layers, were used in soil file construction, following the methodology outlined by (Ritchie, 1998). The data points were then used to construct the weather file (using the weatherman). Additionally, 30 years of historical weather data and five Global Circulation Models (GCMs) were used in evaluating climate change impact.

The GCMs used were CCM4, MPI-ESM-MR, HadGEM2-ES, GFDL-ESM2M, and MIROC5. In creating the management file for the model, crop management factors consisting of planting date, planting depth, planting distance, plant population, fertilizer application times and rates, and irrigation were used. The crop growth and yield parameters, including days to anthesis, maturity, biomass, and grain yields, were measured for four rice genotypes (*CRI-Amankwatia*, *CRI-Dartey*, *Ex-Baika*, and *Ex-Viono*). These genotypes were grown under three rates (0N, 45N, and 90N kg ha$^{-1}$) of inorganic nitrogen fertilizer (urea) during two cropping seasons

### The description of the DSSAT-CERES-Rice model

The DSSAT-CERES-Rice model (version 4.8) is a process-based simulation tool. This model is a computer-based simulation tool developed to assess rice growth, development, and yield across various environmental conditions, management strategies, and genetic traits. The model integrates various biophysical processes, including crop phenology, photosynthesis, water and nutrient dynamics, and soil-plant-atmosphere interactions. The model also supports a range of applications, such as climate change impact assessment, management practice maximization, and enhancement of crop breeding (Jones et al., 2003; Hoogenboom et al., 2019).

The DSSAT model also includes modules to assess water stress, nitrogen uptake, and soil moisture dynamics, providing a detailed understanding of crop responses to environmental factors and management strategies (Tsuji et al., 1998). The updated DSSAT-CERES-Rice model improves usability, aligns with recent scientific advances, and enables scenario analysis of agricultural practices and environmental conditions (Hoogenboom et al., 2019). The model was calibrated using data on soil characteristics, climatic factors, agricultural management practices, and empirical results derived from field trials. Simulations were performed using weather data from the past 30 years, covering the period from 1980 to 2009.

The output from the simulations and the yield from predicted weather data, obtained from the five GCMs were compared. The research focused on two distinct climate scenarios, namely RCP 4.5, which represents moderate greenhouse gas emissions, and RCP 8.5, indicative of high greenhouse gas emissions, spanning the mid-21st century (2040 to 2069). The DSSAT program includes a sensitivity analysis module that allows users to evaluate the effects of various variable values on crop development and yield. Further details regarding the DSSAT-CERES-Rice model refer to the works of (Ritchie, 1998; Hoogenboom et al., 2019).

### Model setup, calibration and evaluation

For the model calibration and validation, we used data sets from the 2022 wet and dry cropping seasons with the highest nitrogen fertilizer application (90 kg ha$^{-1}$) and without water trees. The data obtained from the wet season were used for calibration, while those obtained from the dry season were used for validation. The assessment of model performance concerning calibration and validation was conducted using two statistical metrics: the root means square error (RMSE) and Willmott's d-value, which serves as an indicator of agreement.

RMSE = [n−1 ∑ (Yieldsimulated − Yieldobserved) 2]0.5

$$d - value = 1 - \frac{\sum_{i=1}^{n}(Observed_i - Simulated_i)}{\sum_{i=i}^{n}(|Simulated_i - Mean_{observed}| + |Observed_i - Mean_{observed}|)}$$

The d-values span from 0 to 1, with a value of 1 signifying a perfect fit, while a value of 0 denotes complete disagreement between the observed and predicted datasets. A comprehensive discussion of the above statistical metrics is available in the publications by (Willmott et al., 1985).

The ideal combination of genetic coefficients that provides the most precise estimation of growth and yield for the four rice genotypes is presented in (Table 1). This set of genetic coefficients includes phenological coefficients (P1, P2O, P2R, and P5) as well as growth coefficients (G1, G2, G3, and G4). The coefficients were established following the model's consistent ability to reproduce the observed growth and yield data from the 2022 major (wet) and minor (dry) cropping season experiments.

**Table 1** Genetic coefficients of rice parameters for calibration

| Co-efficient definition | Genotypes | | | |
|---|---|---|---|---|
| | CRI-Amankwatia | CRI-Dartey | Ex-Baika | Ex-Viono |
| P1 | 731.6 | 697.1 | 650.8 | 559.2 |
| P2O | 224.1 | 226.4 | 206.3 | 184.3 |
| P2R | 631.4 | 582.7 | 586.6 | 552.9 |
| P5 | 11.63 | 12.88 | 12.5 | 11.23 |
| G1 | 58.63 | 61.59 | 59.37 | 55.2 |
| G2 | 0.033 | 0.023 | 0.026 | 0.025 |
| G3 | 1.311 | 1.145 | 0.914 | 1.312 |
| PHINT | 83 | 88 | 83 | 55 |
| THOT | 32.12 | 33.21 | 33.07 | 32.06 |

## 3. RESULTS

**Calibration and validation of the model**

The calibration of the model was highly effective across the four rice genotypes (*CRI-Amankwatia, CRI-Dartey, Ex-Baika,* and *Ex-Viono*). Grain yield simulations were precise, with RMSE values ranging from 66.9 to 293.7 kg $ha^{-1}$ for the different genotypes. The d-values were close to or equal to 1 confirming the model's accuracy in predicting the phenology and yields of all tested rice genotypes (Table 2).

The validation process similarly demonstrated that the model using the derived genetic coefficients could deliver an adequate estimate of the growth and yields of the four rice genotypes, as evidenced by its simulated yield outcomes. The RMSE for grain yields of the rice genotypes ranged from 630.7 to 829.3 kg $ha^{-1}$, satisfactorily matched with observed values (Table 3). The DSSAT-CERES-Rice model, therefore, can serve as a valuable tool for projecting future rice growth and yields across various climate change scenarios.

**Table 2** Calibration of the model performance in simulating rice phenology

| CRI-Amankwatia | | | CRI-Dartey | | Ex-Baika | | Ex-Viono | |
|---|---|---|---|---|---|---|---|---|
| | d-value | RMSE | d-value | RMSE | d-value | RMSE | d-value | RMSE |
| ADAT | 1 | 1.3 | 1 | 1.2 | 1 | 1.6 | 1 | 1.5 |
| MDAT | 0.8 | 5.6 | 0.8 | 2.5 | 1 | 1.2 | 0.8 | 2.9 |
| GY | 1 | 152.7 | 1 | 293.8 | 0.9 | 66.9 | 0.9 | 266.9 |

ADAT = anthesis date; MDAT = maturity date; GY = grain yield

**Table 3** Model performance evaluation in simulating rice phenology

| CRI-Amankwatia | | | CRI-Dartey | | Ex-Baika | | Ex-Viono | |
|---|---|---|---|---|---|---|---|---|
| | d-value | RMSE | d-value | RMSE | d-value | RMSE | d-value | RMSE |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ADAT | 0.9 | 3.3 | 1 | 2.6 | 0.8 | 1.5 | 1 | 1 |
| MDAT | 1 | 12.9 | 0.9 | 5.7 | 1 | 1.3 | 1 | 3.7 |
| GY | 1 | 935 | 0.9 | 630.7 | 0.8 | 803.3 | 0.9 | 829.3 |

ADAT = anthesis date; MDAT = maturity date; GY = grain yield

**Future climate impacts on temperature and rainfall**

Results indicated rising temperatures across all seasons covering the 21st mid-century under the RCPs 4.5 and 8.5. The predicted increase in the average maximum temperature (Tmax) throughout the wet season is estimated to be between 1.20 and 2.12 °C for RCP 4.5 and between 1.7 and 3.59 °C for RCP 8.5. Similarly, the average minimum temperature (Tmin) could rise by 1.18 to 2.40 °C under RCP 4.5 and by 1.67 to 2.65 °C under RCP 8.5. The dry season showed similar trends. The anticipated total rainfall for the minor seasons under RCP 4.5 and RCP 8.5 is estimated to decrease under the five GCMs. The baseline rainfall for wet and dry growing seasons was 488.05 mm and 290.5 mm, respectively.

The average rainfall for the wet season under RCP 4.5 could increase by about 7.22 mm across GCMs for the mid-century (2040-2069), while rainfall for the dry season is projected to decrease by about 18.88 mm. Under RCP 8.5, rainfall for the wet season is projected to increase by 18.53 mm, but for the dry season, rainfall is anticipated to decrease by about 27.37 mm (Figure 1). The Coastal Savanna zone experiences two growing seasons (wet and dry). Future climate projections were also grouped into two separate seasons under various scenarios. The wet season in Ghana comes with the highest total rainfall. The future changes in rainfall indicate that precipitation could become increasingly concentrated during the wet season, while the minor season is projected to experience a reduction in rainfall.

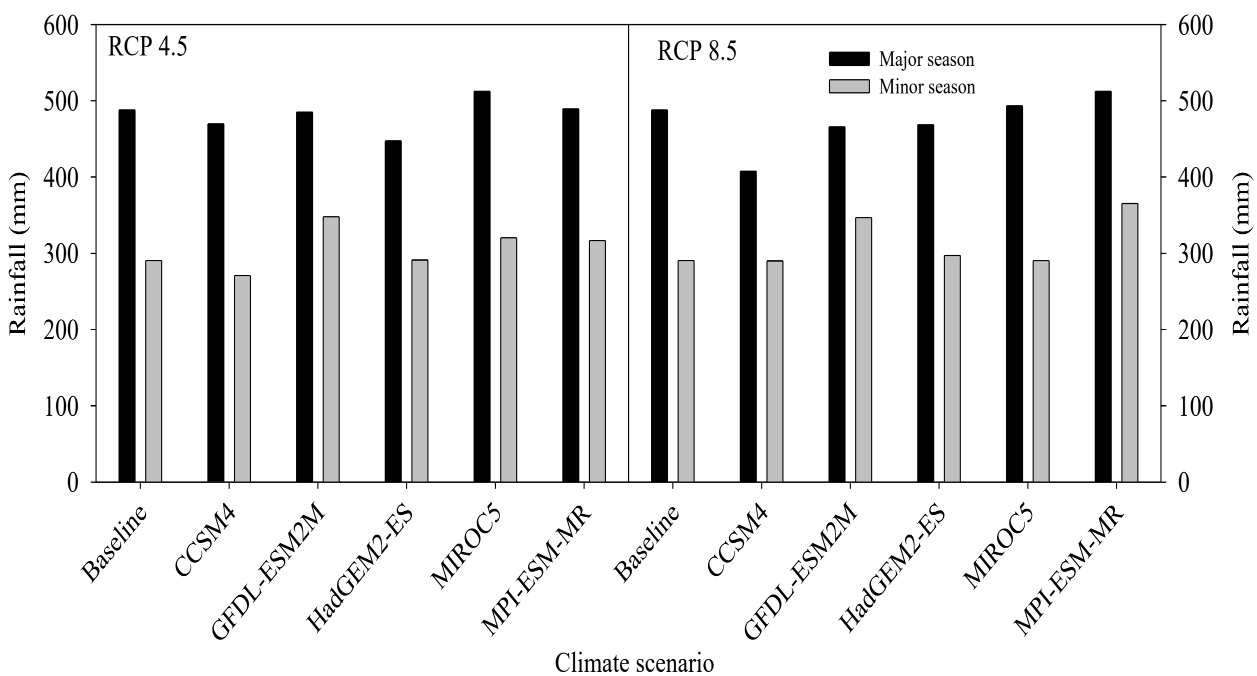


**Figure 1** Comparison of baseline total rainfall amount with the projections made by the five GCMs for the major and minor cropping seasons

**Impact of climate change on rice production**

***Anthesis date (ADAT)***

The CERES-Rice simulation outcome across the four GCMs indicated a reduction in the anthesis date (ADAT) under RCPs. The ADAT for *CRI-Amankwatia*, compared to the baseline, could decrease by up to 0.8% for the wet season and up to 4.1% (3 days) for the dry season under RCPs 4.5 and 8.5. For *CRI-Dartey*, the average baseline ADAT was 76.2 and 74.3 days for major and minor cropping seasons, respectively. However, during the major season, it is projected to decline slightly under RCP 4.5 and 8.5, with reductions of 0.4–0.8% and 0.4–0.6%, respectively. In the dry season, more substantial decreases are anticipated, with 3.0–3.7% (2–3 days) under RCP 8.5 and 3.1–3.6% (2–3 days) under RCP 4.5.

Again, the baseline average ADAT for *Ex-Baika* was 76.5 days for the wet season and 72.3 days for the dry season. For RCP 4.5, ADAT may decline by 0.3–0.7% (1 day) in the wet season and 3.0–3.7% (1–3 days) in the dry season. Similarly, under RCP 8.5, ADAT could decline by 0.2–0.35% in the wet season and by 3.1–4.0% in the dry season. For Ex-Viono, the baseline ADAT was 77.4 days for the wet season and 73.6 days for the dry season, with projected declines under RCP 4.5 (0.1-1.1% and 3.3-4.5%) and RCP 8.5 (0.6-0.7% and 3.8-4.8%) for the respective seasons (Figure 2).

***Maturity date (MDAT)***

The maturity date MDAT for *CRI-Amankwatia* is projected to shorten by 1.3-2.2% (2-3 days) in the wet season and 2.7-4.0% (3-5 days) in the dry season. The baseline MDAT for *CRI-Dartey* was 117.3 days for the major season and 112.3 days for the minor season. It has projected reductions of 1.0–1.8% (1–2 days) in the wet season and 2.6–3.8% (3–4 days) in the dry season under RCPs 4.5 and 8.5. For *Ex-Baika*, the baseline MDAT was 116.5 days for the wet season and 115.5 days for the dry season.

Future projections indicate decreases in MDAT across all GCMs, with reductions of 0.9–1.7% (1–2 days) in the wet season and 2.8–3.9% (3–5 days) in the dry season under RCP 4.5 and 1.1–1.9% (1–2 days) in the wet season and 1.5–4.0% (2–5 days) in the dry season under RCP 8.5. Similarly, *Ex-Viono* has a baseline MDAT of 116.8 days for the wet season and 113.2 days for the dry season. The MDAT could decrease during the wet and dry seasons by 1.3-2.3% (2-3 days) and 2.2-4% (3-5 days), under RCP 4.5. The reductions in MDAT are more pronounced under RCP 8.5, with 1.8-2.4% for the wet season and 4.3.3-4.7% (3-5 days %) for the dry season (Figure 3).

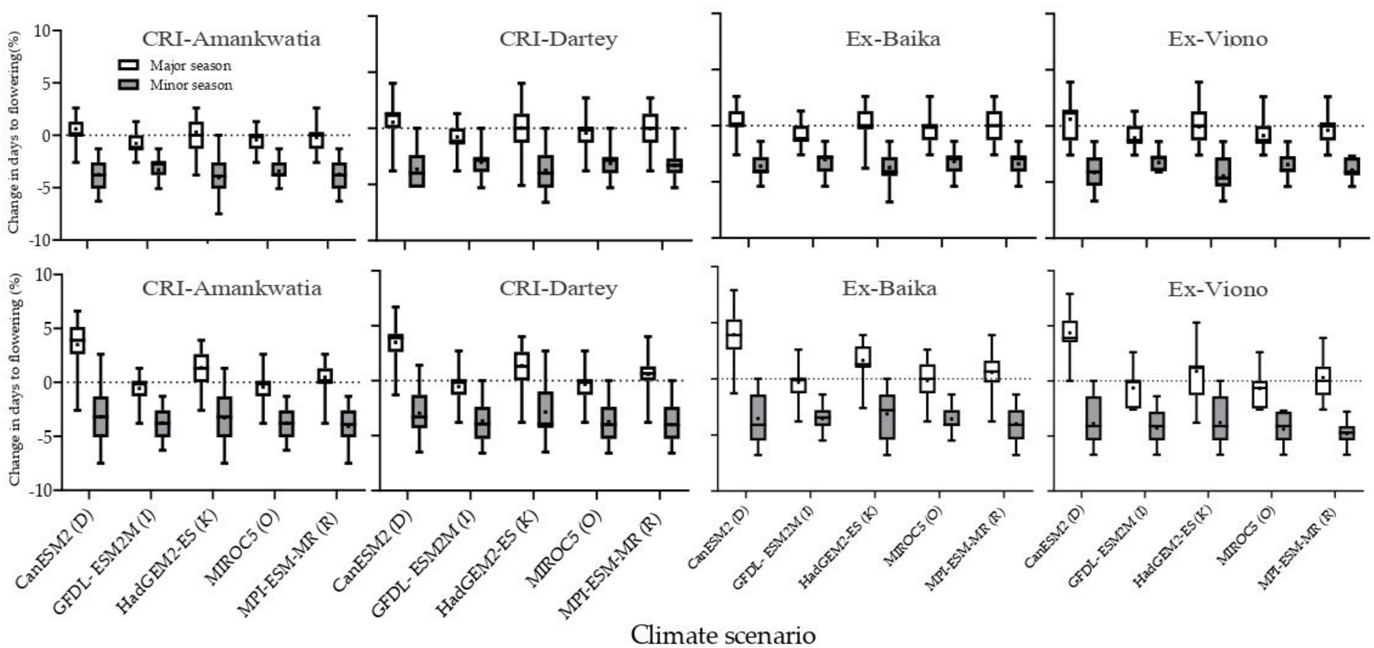


**Figure 2** Predicted impact of climate change on anthesis date (ADAT) under RCP 4.5 (top) and RCP 8.5 (bottom) on four rice genotypes

***Grain yield***

Future climate forecasts based on RCP 4.5 and RCP 8.5 suggest a reduction in grain production for both wet and dry cropping seasons compared to baseline levels. For *CRI-Amankwatia*, simulated mid-century mean yields will decline by 3.3-12% in the wet cropping season and 1.4-16.4% under RCP 4.5 in the dry season. Yield declines are more severe under RCP 8.5, ranging from 6.9-26% in the major season and 5.7-28.3% in the minor season. The baseline mean grain yields for *CRI-Dartey* were 4659.3 kg ha-1 and 3526.1 kg ha-1 for wet and dry seasons, respectively. Under RCP 4.5, yield reductions were projected at 4.7-13.3% for the wet season and 3.1-15.1% for the dry season.

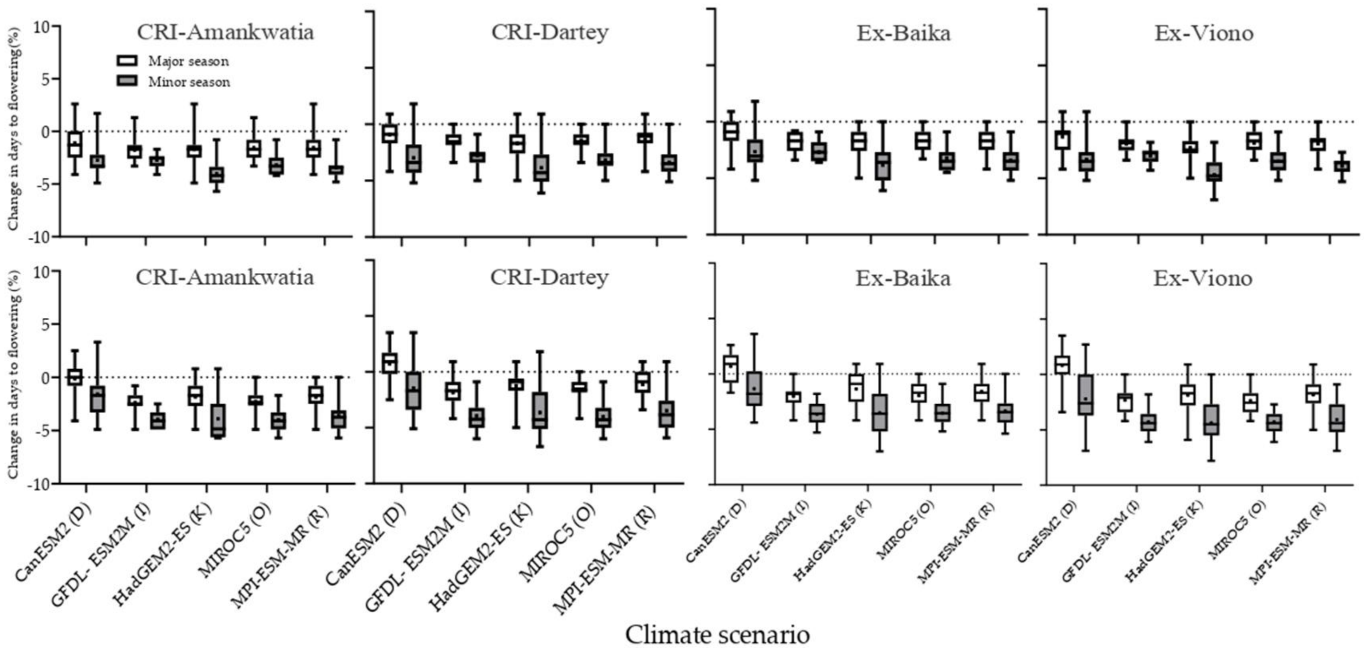


**Figure 3** Predicted impact of climate change on maturity date (MDAT) under RCP 4.5 (top) and RCP 8.5 (bottom) on four rice genotypes

For RCP 8.5, yield declines were more severe, ranging from 7.0-26.1% for the wet season and 5.6-23.5% for the dry season. For *Ex-Baika,* the baseline grain yield was 5078.8 kg ha-1 and 3661.0 kg ha-1 for the wet and dry seasons, respectively. Under RCP 4.5, yield reductions ranged from 2.5-11.0% in the wet season and 2.1-14.7% in the dry season. Similarly, RCP 8.5 projected declines of 5.3-23.4% for the wet season and 3.9-24.3% for the dry season. Furthermore, simulated baseline yields for *Ex-Viono* were 4394.5 kg ha-1 and 3093.1 kg ha-1 for the wet and dry seasons, respectively. Under RCP 4.5, yields dropped by 4.4% to 11.3% in the wet season and by 4.0% to 21.5% in the dry season, whereas under RCP 8.5, wet season declines ranged from 5.2% to 21.4%, and dry season losses varied from 6.2% to 27.9% (Figure 4).

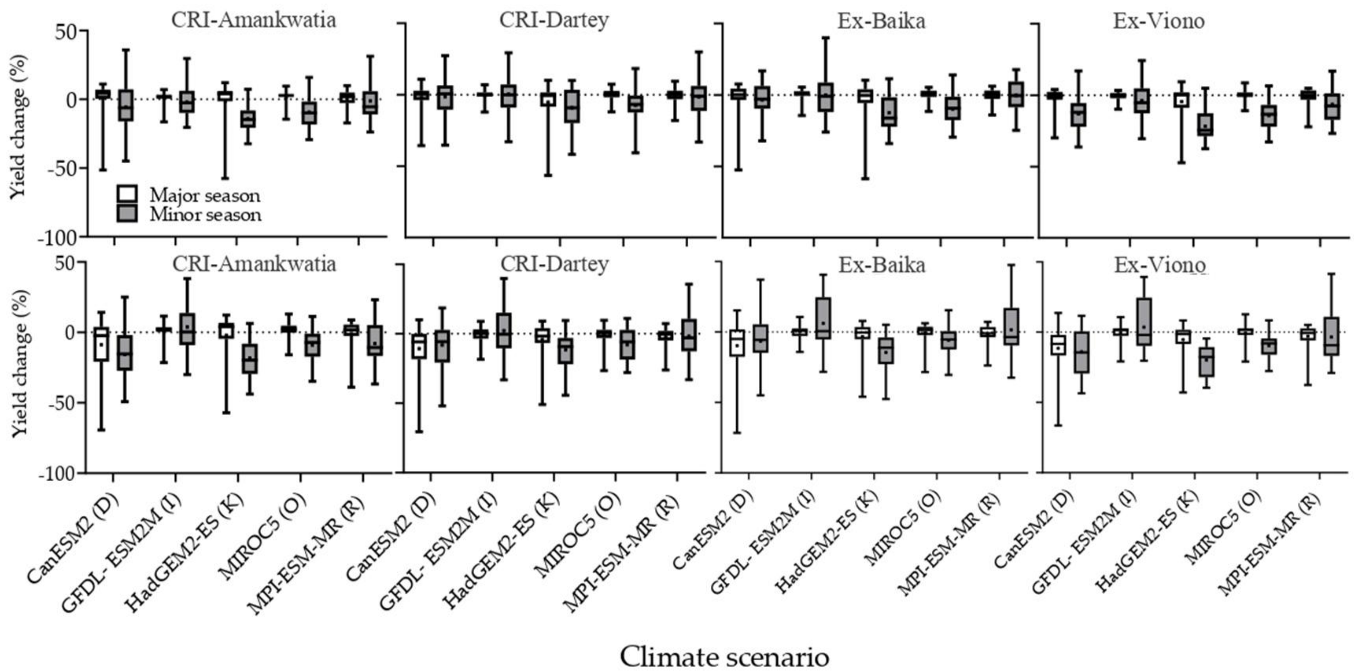


**Figure 4** Predicted impact of climate change on rice grain yield under RCP 4.5 (top) and RCP 8.5 (bottom)

## 4. DISCUSSIONS

The simulation of the CERES-Rice model showed a strong agreement between observed and predicted data, with d-values near one for all four rice genotypes, indicating the high accuracy of the model. The results validate the accuracy of the CERES Rice model in predicting rice production under climate change in the Coastal Savannah zone of Ghana. Climate change has long affected temperature and rainfall patterns. This study predicted temperature increases and rainfall declines under RCP 4.5 and RCP 8.5 for the 21st mid-century (2040-2069). These findings aligned with (Nicolas et al., 2020; MacCarthy et al., 2017).

Both studies used the DSSAT model, and the results showed the impact of climate change on crop growth and yield in diverse regions. Rice is a vital crop and food source globally. Variability in rainfall and temperature make rice crop highly vulnerable to the effects of climate change. Higher temperatures affect rice growth and yield, leading to lower grain yields. This threatens food security, affordability, and accessibility, particularly in developing nations (Fahad et al., 2018). The results from the simulation showed a reduction in phenological durations (flowering and maturity) for all four rice genotypes under future climate conditions.

Increased temperatures across all seasons are projected to shorten anthesis and maturity dates, consistent with findings from other studies using the DSSAT-Rice model (Alejo, 2021; Ansari et al., 2021; Nicolas et al., 2020; MacCarthy et al., 2017). Temperature significantly influences photosynthesis, but increases beyond the optimal threshold can negatively impact rice growth and productivity. During the dry season, *Ex-Viono* experienced the most significant reductions in flowering duration (3.8-4.2%) and days to maturity (approximately 5 days) under RCPs 4.5 and RCP 8.5. This season in Ghana is associated with limited rainfall, low humidity, and elevated temperatures.

Adequate water supply, nutrient availability, and temperature are the three most critical factors responsible for rice growth and productivity. In this study, rice genotypes were grown without water or nutrient stress, isolating the effects of temperature variations. The reductions in phenology observed across the four rice genotypes were caused by temperature changes. Rice productivity will decline under climate change scenarios, with more significant yield losses consistently observed in the dry season across all four rice genotypes under RCPs 4.5 and 8.5. Overall, the findings highlight the vulnerability of rice yields to future climate conditions. The adequate water supply during key growth stages enhances plant productivity.

However, rising temperatures negatively affect crop yields (Fahad et al., 2018). Additionally, warm daytime temperatures create favorable conditions for rice growth, but extreme heat above 35°C negatively affects plant physiology, leading to yield and quality decline. Elevated temperatures decrease net photosynthesis, causing plants to consume more glucose than they produce, which hampers growth and productivity (Hussain et al., 2019). Additionally, thermal stress reduces yield by causing spikelet sterility, a shorter grain filling period and decreased grain size and count (MacCarthy et al., 2020; Hussain et al., 2019). Temperature fluctuations significantly challenge rice production in the Coastal Savannah zone of Ghana.

## 5. CONCLUSIONS

The research investigated the impact of climate change on four rice genotypes (*CRI-Amankwatia, CRI-Dartey, Ex-Baika,* and *Ex-Viono*). The DSSAT-CERES Rice model was employed to predict rice production for the future, using an ensemble of five Global Climate Models under two distinct RCPs, namely 4.5 and 8.5. The calibration and validation of the DSSAT-CERES-Rice model was successful, demonstrating its appropriateness for forecasting the future yields of the four rice genotypes under climate change scenarios. The future climate under both RCPs predicted rising temperatures and declining rainfall patterns, with RCP 8.5 showing the most significant variations.

The simulation revealed a decrease in the average duration of phenological phases for both wet and dry cropping seasons across various GCMs under both RCPs. Rice production experienced a reduction in both growing seasons across all climate change scenarios, with the most significant decrease occurring in the minor (dry) season. This decline could reach as high as 28.3% under the RCP 8.5 scenario by the mid-21st century (2040-2069). Higher temperatures, reduced rainfall, and increased solar radiation are the key factors negatively impacting future rice production under RCPs 4.5 and 8.5. Climate change impacts vary globally, requiring region-specific adaptive strategies tailored to different climatic zones. Thus, we emphasize the need for an urgent and effective adaptive strategy.

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We thank the participants who were all contributed samples to the study.

**Author's Contributions**

Francis Gbefo: Conceptualized the study, designed the field experiment, and led the writing of the manuscript.
Kingsley Joseph Taah: Contributed to the experimental design, and helped to edit the manuscript.
Josiah Wilson Tachie-Menson: Responsible for statistical analysis of the results, and helped in editing the manuscript.
Bright Salah Freduah: Assisted in the simulation of the DSSAT-CERES-Rice model and editing of the manuscript.
Phanuel Klogo: Assisted in data collection during fieldwork, contributed to the introduction section and editing of the manuscript.

**Ethical approval**

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

**Informed consent**

Not applicable.

**Conflicts of interests**

The authors declare that there are no conflicts of interests.

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**Data and materials availability**

All data associated with this study are present in the paper.

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