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Impact assessment of climate change and adaptation measures through different RCPs scenarios using CERES-Wheat model for wheat yield under different agroclimatic zones of Punjab, India

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सार – प्रतिनिधि सांद्रता पथों (RCP 2.6, RCP 4.5, RCP 6.0 और RCP 8.5) के तहत जलवायु परिवर्तन प्रभाव का अध्ययन पंजाब राज्य की स्थितियों में किया गया। अध्ययन क्षेत्र में तीन स्थान शामिल हैं, जिनके लिए एनसेंबल मॉडल के लिए अभिनति शोधित तापमान और वर्षा मौसम संबंधी डेटा एकत्र किया गया और आशंकित और वैध DSSAT CERES-गेहूँ मॉडल में इनपुट के रूप में उपयोग किया गया। दो गेहूं की किस्मों (HD 2967 और PBW 725) के लिए उपज के आकलन के लिए मॉडल को बेसलाइन अवधि (2010-2021) से विचलन का उपयोग करके 70 साल (2025-2095) की समय अवधि के लिए निकट (2025-2055) और दूर (2066-2095) भविष्य के परिदृश्यों में चलाया गया। बुवाई की वर्तमान तारीखों में चार परिदृश्यों जैसे कृषि जलवायु क्षेत्र II बल्लोवाल सौंखरी (4-37% और 0.6- 35%) कृषि जलवायु क्षेत्र III अमृतसर (0.4-32% और 0.3 से 38%) और लुधियाना 0.65-32% और 0.32-38%) के तहत निकट और दूर के भविष्य के लिए विभिन्न कृषि जलवायु क्षेत्रों में उपज में गिरावट देखी गई। दूर भविष्य के दौरान उच्च उत्सर्जन परिदृश्य यानी आरसीपी 8.5 के तहत उपज में बड़ी गिरावट का संकेत दिया गया जबकि आरसीपी 2.6 ने निकट और दूर भविष्य दोनों के दौरान गेहूं की उपज में कम गिरावट का संकेत दिया। विभिन्न स्थानों पर उपज में गिरावट ने विभिन्न भविष्य के परिदृश्यों के तहत अनुकूलित बुवाई गवाक्ष की आवश्यकता का संकेत दिया। अनुकूलित बुवाई खिड़की के परिणामों से पता चला कि दोनों गेहूं की किस्मों को अधिकतम उपज प्राप्त करने के लिए नवंबर के अंतिम सप्ताह में तीनों स्थानों की बुवाई की तारीखों में समायोजन किया गया।

ABSTRACT. The Climate change impact under Representative Concentration Pathways (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5) was studied in Punjab state conditions. The study area includes three locations for which the bias corrected temperature and rainfall meteorological data for Ensemble model was collected and used as input in calibrated and validated DSSAT CERES-Wheat model. The model run for the assessment of yield for two wheat cultivars (HD 2967 and PBW 725) using deviation from the baseline period (2010-2021) for a 70 years (2025-2095) time period in near (2025-2055) and far (2066-2095) future scenarios. The current dates of sowing observed a yield decline at different agroclimatic zones for near and far future under four scenarios as agroclimatic zone II Ballowal Saunkhri (4-37%and 0.6- 35%) agroclimatic zone III Amritsar (0.4-32% and 0.3 to 38%) and Ludhiana 0.65-32% and 0.32-38%). The major decline in yield was indicated under high emission scenario *i.e*. RCP 8.5 during the far future whereas RCP 2.6 indicated low decline in wheat yield during both near and far future. The declination in yield at different locations indicated a requirement of optimized sowing window under different future scenarios. The results for optimized sowing window showed that adjusting in the sowing dates of all the three locations at last week of November for both the wheat cultivars to get maximum yield.

Key words – RCPs, CERES-Wheat, Agroclimatic zone, Optimization, Punjab, India.

1. Introduction

Climate change refers to long-term changes in the earth's climate, primarily due to human activities such as the burning of fossil fuels and deforestation, which release large amounts of greenhouse gases into the atmosphere. Over the last century, the concentration of Co_2 has been increased and becomes long living gas in the atmosphere which act as main contributor of global warming (Mikhaylov *et al*., 2020).

The impact of climate change on wheat crop is well known by various scientists (Asseng *et al*., 2013). As wheat is a staple and third largest crop in the world, wheat plays an important role in maintain the global food security (Balkovic *et al*., 2014).

To understand the projection impacts of climate change, scientists use a variety of scenarios called Representative Concentration Pathways. According to the radiative forcing target level from 2.6 to 8.5 W/m^2, a set of four new pathways, RCP2.6, RCP4.5, RCP6.0 and RCP8.5 were defined. The RCP2.6 emission pathway leads to very low greenhouse gas concentration levels. For the RCP6.0, the radioactive forcing level is at 6.0 W/ m^2 in the year 2100 and RCP8.5 leads to high greenhouse gas emission levels (Riahi *et al*., 2011).

In far future, the world will change in an unimaginable way and it is difficult to imagine how the future climate will be changed and how the crops respond to those climate changes, which results in many uncertainties in these studies (Zhang *et al*., 2019).

In Punjab state, Prabhjyot-Kaur *et al*. (2021) have documented the past climatic changes and the projected changes in temperature and rainfall under RCP scenarios. During the wheat growing season there are projections of increase in temperature especially the minimum temperature, and increased spatio-temporal variability in rainfall. So, the present study investigated the deviation in grain yield in response to climate change for wheat crop under future time period (2021-50 and 2066-2095) in the four agroclimatic zones (ACZs) within Punjab state under four RCPs (RCP 2.6, 4.5, 6.0 and 8.5) scenarios.

2. Material and methods

In present study, two agroclimatic zones of Punjab encompassing three locations which are zone II (Ballowal Saunkhri) and zone III (Ludhiana and Amritsar). These locations were selected due to the availability of meteorological data (temperature and rainfall).

Crop modelling

To predict the yield of mid-century (2021-2050) to end century (2066-2095), the CERES-Wheat model (DSSAT V 4.7.5) was run from the base period (2010-2021) to mid and end century. The temperature and rainfall data as projected by the Ensemble model were downloaded using the MarkSim weather generator (Jones and Thornton 2013) for the four emission-based scenarios (RCPs 2.6, 4.5, 6.0 and 8.5) and bias corrected as per procedures described by Kaur *et al.* (2020).

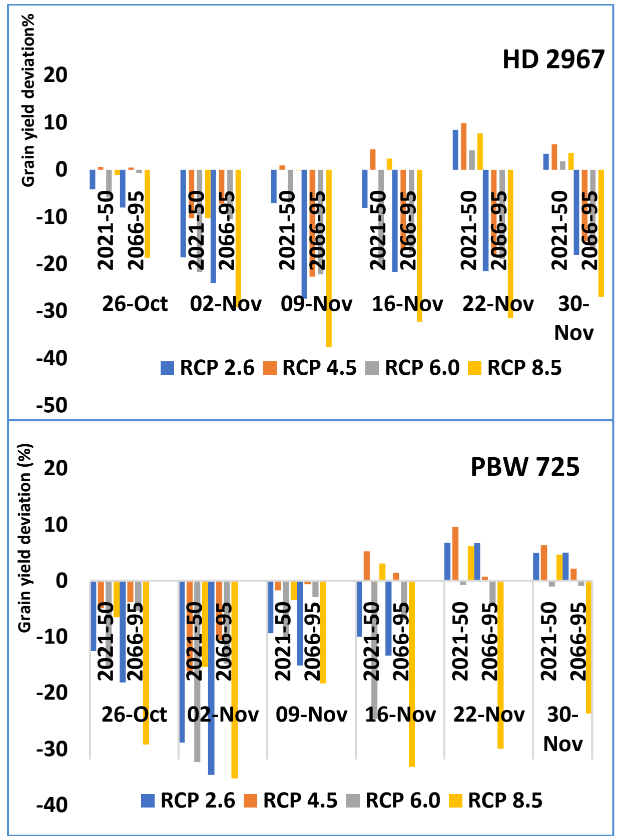

Fig. 1. Deviation in yield of wheat cultivars under RCP scenarios during mid and end century in Agroclimatic zone II (Ballowal Saunkhri)

The CERES-Wheat simulations were performed under the current sowing window of wheat in Punjab as well as for the future sowing window that lies between mid-October to end December and deviation percentage was calculated to quantify the yield increment and decrement (Eq. 1). The simulation study was carried out with two wheat cultivars that are HD 2667 and PBW 725.

$$Deviation\% = \frac{Predicted - Baseline}{Baseline} * 100 \qquad (1)$$

3. Data and methodology

3.1. *Yield trend analysis for different agroclimatic zones of Punjab*

3.1.1. *Agroclimatic zone II (Ballowal Saunkhri)*

The wheat cultivar HD 2967 observed a decline in grain yield for all the RCP scenarios. Where the deviation percent ranged from 4.1 to 27.3% for RCP 2.6: 7.2 to 22.6% for RCP 4.5: 0.7 to 22.1% for RCP 6.0 and 1.1 to 37.0% for RCP 8.5 (Fig. 1) for GCM Ensemble. There is a slightly increment the grain yield by 1.8 to 9.8% near future in mid-century. The RCP 8.5 act as high emission scenario observed a major decline in yield followed by RCP 2.6 in

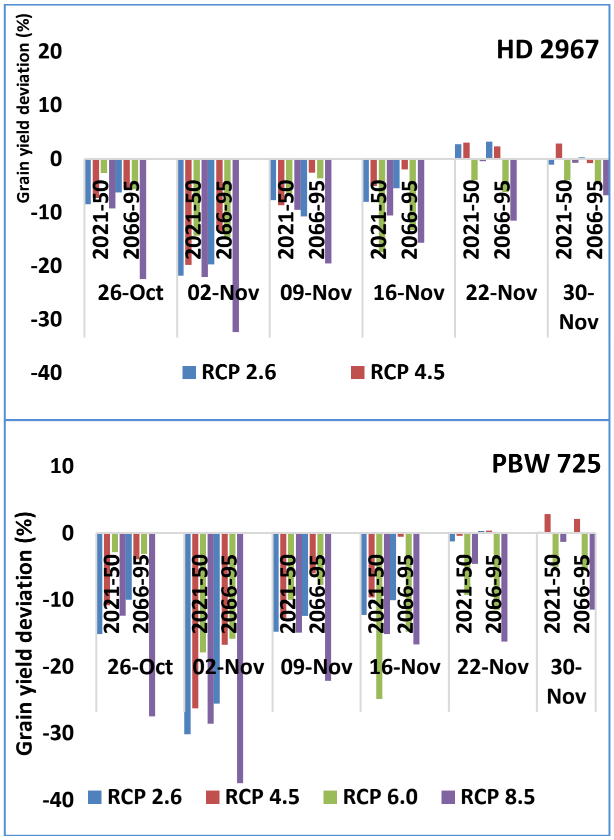

Fig. 2. Deviation in yield of wheat cultivars under RCP scenarios during mid and end century in Agroclimatic zone III (Amritsar)

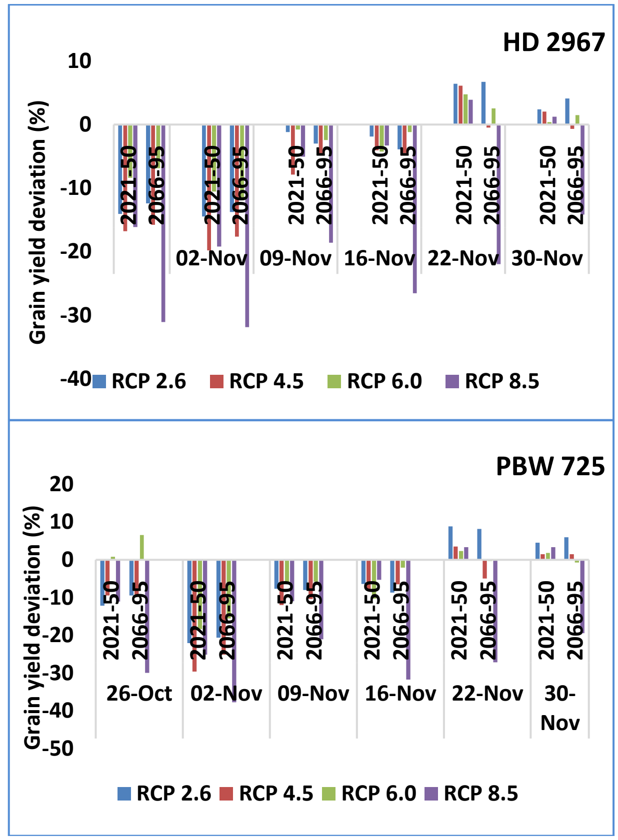

Fig. 3. Deviation in yield of wheat cultivars under RCP scenarios during mid and end century in Agroclimatic zone III (Ludhiana)

end century. HD 2967 were shown intermediate results for RCP 4.5 and RCP 6.0. The wheat cultivar PBW 725 indicated a yield decline by 9.3 to 34.6% for RCP 2.6, 0.6 to 10.6% for RCP 4.5, 0.7 to 32.3% for RCP 6.0 and 3.4 to 35.2% for RCP 8.5 (Fig. 1) for GCM Ensemble. In Agroclimatic zone II (Ballowal Saunkhri) both the cultivars showed a major decline of grain yield and the maximum decline was observed in HD 2967 followed by PBW 725 under RCP 8.5. Hong *et al.* (2019) investigated that an increase in temperature suggesting the negative effects of increasing thermal resources that ultimately reduce wheat yield by 1.92, 4.08 and 5.24% for the RCP 4.5 scenario and by 3.64, 5.87 and 5.81% for the RCP 8.5 scenario.

3.1.2. *Agroclimatic zone III (Amritsar and Ludhiana)*

The wheat cultivar HD 2967 observed a decline in grain yield for all the RCP scenarios. Where the deviation percent for Amritsar ranged 1.11 to 21.80% for RCP 2.6, 0.80 to 19.77% for RCP 4.5, 2.62 to 17.44% for RCP 6.0 and 0.43 to 32.36% for RCP 8.5. (Fig. 2) for GCM Ensemble. Whereas, there is slightly increment the grain yield by 0.30 to 3.22% under RCP 2.6 and 4.5 in mid-century and the maximum yield increment observed in RCP 2.6 on end-century. The wheat cultivar PBW 725 indicated a yield decline by 1.25 to 30.15% for RCP 2.6, 0.36 to 26.26% for RCP 4.5, 2.88 to 24.85% for RCP 6.0 and 1.26 to 37.50% for RCP 8.5 (Fig. 2) for GCM Ensemble. Where the slightly yield increment was observed by 0.13 to 2.81 under the RCP 2.6 and 4.5.

Whereas for Ludhiana, the deviation percent of grain yield ranged 1.19 to 14.46% for RCP 2.6, 0.65 to 19.78% for RCP 4.5, 0.77 to 11.89% for RCP 6.0 and 3.28 to 31.85% for RCP 8.5. (Fig. 3) for GCM Ensemble. The wheat cultivar PBW 725 indicated decline in grain yield by 6.42 to 22.03% for RCP 2.6, 4.96 to 29.57% for RCP 4.5, 0.32 to 18.36% for RCP 6.0 and 5.25 to 37.72% for RCP 8.5 (Fig. 3) for GCM Ensemble.

For Amritsar region, the maximum decline of grain yield was observed in PBW 725 followed by HD 2967 under RCP 8.5 and for Ludhiana region, the same trend has been followed *i.e.*, cultivar PBW 725 showed maximum decline in grain yield followed by HD 2967 under RCP 8.5. Ixchel *et al.* (2018) simulated the climate change impacts, including temperature increase, rainfall change and

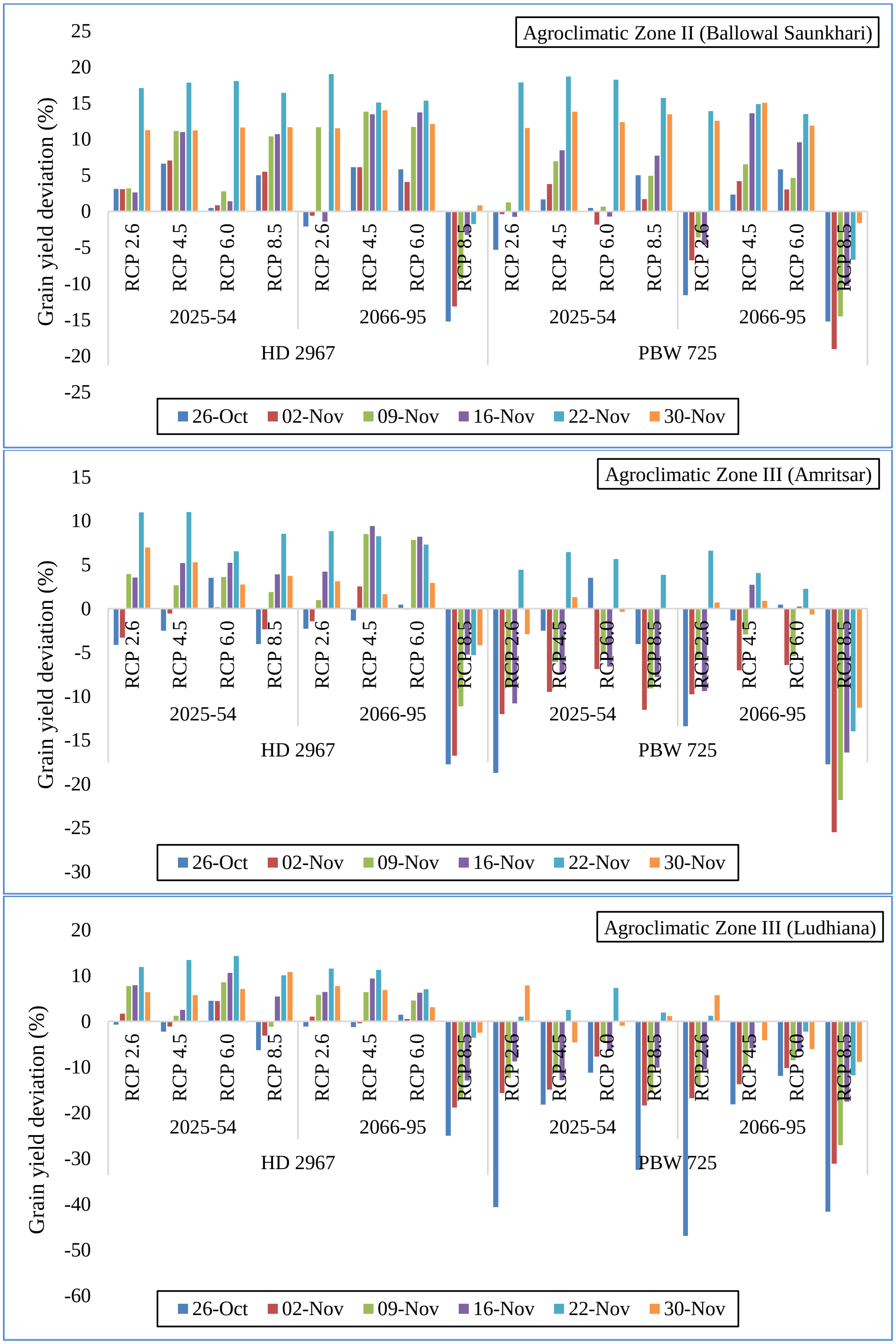

Fig. 4: Deviation in grain yield of optimized dates of sowing for cv HD 2967 and PBW 725 during mid and end century for agroclimatic zone II (Ballowal Saunkhari), and agroclimatic zone III (Amritsar and Ludhiana)

elevated CO_2 concentrations for irrigated and rainfed wheat growing areas of Mexico and found that wheat production is projected to decline between 6.9% for RCP 4.5 and 7.9% for RCP 8.5.

3.2. *Sowing window optimization for different agroclimatic zones of Punjab*

The decline in grain yield observed during the current sowing dates require attention under the predicted scenarios and the considered centuries thus a sowing window from 26th October to 30th November was adopted to observe the yield increment and suitable sowing dates for two wheat cultivars under ensemble model at different agroclimatic zones.

3.2.1. *Agroclimatic zone II (Ballowal Saunkhri)*

The significant yield increment for the cultivar HD 2967 (Fig. 4) was observed during 22th November to 30th November by 11.27 to 17.07% and 11.51 to 19.02% for RCP 2.6, 11.19 to 17.83% and 13.99 to 15.07% for RCP 4.5, 11.62 to 18.03% and to 12.09% to 15.34% for RCP 6.0 during the mid and end century. On same dates, the RCP 8.5 observed increment the grain yield by 11.65 to 16.43% during mid-century while no increment was observed during the end century.

The wheat cultivar PBW 725 (Fig. 4) indicated the increment of grain yield for the same zone ranged by 11.53 to 17.85% and to 12.56 to 13.90% for RCP 2.6, 13.82 to 18.68% and 14.86 to 15.02% for RCP 4.5, 12.37 to 18.23% and 11.90 to 13.49% for RCP 6.0 during 22th November to 30th November. While RCP 8.5 observed increment the grain yield by 13.45 to 15.69% during mid-century while no increment was observed during the end century by GCM ensemble model.

Dubey *et al.* (2020) predicted that terminal heat stress will reduce wheat yield by 18.1%, 16.1% and 11.1%, respectively in present, 2020 and future 2050 scenarios. For preventing the yield loss, early sowing by 10 days from normal, additional 30 kg/ha nitrogen fertilizer and one additional irrigation at grain filling stage was found most suitable options to mitigate the impact of heat stress.

3.2.2. *Agroclimatic zone III (Amritsar and Ludhiana)*

The observed increment in grain yield of HD 2967 (Fig. 4) ranged by 6.96 to 10.97% and 3.11 to 8.83% for RCP 2.6, 5.27 to 11.00% and 1.65 to 8.24% for RCP 4.5, 2.76 to 6.55% and 2.93 to 7.30% for RCP 6.0 during 22th November and 30th November. On same dates, the RCP 8.5 observed increment the grain yield by 3.71 to 8.52% during mid-century while no increment was observed during the end century by GCM ensemble model by.

The cultivar PBW 725 (Fig. 4) indicated the increment of grain yield by 4.44% and 0.69 to 6.60% for RCP 2.6, 1.30 to 6.46% and 0.86 to 4.05% for RCP 4.5 during mid and end century. While RCP 6.0 observed increment of grain yield 2.25 to 5.64% on 22th November during mid and end century and no yield increment was observed on 30th of November. On the other RCP 8.5 observed increment of grain yield 3.86% in mid-century during 22th November and no increment was observed on 30th November during mid and end century by GCM ensemble model.

For Ludhiana (Fig. 4) the agroclimatic zone III observed the increment the grain yield of cultivar HD 2967 ranged by 6.36 to 11.9% and 7.75 to 11.55% for RCP 2.6, 5.75 to 13.45% and 6.84 to 11.26% for RCP 4.5, 7.08 to 14.29% and 3.09 to 7.04% for RCP 6.0 during 22th to 30th November. While, the RCP 8.5 observed increment in grain yield by 10.06% and 10.76% during mid-century while no increment was observed during the end century by GCM ensemble model.

The cultivar PBW 725 (Fig. 4) indicated the increment of grain yield by 1.03 to 7.87% and 1.20 to 5.71% for RCP 2.6, 2.49 to 4.57% and 0.27 to 4.13% for RCP 4.5 during mid and end century on 22th to 30th November. The RCP 6.0 observed the increment of grain yield 7.34% during mid-century, while no increment was observed during end of century. On the other hand, RCP 8.5 observed slightly increment of grain yield like 1.16 to 1.94% during mid-century, while no increment was observed during end of century by GCM ensemble model.

4. Conclusions

The RCP8.5, a high emission scenario where high temperatures are projected represents a maximum linear decrease in grain yield over the years if no optimization practices are followed. The results showed an increase in yield at agroclimatic zone II and III was observed when sowing window was adopted in between 22th to 30th November.

Authors' Contributions

Dr. Prabjyot Kaur: Conceptualizing the research, designing the study.
Mr. Sarabjit Singh: Collecting and analyzing data, designing the study.

Dr. Amarinder Singh: Writing the manuscript, and critically reviewing the work.

Disclaimer: The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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