

Original Research Article

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Implications Test of Temperature, Rainfall and Carbon Dioxide Combinations on Indian Mustard Using Multi Crop Simulation Models for Western Haryana, India

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ABSTRACT

The sensitivity analysis of three *Brassica spp.* (cv. RH30, Laxmi and RH0749) cultivar of wheat was performed to see the possible change in the grain yield due to change in weather (T_{max} , T_{min} and rainfall) and non-weather parameters (CO_2) using InfoCrop and WOFOST model. The potential condition was assumed with congenial weather and adequate management practices. The higher per cent of benefits was obtained at 500 ppm but further increase in CO_2 (550, 600, 650 and 700 ppm) combined with one unit increase in mean ambient temperature reduced the percent change in mustard yield. The interaction effect of temperature and CO_2 concentration revealed that the response of variety Laxmi was quite higher followed by RH 0749 and RH 30. At highest CO_2 concentration (700 ppm), the negative impact of temperature was simulated only at $-1^\circ C$ in all the mustard varieties. Under increasing of 20% rainfall scenario, the increase in the yield levels are higher in RH 0749 followed by Laxmi and RH 30 using both crop simulation models. The higher benefits was obtained at +20% rise in rainfall but further decrease or increase (-30 to -10% and +30 to +40%) in rainfall combined with change in mean ambient temperature ± 3 to $\pm 5^\circ C$ reduced the percent change in mustard yield. The interaction effect of temperature and rainfall change revealed that the response of RH 0749 variety was quite higher followed by RH 30 and Laxmi.

Keywords

InfoCrop, WOFOST validation, Sensitivity analysis, Temperature, CO_2 mustard

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Introduction

Current global climate models predict a mean increase in temperature of 1.0–3.7 °C with greater likelihood of increased frequency of heat waves with variable precipitation patterns over most land areas by the mid- to late twenty-first century (IPCC, 2013). The higher greenhouse gases could leads to vagaries in regional and seasonal climate patterns during

coming century (Gates *et al.*, 1992). Tropical countries are more vulnerable to climatic effects in agricultural productivity. Simulation models provide a scientific approach to study the impact of climate change on agricultural production and world food security. Crop simulation modeling has the capability of forecast yield levels based on the prevailing weather conditions and past production records. Crop growth simulation models are

quantitative tool based on scientific knowledge that can evaluate the effect of climatic, edaphic, hydrological and agronomic factors on crop growth and yield.

Mustard crop is highly vulnerable, particularly in the semi-arid and arid regions of India. The climate is warming through the processes such as CO₂ and changed pattern of temperature and precipitation resulting in heat and drought stresses, respectively (Ram Niwas and Khichar, 2016). Sensitivity test of the crop simulation models is the process by which various input parameters are evaluated with regard to their importance relative to simulation relations. Catalin *et al.*, (2009) validated the WOFOST model from crop growth monitoring system (CGMS) for Romania and checked the adaptability for the climate change study for winter crops mainly for cereals. They validated the WOFOST and Crop Growth Monitoring System (CGMS) and found that these were interesting tools for study the plant-soil-atmosphere interactions. InfoCrop model simulated yield of mustard was found to be sensitive to changes in the atmospheric concentration of CO₂ and temperature and mustard yield was increased with elevated CO₂ concentration, while the positive effect of increased CO₂ was nullified by temperature rise and (Bhoomiraj *et al.*, 2010) also found that the rainfed conditions crop was found to be more susceptible to changing climate in north India due to projected reduction in rainfall in future scenarios. Bhaskaran *et al.*, (1995) used the UKMO GCM model which was predicted that with elevated CO₂ concentration, approximately 20% increase in total precipitation occurs in winter or *rabi* crop seasons.

In general, it is evident that many C₃ crops, in the absence of biotic (pests, diseases and weeds) or abiotic (water and nutrients) stresses will be able to capitalize on elevated CO₂ and

convert it into photosynthates and consequently improved growth and yield (Ainsworth and Rogers, 2007; Leakey *et al.*, 2009). The effect of low temperature (frost) during podding and seed development stage in mustard causes freezing injury in seeds and sizable reduction in seed yield (Ram Niwas and Khichar, 2016), whereas Rise in atmospheric temperature reduced leaf area index, grain number as well as weight of grains which was in turn reflected in yield of mustard crop. Seed yield reduction occurred by low water availability during stem elongation, flowering and pod development in mustard. Fertilization effects on CO₂ on crop production will be necessary in future climate change scenarios to offset the anticipated negative impacts of high temperature and to feed ever increasing human population (Ainsworth *et al.*, 2008). Indian mustard suffers from exposure of low temperature during vegetative and early pod filling stage and relatively higher temperature during vegetative and early pod filling stage and relatively higher temperature during grain filling and maturity (Kumar *et al.*, 2007; Adak *et al.*, 2010).

Materials and Methods

The field experiments were conducted in two consecutive *rabi* seasons during 2012-13 and 2013-14 at the research farm of the Department of Agriculture Meteorology, CCS HAU, Hisar, India situated at latitude 29°10' N, longitude 75°46'E and at altitude of 215.2 m above mean sea level. The daily meteorological variables were collected from agrometeorological observatory situated near the experimental plot. The InfoCrop (v. 2.0.) and WOFOST (v 7.1.7) model were calibrated and validated under three dates of sowing *viz.*, D₁: Oct. 10, 2012 and Oct. 21, 2013; D₂: Oct. 25, 2012 and Oct. 30, 2013; and D₃: Nov. 8, 2012 and Nov. 10, 2013 by Choudhary *et al.*, (2014) for cv. V₁: RH 30, V₂: Laxmi and V₃:

RH 0749. To validate the models, same year weather (2012-13 and 2013-14) and soil files were used. The actual/base yield of mustard was used to compare with sensitivity analysis results. Here, an effort has been made to test the models under two situations in terms of mathematical logic and stability to extreme values of weather and non-weather parameters. The first situation is combined effect of change in mean ambient temperature (± 1 to ± 5 °C) and concentration of carbon dioxide (base value-360 ppm; 400, 450, 500, 550, 600, 650, and 700 ppm) and; second situation is combined effect of mean ambient temperature (± 1 to ± 5 °C) and change in rainfall (-30 to +40%) from the normal value (Table 1). The models were simulated the mustard seed yields under altered weather and non-weather parameters.

Results and Discussion

Effect of mean ambient temperature and carbon dioxide

Sensitivity analysis was carried out for combined effect of change in mean ambient temperature and different levels of CO₂ concentration (400, 450, 500, 550, 600, 650 and 700 ppm) using InfoCrop and WOFOST models in Figures 1 and 2. The results revealed that CO₂ concentration of 400 ppm there was less reduction in seed yield either

increased or decreased in mean ambient temperature (± 1 to ± 5 °C) in all three mustard varieties with both the models. The desirable effects for InfoCrop model were simulated under downscaling of the temperature, the total effect being -22 to 26% (RH 30), -22 to 29% (Laxmi) and -25 to 24% (RH 0749), whereas, using WOFOST model, the effect was -28 to 19% (RH 30), -28 to 22% (Laxmi) and -31 to 20% (RH 0749), respectively. At CO₂ concentration 450 ppm, using InfoCrop model the net effect on yield was -29 to 36% (RH 30), -31 to 36% (Laxmi) and -31 to 35% (RH 0749), however, the effect under using WOFOST model was -35 to 22% (RH 30), -33 to 25% (Laxmi) and -34 to 23% (RH 0749), respectively. Under increasing of CO₂ concentration 500 ppm scenario, increased yield levels were higher in RH 30 followed by Laxmi and lowest in RH 0749 using these models. The higher benefits was obtained at 500 ppm but further increase in CO₂ (550, 600, 650 and 700 ppm) combined with one unit increase in mean ambient temperature reduced the per cent change in mustard yield.

The interaction effect of temperature and CO₂ concentration revealed that the response under variety Laxmi was showed high response followed by RH 0749 and RH 30. The per cent change in yield decreased in both ways *i.e.* either increasing or decreasing the mean ambient temperature from mean value.

Table.1 Base values and change in parameter values used in InfoCrop and WOFOST models for sensitivity analysis

Parameters	Base values	Change in parameter used in InfoCrop and WOFOST model
Mean ambient temperature (°C)	Temperature of crop season 2012-13 & 2013-14	± 1 to ± 5 °C
Rainfall (mm)	Rainfall of crop season 2012-13 & 2013-14	-30 to +40 %
Carbon dioxide (ppm)	360 ppm	400, 450, 500, 550, 600, 650, and 700 ppm

Fig.1 Interaction effect of change in mean ambient temperature ($^{\circ}\text{C}$) and CO_2 conc. (ppm) on simulated mustard seed yield (% change) using InfoCrop model

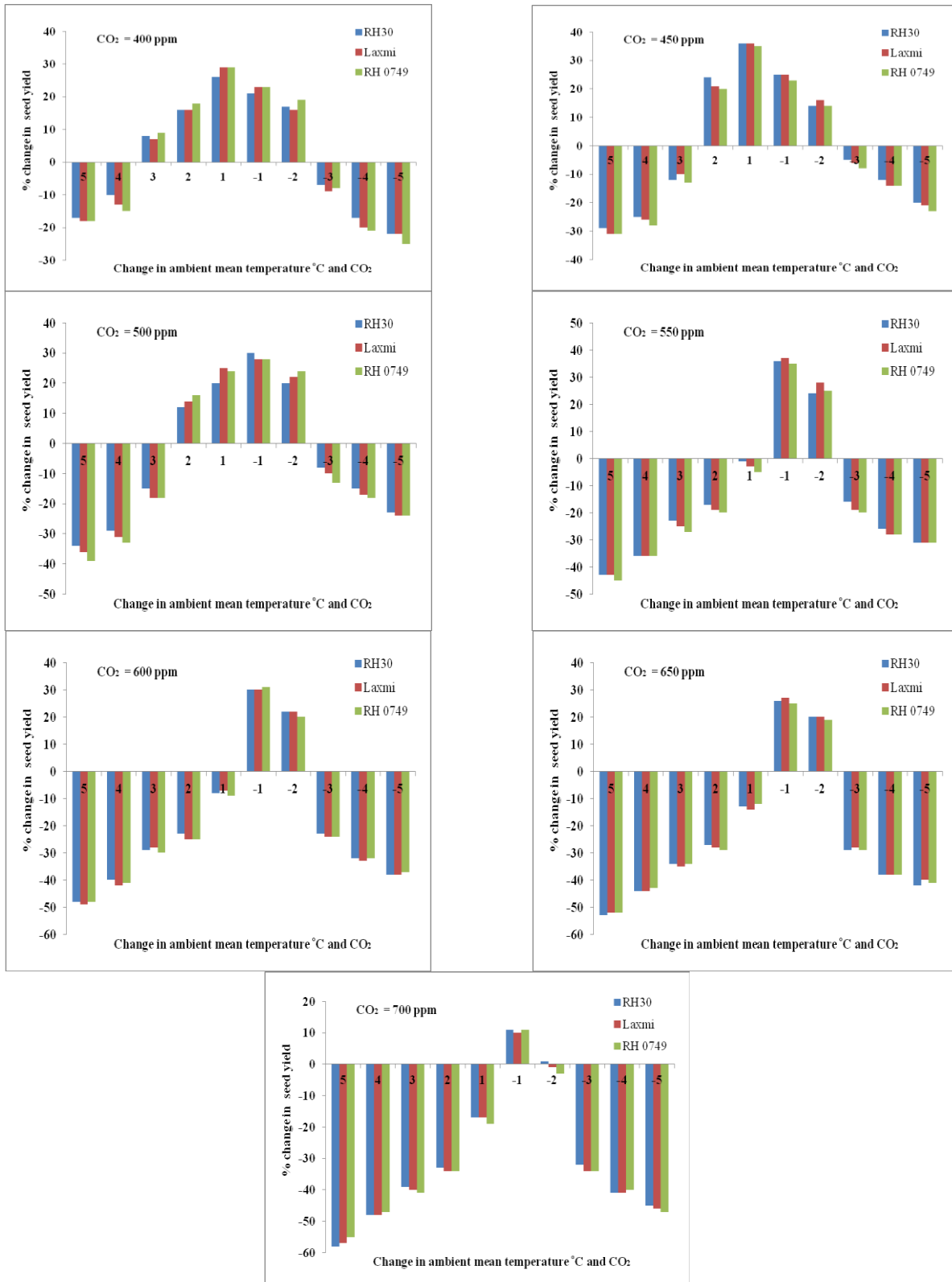


Fig.2 Interaction effect of change in mean ambient temperature (°C) and CO₂ conc. (ppm) on simulated mustard seed yield (% change) using WOFOST model

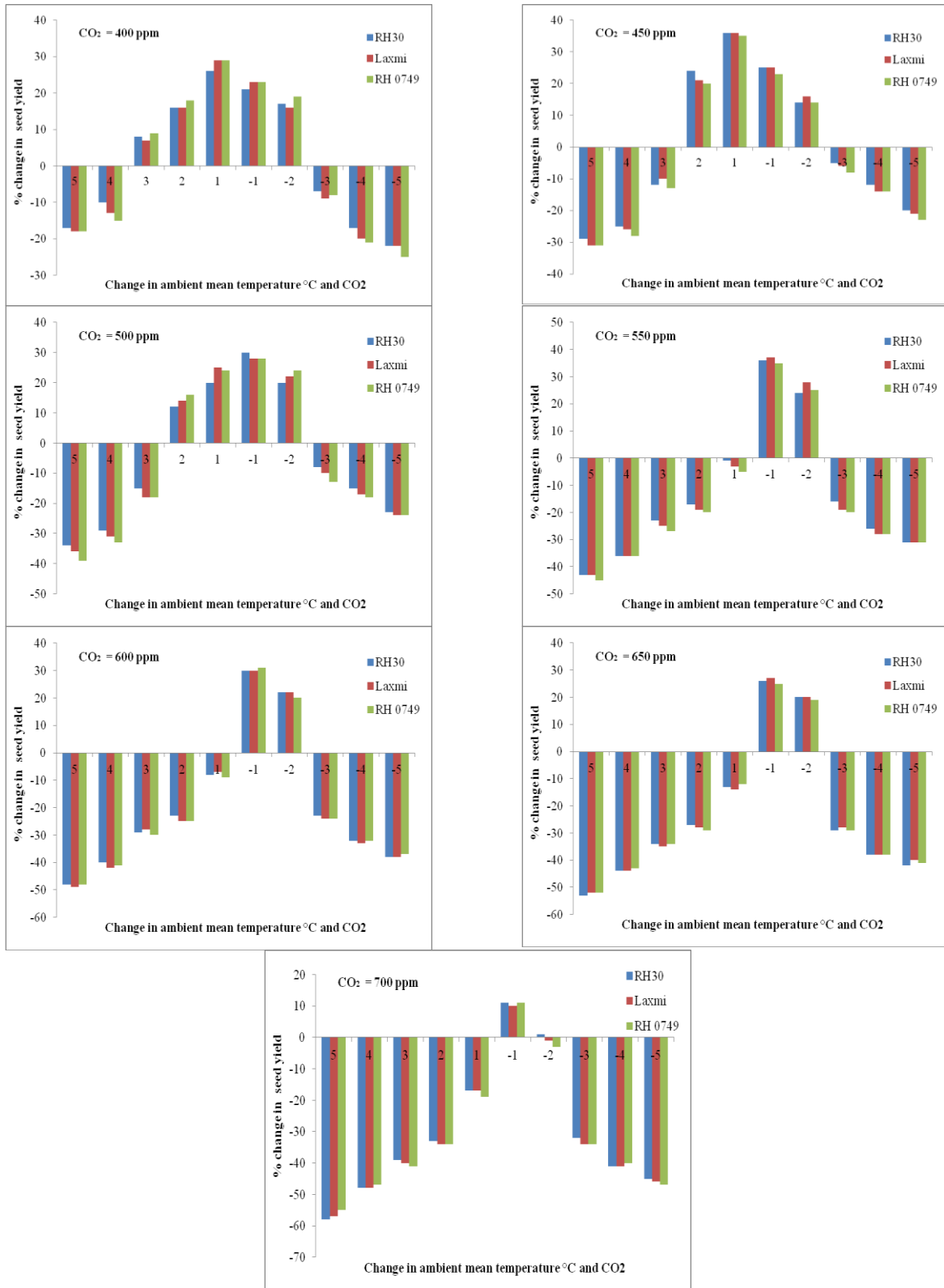


Fig.3 Interaction effect of change in mean ambient temperature (°C) and rainfall change (%) on simulated mustard seed yield (% change) using InfoCrop model

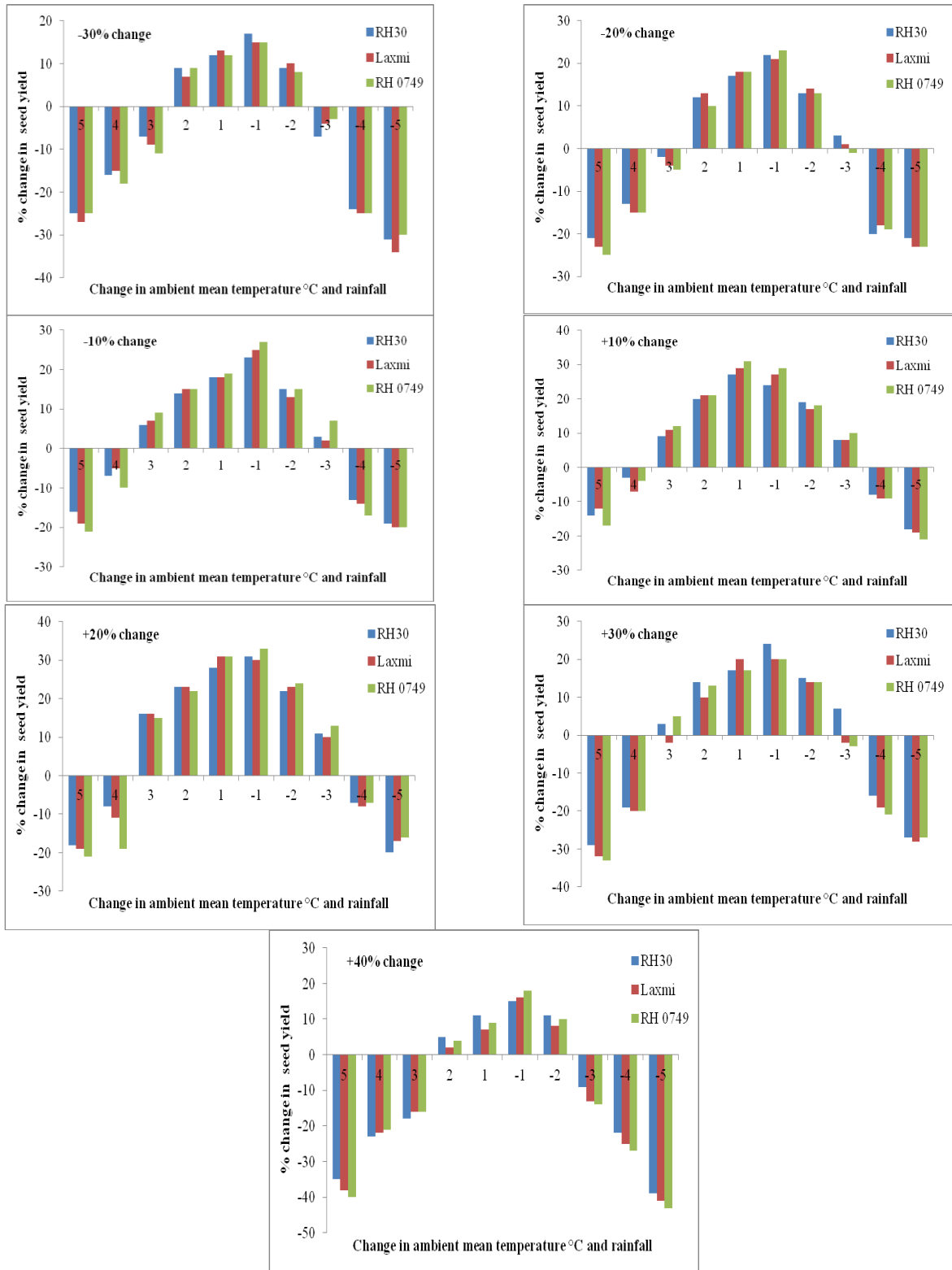
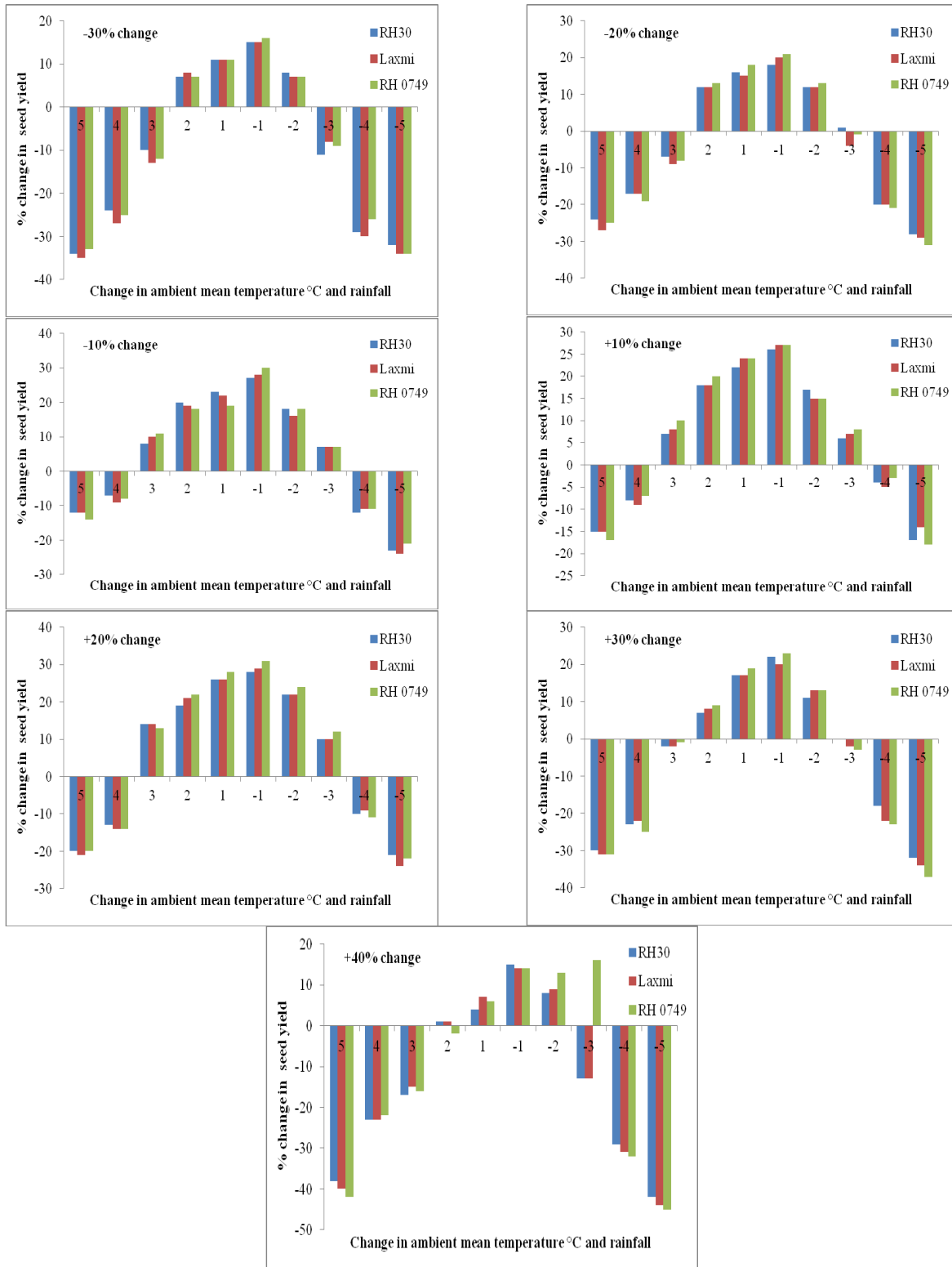


Fig.4 Interaction effect of change in mean ambient temperature (°C) and rainfall change (%) on simulated mustard seed yield (% change) using WOFOST model



The results indicated that the elevated CO₂ concentrations at 550, 600 and 650 ppm could alleviate and positive impact of temperature upto -3 to +1°C, however, 700 ppm CO₂ concentration the negative impact of temperature was simulated only at -1°C in all the mustard varieties through both the models. In general an increase in carbon dioxide concentration was found to increase yield while increase in temperature reduced yield (Matthews et al., 2002).

Increase in yield was due to the increase in photosynthesis resulting from higher carbon dioxide concentration. C₃ crops (i.e. rice, wheat, mustard) respond more to carbon dioxide enrichment than C₄ crops (i.e. maize, sorghum, sugarcane). But photosynthetically, these plants (C₃) are underachievers because, on the one hand, they assimilate atmospheric carbon dioxide into CH₂O but, on the other, part of the potential for CH₂O production is lost by respiration in daylight, releasing carbon dioxide into the atmosphere, a wasteful process termed photorespiration (Ku, 2000).

Several reviews have exposed that the above increase in photosynthetic rates is translated to increase in biomass production and grain yield of mustard crop (Lawlor and Mitchell, 1991; Jablonski *et al.*, 2002). These analyses were match with the findings of Kadam *et al.*, (2014); Akula (2005a); Mukherjee *et al.*, (2011); Ruhil *et al.*, (2015) and Mishra *et al.*, (2015).

Effect of mean ambient temperature and rainfall

Sensitivity analysis was carried out for combined effect of change in mean ambient temperature and percent change in rainfall (-30 to +40%) from actual rainfall of study period using InfoCrop and WOFOST models in Figures 3 and 4. The results revealed that

rainfall change of +10%, less reduction in seed yield was observed either increased or decreased in mean ambient temperature (± 1 to $\pm 5^\circ\text{C}$) in all three mustard varieties with both the models. The desirable effects for InfoCrop model were simulated under downscaling of the temperature, the total effect being -18 to 27% (RH 30), -19 to 29% (Laxmi) and -21 to 31% (RH 0749), whereas, using WOFOST model, the effect was -17 to 26% (RH 30), -15 to 27% (Laxmi) and -18 to 27% (RH 0749), respectively.

At +20% change in rainfall, using InfoCrop model the net effect on yield was -20 to 31% (RH 30), -19 to 31% (Laxmi) and -21 to 33% (RH 0749), however, the effect seen under using WOFOST model was -21 to 28% (RH 30), -24 to 29% (Laxmi) and -22 to 31% (RH 0- 749), respectively. By increasing the 20% rainfall scenario, the increase in yield levels are higher in RH 0749 followed by Laxmi and lowest in RH 30 using both crop simulation models. The higher benefits was obtained at +20% rise in rainfall but further decrease or increase (-30 to -10% and +30 to +40%) in rainfall combined with change from ± 3 to $\pm 5^\circ\text{C}$ in mean ambient temperature reduced the percent change in mustard yield.

The interaction effect of temperature and rainfall change revealed that the response of the variety RH 0749 was quite high followed by RH 30 and Laxmi.

The percent change in yield decreased in both ways *i.e.* either increasing or decreasing the mean ambient temperature from mean value. The results indicated that the change in rainfall from -30 to -10% and +30 to +40% could alleviate and positive impact of temperature upto -2 to +2°C on seed yield by InfoCrop model, however, rainfall change from -10 to +20% have positive impact of temperature was simulated from -3 to +3°C on seed yield in all the mustard cultivars by

using WOFOST model. The results were supported by Catalin *et al.*, (2009); Kadam *et al.*, (2014) and Mishra *et al.*, (2015).

The results of the study described the tolerance power of various mustard cultivars in relation to changed temperature, rainfall and CO₂ conditions. The higher per cent of benefits was obtained at 500 ppm but further increase in CO₂ (550, 600, 650 and 700 ppm) combined with one unit increase in mean ambient temperature reduced the percent change in mustard yield.

The interaction effect of temperature and CO₂ concentration revealed that the response of variety Laxmi was quite higher followed by RH 0749 and RH 30. At highest CO₂ concentration (700 ppm), the negative impact of temperature was simulated only at -1°C in all the mustard varieties.

Under increasing of 20% rainfall scenario, the increase in the yield levels are higher in RH 0749 followed by Laxmi and RH 30 using both crop simulation models. The higher benefits was obtained at +20% rise in rainfall but further decrease or increase (-30 to -10% and +30 to +40%) in rainfall combined with change in mean ambient temperature ± 3 to ± 5 °C reduced the percent change in mustard yield. The interaction effect of temperature and rainfall change revealed that the response of RH 0749 variety was quite higher followed by RH 30 and Laxmi. This is of course, a need to further refine the existing models and also to develop models for more crop species.

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