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Climate change and potato productivity in Madhya Pradesh-Impact and adaptation

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ABSTRACT

The impact of climate change on potato productivity in Madhya Pradesh was analysed using WOFOST crop growth simulation model. The potato cultivars of three maturity groups viz., *Kufri Badshah* (late), *Kufri Jyoti* (medium) and *Kufri Pukhraj* (short) were selected. The study was carried out for 38 representative locations of the state. The study was done for baseline scenario (2000) and for future climate scenarios for the years 2020 and 2055 using A1FI scenario of temperature (SRES A1FI pathway) and atmospheric CO_2 (based on the Bern-CC model for A1FI scenario). Simulation revealed that although the increase in temperature is likely to reduce the yield by 10 to 11.4 per cent in 2020 and 22.9 to 27 per cent in 2055, a corresponding increase in CO_2 may increase the yields by 4.6 to 4.9 per cent in 2020 and 19.6 to 21 per cent in 2055. However, the combined effect of CO_2 and temperature will lead to a decline in productivity of *Kufri Pukhraj* by 7.6 per cent, followed by 7.3 per cent in *Kufri Jyoti* and 6.4 per cent in *Kufri Badshah* in 2020, with corresponding figures of 14.3, 12.8 and 10.9 per cent in 2055. Results, further revealed that the negative effect of climate change on potato productivity can be counter balanced to some extent by changing the dates of planting and/or selection of suitable varieties for the location, as it may bring down the reduction in yield from 3.7 to 0.7 per cent in 2020 and 7.7 to 3.3 per cent in 2055.

Key Words: Adaptation, climate change, potato, productivity, WOFOST

Potato is a major food crop of the world and is largely grown during winter season in India, being mainly consumed as vegetable. Madhya Pradesh (MP) is the fourth largest potato producing state after Uttar Pradesh, Bihar, Gujarat and West Bengal in India. With the production of 2322.4 MT, it accounts for about 6 per cent of total national potato production (Saxena and Gandhi, 2014). Ezekiel *et al.,* (1999) reported that the areas having minimum night temperature above 10 °C during the last 30 days of the crop growth produces potatoes with high dry matter (>20%) and low reducing sugars. Such favorable climatic conditions for producing potatoes with high dry matter yield are present in certain parts of Madhya Pradesh.

As per the IPCC 4th Assessment report, an increase in temperature ranging from 0.78 ºC during September, October, November to 1.17 ºC during December, January, February is expected under A1FI scenario by 2020, in South Asia. These changes are expected to aggravate and range from 1.71 ºC during June, July, August to 3.16 ºC during December, January, February, *i.e.* the main potato growing season in 2055. Thus, in 2020 the potato season is likely to be warmer by 0.78 to 1.18 ºC and in 2055, by 2.41 to 3.16 ºC under A1FI scenario. During the same period, the CO_2 concentration is likely to increase from present 400 ppm to 415 in 2020 and 590 ppm in 2055 (IPCC, 2007). The projected increase in atmospheric levels of CO_2 may benefit the potato productivity is reported by many workers (Finnan *et al.,* 2005). However, the positive role of carbon dioxide in enhancing photosynthesis and productivity of plant is expected to counteract the negative effects of increase in temperature (Yadav *et al.,* 2016).

Due to rise in the temperature, the availability of suitable growing period for potato is likely to be impacted in MP and probably will lead to a decline in productivity. Being an important potato growing region, there is an urgent need to study the impact of likely changes in temperature and CO_2 on regional vulnerability of potato productivity in future in this area in order to direct our research efforts to meet the challenges and devise adaptation strategy to minimize the likely impact of climate change. For this purpose, crop growth models are very useful and are used widely to simulate crop growth and yield of annual and perennial crops under diverse situations. Keeping this in view, a study was undertaken to forecast the impact of climate change on potential potato productivity of Madhya Pradesh and to select the suitable variety and date of planting to minimize the impact of climate change.

MATERIALS AND METHODS

Selection of model

Worldwide, various models are used to study climate change impact on various crops and WOFOST (World Food Studies) crop growth model, developed at Wageningen University, the Netherlands, is one of them. This model is widely used to assess the effect of climate change on growth and yield of many crops viz., wheat, rice, maize potato, barley, soybean, sugar beet etc. (Reidsma *et al.,* 2015; Wolf *et al*., 2010; Van Diepen *et al*., 1987). We used this model in our study for impact assessment of climate change on potato productivity and for scheduling planting date and selection of suitable cultivar to overcome climatic impact in Madhya Pradesh. Using the time course data on potato growth and development, derived from field experiments conducted at Jalandhar (Punjab) and Patna (Bihar) during 1999 to 2001 (Dua *et al.*, 2014), this model has been validated for Indian potato cultivars *i.e.* late (*Kufri Badshah*), medium (*Kufri Jyoti* and *Kufri Bahar*) and early (*Kufri Pukhraj*) maturity groups.

Selection of potato cultivars

Three potato cultivars, belonging to long duration (*Kufri Badshah*), medium duration (*Kufri Jyoti*) and short duration (*Kufri Pukhraj*) maturity group were selected for simulation studies. 20th October was taken as normal date of planting for all the locations in M.P (Pandey and Kang, 2003). The simulation study was carried out to estimate potential yields of potato cultivars for baseline and the future scenarios.

Weather data

Indian meteorological department (IMD) district normal of 1971-2000 of 38 districts of Madhya Pradesh (Table 1) were used for baseline scenario (year 2000). For generation of 2020 and 2055 scenario, projected changes in surface air temperature for sub-regions of Asia under SRES A1FI pathway based on the Fourth Assessment Report (AR4) Atmosphere-Ocean General Circulation Models (AOGCMs) were added to the baseline data (IPCC, 2007). Hargreaves-Samani equation, which is reported to be best suited for Indian conditions, was used for working out total solar radiation (Samani, 2000). Using A1FI high emission scenario of temperature and CO_2 emission, the model was run for 38 locations spread across the state (Balaghat, Betul, Bhind, Bhopal, Chhatarpur, Chhindwara, Datia, Dewas, Dhar, Dindori, Guna, Gwalior, Harda, Hoshangabad, Indore, Jabalpur, Katni, Khandwa, Mandla, Mandsaur, Morena, Neemuch, Panna, Raisen, Ratlam, Rewa, Sagar, Satna, Seoni, Shahdol, Shajapur, Sheopur, Shivpuri, Sidhi, Tikamgarh, Ujjain, Umaria and Vidisha) for three popular potato cultivars over three climatic scenarios; baseline (2000), 2020 and 2055. Projected atmospheric CO_2 concentration based on the Bern-CC model for A1FI scenario was used for incorporating the effect of change in CO_2 concentration in WOFOST model (IPCC, 2007). Atmospheric CO_2 concentration of 367 ppm (for baseline), 415 ppm (for 2020) and 590 ppm (for 2055) were used in the present study.

Incorporation of CO_2 impact in the model

Due to doubling of CO_2 from 355 - 710 ppm, 25 to 40 per cent (mean 32.5%) increase in yield of C_3 plants has been reported (Wolf *et al.,* 2010) hence for incorporating the impact of CO_2 in the WOFOST model changes were made in parameters like light-use efficiency of single leaf and maximum leaf CO_2 assimilation rate. Based on earlier studies, changes have been made in initial angle (+11%) and in maximum leaf CO_2 assimilation rate - light response curve (+60%) parameters of WOFOST model for doubling CO_2 concentration from 355 -710 ppm. Therefore, assuming linear relationship between the CO_2 increase and the growth processes we have taken these figures as +10 per cent (30/ 32.5 x 11) and +55 per cent (30/32.5 x 60) with doubling CO_2 concentration for potato. Accordingly, these parameters were changed for 2020 and 2055 for A1FI scenario as given in Table 2.

RESULTS AND DISCUSSION

Impact of climate change on potato productivity

The WOFOST model derived simulation results have shown that there was a great variation in potato productivity within the state under the baseline climate scenario (2000). A large variation in potato yield was observed within state. In general, the yield of *Kufri Badshah* ranged from 26.8 t ha^{-1} (Dhar) to 52.2 t ha^{-1} (Shivpuri), while that of *Kufri Jyoti* ranged from 23.6 t ha^{-1} (Dhar) to 48.6 t ha^{-1} (Gwalior and Shivpuri) and of *Kufri Pukhraj* from 24 t ha^{-1} (Dhar) to 52.2 t ha^{-1} (Raisen). The average productivity of 38 districts was 44.2, 40.6 and 42.8 t ha^{-1}, respectively for *Kufri Badshah, Kufri Jyoti* and *Kufri Pukhraj*. The mean productivity of top 10 potato producing districts was also near to these figures (Table 1). The extrapolated results have shown a respective baseline productivity of 43.6, 40.0, 42.2 t ha^{-1} for these cultivars (Table 3).

A gradual decrease was observed in the productivity on moving from north to south and south west with Ratlam,

Table 1: WOFOST simulated potential productivity of potato cultivars under baseline (2000) and future climate scenario at top ten potato producing districts of Madhya Pradesh.

S. No.	Station	Area (ha) under potato (2012-13)*	*Kufri Badshah*			*Kufri Jyoti*			*Kufri Pukhraj*		
			Base line yield	Change (%)		Base line yield	Change (%)		Base line yield	Change (%)	
			(t ha^{-1})	2020	2055	(t ha^{-1})	2020	2055	(t ha^{-1})	2020	2055
1	Chhindwara	4897	48.3	-5.7	-9.8	44.9	-6.9	-11.6	48.1	-6.9	-13.3
2	Dewas	8560	38.0	-5.5	-11.0	34.8	-5.6	-13.2	37.0	-6.9	-16.3
3	Indore	20124	39.4	-6.5	-11.2	35.5	-6.7	-13.3	37.2	-7.1	-13.7
4	Morena	2076	49.7	-6.5	-12.0	44.5	-7.5	-14.0	46.7	-9.0	-16.9
5	Panna	1683	44.9	-5.7	-11.1	41.4	-6.8	-12.7	42.8	-7.4	-13.8
6	Rewa	2463	48.2	-5.0	-9.9	44.9	-6.7	-12.1	47.2	-6.7	-12.8
7	Sagar	2543	34.5	-7.7	-14.0	30.0	-7.7	-13.2	30.0	-6.5	-13.0
8	Satna	3536	44.0	-5.7	-10.4	40.2	-6.6	-11.9	42.1	-7.8	-14.1
9	Shajapur	6066	45.3	-6.0	-9.9	41.5	-6.6	-10.9	44.3	-6.7	-11.6
10	Ujjain	7211	44.8	-6.1	-10.4	40.9	-6.9	-11.7	43.7	-7.1	-12.7
Mean of top 10 districts			43.7	-6.0	-10.9	39.9	-6.8	-12.5	41.9	-7.2	-13.8
Mean of 38 districts			44.2	-5.8	-10.4	40.6	-6.6	-12.3	42.8	-7.1	-13.9

*Source: https://data.gov.in/resources/district-wise-season-wise-crop-production-statistics-1997

Table 2: Relationship between the CO_2 increase and the growth processes

	2020	2055
Change in light-use efficiency of single leaf	+10% x (415-367)/355 = +1.4%	+10% x (590-367)/355 = + 6.28%
Change in maximum leaf CO_2 assimilation rate	+55% x (415-367)/355 = +7.4%	+55% x (590-367)/355 = +34.5%

Jhabua, Dhar and Barwani and nearby districts recording less than average yield. The productivity of potato cultivars was also low in Sagar and Seoni districts.

Change in potato productivity in future climate

For 2020, model results have simulated a reduction in the yield of *Kufri Badshah* due to increase in temperature in the range of 8.3 per cent (Balaghat) to 11.6 per cent (Vidisha) with mean of 10 per cent. In general, potato is best adapted to temperate climates and an increase in temperature above 17 ºC is reported to diminish its tuberization and ultimately affects the yield (Haverkort 1990). Patel *et al.,* (1999) have also reported that higher minimum and mean air temperature during tuber formation and maturity phases of the crop are unsuitable and may adversely affect the final tuber yield. On the other hand, increase in CO_2 (from 367 ppm in 2000 to 415 ppm in 2020) had a fertilization effect with a mean increase of 4.6 per cent (range 4.2 to 4.9%) over the baseline scenario. Katny *et al.,* (2005) have also reported that photosynthesis in potato is increased by 10–40 per cent under elevated CO_2. However, under the combined effect of increase in temperature and CO_2 lower yield losses are likely over the effect of temperature alone, although the losses are not completely compensated at any location. The results are corroborated with the findings of Dua *et al.,* (2015) who also reported that CO_2 fertilization bring down the decline in productivity caused by temperature, from 9.7 to 5.9 per cent, 9.9 to 5.8 per cent and 10.5 to 6.5 per cent for *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj* in Uttar Pradesh. Overall, a mean reduction of 5.8 per cent is expected in the yield of *Kufri Badshah* with the A1FI scenario of climate change in 2020, over the baseline scenario of 2000. When extrapolated for entire state, this figure is likely to be 6.4 per cent. In case of *Kufri Jyoti* and *Kufri Pukhraj*, with the minimum loss due to temperature (9.4 and

Table 3: Productivity of potato cultivars in baseline year and changes thereof in future climates (interpolated results for total geographical area of MP)

	Kufri Badshah	*Kufri Jyoti*	*Kufri Pukhraj*
Baseline yield (t ha^{-1})	43.6	40.0	42.2
Overall reduction in yield (%)			
2020	6.4	7.3	7.6
2055	10.9	12.8	14.3
Yield reduction classes (%) in 2020		% geographical area of MP	
5-6%	56.3	6.9	0.9
7-8%	43.7	93.1	96.7
9-10%	-	-	2.4
Yield reduction (%) classes in 2055			
7-9%	34.8	5.0	-
10-12%	63.3	83.7	69.2
13-15%	1.9	11.3	24.7
16-18%	-	-	6.1

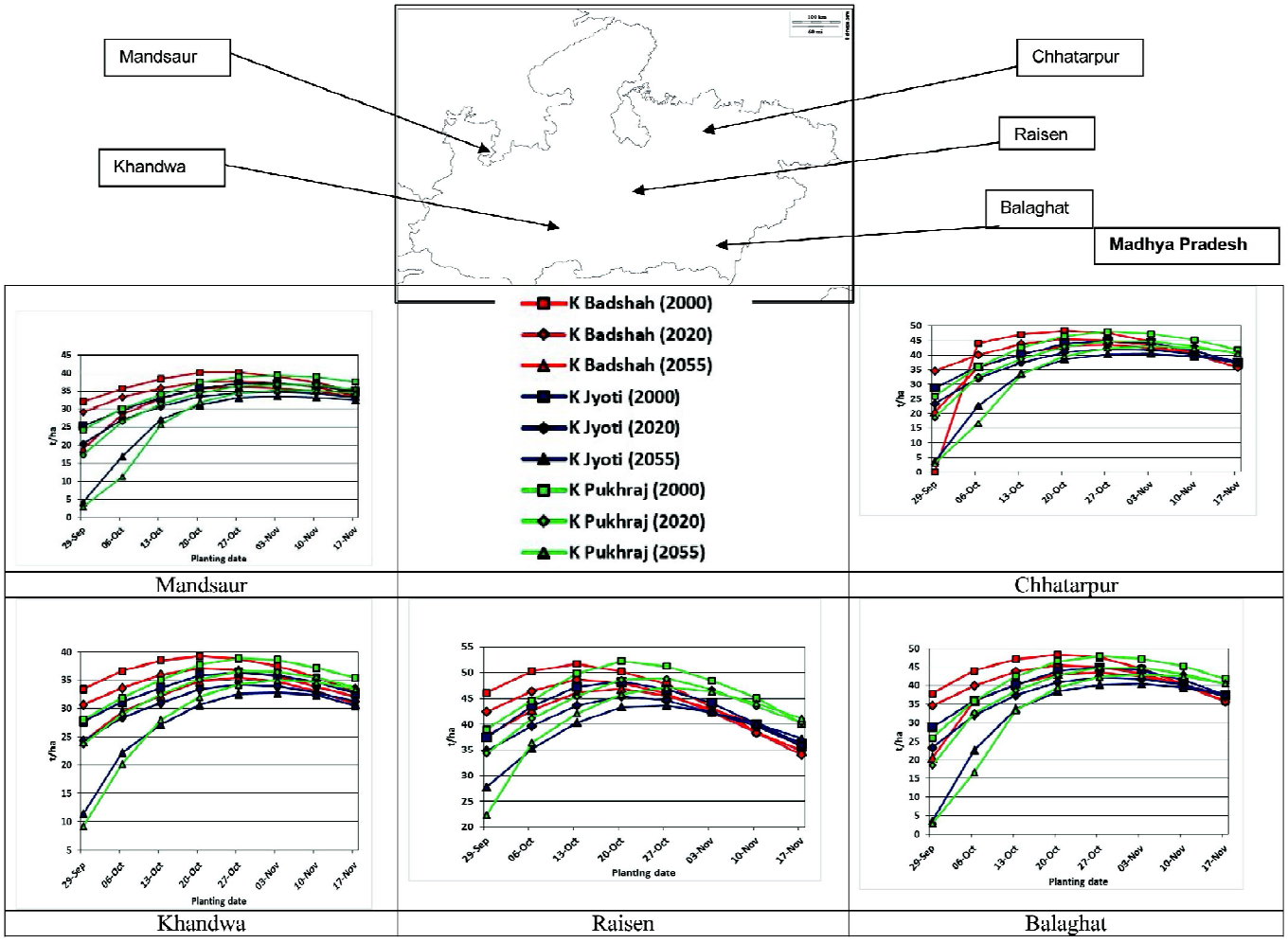

Fig 1: Simulated productivity of different potato cultivars in different parts of Madhya Pradesh as affected by date of planting under baseline and future climate scenario.

Table 4: Potential productivity at normal date of planting in baseline year (2000) and change in date of planting in future climates

Location	2000		2020				2055			
	Normal DOP*	Productivity ($t\,ha^{-1}$)	Best DOP	Productivity ($t\,ha^{-1}$)	Change over baseline		Best DOP	Productivity ($t\,ha^{-1}$)	Change over baseline	
					Best DOP (days)	Productivity (%)			Best DOP (days)	Productivity (%)
Kufri Badshah										
Mandsaur	20-Oct	32.1	03-Nov	32.8	+14	2.2	17-Nov	31.5	+28	-1.9
Chhatarpur	20-Oct	48.3	20-Oct	45.5	0	-5.8	27-Oct	43.5	+7	-9.9
Raisen	20-Oct	50.2	13-Oct	48.6	-7	-3.2	20-Oct	46.8	0	-6.8
Khandwa	20-Oct	39.3	20-Oct	37.0	0	-5.9	27-Oct	35.4	+7	-9.9
Balaghat	20-Oct	48.3	20-Oct	45.5	0	-5.8	27-Oct	43.5	+7	-9.9
Mean		43.6		41.9		-3.7		40.1		-7.7
Kufri Jyoti										
Mandsaur	20-Oct	26.9	17-Nov	30.8	+28	14.5	17-Nov	29.0	+28	7.8
Chhatarpur	20-Oct	43.9	27-Oct	42.2	+7	-3.9	03-Nov	40.4	+14	-8.0
Raisen	20-Oct	48.2	20-Oct	45.4	0	-5.8	27-Oct	43.6	+7	-9.5
Khandwa	20-Oct	35.8	27-Oct	34.2	+7	-4.5	03-Nov	32.8	+14	-8.4
Balaghat	20-Oct	43.9	27-Oct	42.2	+7	-3.9	03-Nov	40.4	+14	-8.0
Mean		39.7		39.0		-0.7		37.2		-5.2
Kufri Pukhraj										
Mandsaur	20-Oct	25.5	17-Nov	31.6	+28	23.9	17-Nov	29.5	+28	15.7
Chhatarpur	20-Oct	46.5	27-Oct	48.0	+7	3.2	03-Nov	42.9	+14	-7.7
Raisen	20-Oct	52.2	27-Oct	48.8	+7	-6.5	27-Oct	47.1	+7	-9.8
Khandwa	20-Oct	37.7	27-Oct	36.5	+7	-3.2	03-Nov	35.0	+14	-7.2
Balaghat	20-Oct	46.5	03-Nov	44.7	+14	-3.9	03-Nov	42.9	+14	-7.7
Mean		41.7		41.9		2.7		39.5		-3.3

10.2% respectively) expected in Balaghat district. In 2020, mean decrease of 11.0 to 11.4 per cent due to temperature and increase of 4.9 to 4.8 per cent due to CO_2 is expected in the yields of *Kufri Jyoti* and *Kufri Pukhraj* respectively. However, when the combined effect of temperature and CO_2 are taken, the mean of 38 locations has shown a likely decline of 6.6 and 7.1 per cent in respective yields. Among the major potato producing districts, the maximum decline in productivity of *Kufri Badshah* and *Kufri Jyoti* is expected in Sagar district while the maximum decline in the productivity of *Kufri Pukhraj* is projected in Morena district (Table 2).

The extrapolated results have shown a decline of 6.4, 7.3 and 7.6 per cent in the yield of *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj* respectively, under the A1FI climate change scenario of 2020 (Table 3). While, 56.3 per cent geographical area of Madhya Pradesh is likely to witness yield reduction in the range of 5-6 per cent in 2020, 93.1 per cent area is likely to see 7-8 per cent yield reduction in *Kufri Jyoti* and almost entire Madhya Pradesh may experience 7–10 per cent yield reduction in *Kufri Pukhraj*.

During 2055, greater yield losses are expected in the yield of all the three potato cultivars. While the increase in temperature is likely to decrease the yield of *Kufri Badshah*, *Kufri Jyoti* and *Kufri Pukhraj* with respective values of 22.9, 23.9 and 27 per cent, rise in CO_2 concentration is expected to increase the yield by 19.6, 18.4 and 21.0 per cent for respective varieties. Patil *et al.* (2018) have also reported reduction in tuber yield upto 16-17 per cent due to

Table 5: Potential productivity of potato cultivars at representative locations in MP under baseline (2000) and future climate scenarios.

Location	Baseline (2000)					2020					2055				
	Normal DOP*	Productivity (t ha^{-1}) at normal DOP				Highest yielding cultivar	DOP	Productivity (t ha^{-1})	Change over baseline mean		Highest yielding variety*	DOP	Productivity (t ha^{-1})	Change over baseline mean	
		Kufri Badshah	*Kufri Jyoti*	*Kufri Pukhraj*	Mean				DOP (days)	Productivity (%)				DOP (days)	Productivity (%)
Mandsaur	20-Oct	32.1	26.9	25.5	28.2	*Kufri Badshah*	03-Nov	32.8	+14	16.4	*Kufri Badshah*	17-Nov	31.5	+28	11.8
Chhatarpur	20-Oct	48.3	43.9	46.5	46.2	*Kufri Pukhraj*	27-Oct	48	+7	3.8	*Kufri Badshah*	27-Oct	43.5	+7	-5.9
Raisen	20-Oct	50.2	48.2	52.2	50.2	*Kufri Pukhraj*	27-Oct	48.8	+7	-2.8	*Kufri Pukhraj*	27-Oct	47.1	+7	-6.2
Khandwa	20-Oct	39.3	35.8	37.7	37.6	*Kufri Badshah*	20-Oct	37	0	-1.6	*Kufri Badshah*	27-Oct	35.4	+7	-5.9
Balaghat	20-Oct	48.3	43.9	46.5	46.2	*Kufri Badshah*	20-Oct	45.5	0	-1.6	*Kufri Badshah*	27-Oct	43.5	+7	-5.9
Mean		43.6	39.7	41.7	41.7			42.4		2.9			40.2		-2.4

increase in temperature by 3 ^{0}C. However, the respective figures for decline in yield under the combined influence of temperature and CO_2 are 10.4, 12.3 and 13.9 per cent, when the means of 38 locations were considered. The results are in conformity with the findings of Rosenzweig and Hillel (1998) who also found yield increase of potato by 51 per cent due to increase in CO_2 concentration. Among the major potato producing districts of the state; Sagar, Indore and Morena are likely to take the biggest hit in term of productivity of *Kufri Badshah, Kufri Jyoti* and *Kufri Pukhraj*, respectively in 2055.

The extrapolated results have shown that yield of Kufri Badshah could reduce by about 7-12 per cent in around 98 per cent of the area. Some parts of Ratlam and Jhabua districts may experience up to 13-15 per cent yield reduction in *Kufri Badshah* in 2055. In case of *Kufri Jyoti*, most part of Madhya Pradesh (95%) may experience the yield reduction in the range of 10-15 per cent, with south-western district, particularly Ratlam, Jhabua, Dhar and Barwani, expecting greater yield losses.

The extrapolated results from WOFOST output for the entire geographical area of Madhya Pradesh has projected 10.9, 12.8 and 14.3 per cent decline in the yields of *Kufri Badshah, Kufri Jyoti* and *Kufri Pukhraj* respectively in 2055 (Table 3). Decline in the yield of potato cultivars in future climate due to higher temperature was on account of reduced photosynthetic efficiency (minimum (0–7 °C), optimum (16–25 °C) and maximum (40 °C) temperatures) and reduced duration of crop growth, leading to shorter bulking period (Kooman and Haverkort, 1995). When the mean was taken over 38 locations, *Kufri Badshah, Kufri Jyoti* and *Kufri Pukhraj* matured in 104, 94 and 89 days respectively under the baseline situation. However, the respective duration was reduced by 6, 6 and 5 days in 2020 and 16, 15 and 14 days in 2055, leading to a substantial decrease in the duration of tuber bulking phase. These results are in conformity to the findings of Haris *et al.,* (2015).

Adaptation strategies

Selection of suitable variety and date of planting are two of the major options which can be easily adopted against climate change. WOFOST model was run for potato cultivars for all climatic scenarios (Baseline, 2020 and 2055) for 8 dates, starting from 29th September, at a weekly interval. Five locations in Madhya Pradesh were selected for this study representing different parts of the state *i.e.* North-eastern (Chhatarpur), North-western (Mandsaur), South-eastern (Balaghat), south western (Khandwa) and Central part (Raisen). The perusal of Fig. 1 shows that at all locations,

yield of *Kufri Badshah* was highest at the earliest planting while that of *Kufri Pukhraj* was lowest. But as the planting was delayed, a drastic increase in yield of *Kufri Pukhraj* was observed, it gave highest yields at last date of planting for which the model was run. All the varieties showed a yield decline in future climates at all dates of planting although the magnitude varied.

While comparing the date of planting and varieties, it was observed that delaying planting by two weeks in North-western part (Mandsaur) in fact increased the productivity of *Kufri Badshah* by 2.2 per cent in 2020 while in Raisen 97 days earlier planting showed 3.2 per cent decline in yield against 4.6 per cent at normal date of planting (Table 4). Delaying planting by 1-4 weeks at different locations caused a depression in the reduction of tuber yield of *Kufri Jyoti* and *Kufri Pukhraj* in 2020. Similar trend was also observed in 2055 for all the varieties. Thus, the model results have indicated that shifting planting date in Madhya Pradesh by about a week to 28 days can bring down the reduction in tuber yield of *Kufri Badshah* from 6.4-3.7 per cent in 2020 and 10.9- 7.7 per cent in 2055. Corresponding figures for *Kufri Jyoti* are 7.3–0.7 per cent in 2020 and 12.8-5.2 per cent in 2055. While in *Kufri Pukhraj*, simply by selection of suitable date, reduction in tuber yield can be minimized from 7.6 to 2.7 per cent in 2020 and 14.3 to 3.3 per cent in 2055 (Table 4).

Overall, *Kufri Badshah* was found to be most suitable variety under climate change scenario in north western, south eastern and south western parts and *Kufri Pukhraj* in Central and North eastern parts in 2020. However, in 2055 except at Central part where *Kufri Pukhraj* was found to be most suitable, *Kufri Badshah* performed the best in rest of the Madhya Pradesh. The model results thus show that simply by selection of suitable variety and date of planting, the effect of climate change on potato productivity in Madhya Pradesh can be offset and the productivity can be kept almost at baseline levels till 2055.

CONCLUSIONS

The increasing temperature in the future climate is likely to reduce the potato productivity in Madhya Pradesh despite concomitant rise in CO_2. The simulation studies have shown that the potato productivity may decline by 6.42 to 7.6 per cent in 2020 and 10.9 to 14.3 per cent in 2055. However, the selection of suitable variety and change in the date of planting may arrest the decline in productivity to a greater extent. The study shows that there is a need to develop potato cultivar which are adapted to high temperature with a greater bulking rate.

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