

## Forecasting the impact of climate change on potato (*Solanum tuberosum*) productivity in Gujarat and relative adaptation strategies

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### ABSTRACT

A study was carried out in Gujarat to assess the impact of climate change on potato (*Solanum tuberosum* L.) productivity, using the WOFOST crop growth-simulation model. Three potato cultivars of different maturity, viz 'Kufri Badshah', 'Kufri Jyoti' and 'Kufri Pukhraj', were selected as test varieties. The study was done for baseline scenario (2000) and for future climate scenarios (2020 and 2055) using A1FI scenario of temperature (SRES A1FI pathway) and atmospheric CO<sub>2</sub> (based on the Bern-CC model for A1FI scenario). Potential production of potato cultivars was estimated for 20 different locations across Gujarat. Under the baseline scenario, the mean productivity of 'Kufri Badshah', 'Kufri Jyoti' and 'Kufri Pukhraj' was 40.0, 36.0 and 37.4 t/ha, respectively. The increase in temperature during 2020 and 2055, decreased the productivity ranging from 11.5 to 14.5% during 2020 and from 22.9 to 33.9% in 2055 climate scenarios. The corresponding increase in CO<sub>2</sub> concentration enhanced the productivity ranging from 4.9 to 5.3% and 20.8 to 22.9% during 2020 and 2055 scenarios respectively. Overall, the combined effect of CO<sub>2</sub> and temperature decreased the productivity of 'Kufri Badshah', 'Kufri Jyoti' and 'Kufri Pukhraj' by 6.7, 9.4 and 9.5%, respectively, during 2020 and by 19.9, 23.3 and 25.6% for respective varieties during 2055. It was also found that rescheduling the date of planting and selecting suitable varieties can completely offset the impact of climate change on potato productivity during 2020 while it can reduce the decrease in yield from 22.3 to 9.7% during 2055. However, development of potato cultivars with high bulking period proportionate to their total crop duration are required to meet the challenges posed by climate change on potato crop in future.

**Key words:** Bern CC model, Climate change, Forecasting, Simulation, WOFOST model

The climate is changing immensely and is bringing new challenges. It is happening in every part of the Globe-from equator to poles (Gearheard *et al.*, 2010). The impact of climate change on agriculture is already being felt. Poor and developing countries, especially those located in tropical and subtropical zone, are most influenced by the effects of these changes, severely negatively. It is reported that currently observed trend of global warming, which has been  $0.6 \pm 0.2^{\circ}\text{C}$  since 1900, will continue and average global temperature will increase by between 1.4 and 5.8<sup>o</sup>C over the period 1990 to 2100 (Houghton *et al.*, 2001). The impact of this type of climate change will probably lead to a decrease in crop productivity, but with important differences between regions (McCarthy *et al.*, 2001). Hence, development of varieties with different duration that can withstand the climate change, release of varieties for high

temperature, which respond positively in growth and yield to high CO<sub>2</sub> concentration, can also be a future adaptation strategy against climate change (Venkateswarlu and Shanker, 2009).

Potato is one of the most important food crops after wheat, maize and rice, contributing to food and nutritional security and in terms of human consumption, it is the third most important food crop in the world, following rice and wheat (FAO, 2014). Since tuberization rate of potato declines above a temperature of 17<sup>o</sup>C, increasing temperature may lead to reduced yields in potato. On the other hand, a simulation study has shown that, in northern European countries a warmer climate would bring a longer growing season and big increase in yields. However, increase in temperature and atmospheric CO<sub>2</sub> are interlinked that occur simultaneously and CO<sub>2</sub> enrichment does not appear to compensate for the detrimental effects of higher temperature on tuber yield. But the global picture is worrying: worldwide research shows that, without adaptation, higher temperatures may reduce yield by 10–19% in 2010–2039 and 18–32 % in 2040–2069. The most vulnerable area is

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the tropical belt, where the loss could be more than 50% (FAO, 2008). The impact of changing climate has been estimated on potato productivity in India, a likely rise in temperature to 3°C will result in decline of potato production by 13.72% in the year 2050 (Singh *et al.*, 2013). The temperature in India is estimated to rise approximately by 1, 3 and 5°C during main Indian potato-growing winter season by year 2020, 2050 and 2080 respectively (Lal *et al.*, 2008).

In terms of area under potato cultivation and production, India is the 4th and 2nd largest country, respectively, in the world. Potato has a significant contribution to the socio-economic condition of Indian people. In Gujarat, fastest annual compound growth rate (ACGR) in terms of potato area, production and productivity has been reported among all the Indian states. The ACGR of area and production from 1998–99 to 2006–07 was 4.5 and 7.9% for Gujarat against 1.31 and (-) 0.5% for whole country. Gujarat has elevated to the third largest potato-producing state from the fourth one (Kesari and Rana, 2008). In Gujarat, the mean temperature during potato-growing season is quite higher than other major potato-producing states like Punjab, Uttar Pradesh, Bihar and West Bengal. Since, in states like Uttar Pradesh and Bihar potato productivity is likely to fall by 6.1% and 6.1% in 2020 and 11.2% and 10.7% by 2055 respectively (Dua *et al.*, 2015, 2016), a similar trend is expected in Gujarat. Therefore, considering above facts, a study was conducted to investigate the impact of climate change on potato productivity in Gujarat and to formulate the relative adaptation strategies to minimize its impact.

## MATERIALS AND METHODS

### *Selection of model*

World Food Studies (WOFOST) crop-growth model, developed at the Wageningen University, the Netherlands, is a mechanistic model that simulates the growth of a crop, based on eco-physiological processes. Phenological development, CO<sub>2</sub>-assimilation, transpiration, respiration, partitioning of assimilates to various organs, and dry-matter formation are the major processes incorporated in this model. Worldwide, this model is widely used (Tubiello and Ewert, 2002) to assess the effect of climate change on growth and yield of many crops, viz. wheat, rice, maize potato, barley, soybean, sugar beet etc. (Wolf *et al.*, 2010; Reidsma *et al.*, 2015). This model has been validated for Indian potato cultivars under study using the time course data on potato growth and development, derived from field experiments conducted at Jalandhar (Punjab) and Patna (Bihar) during 1999–2001 (Dua *et al.*, 2014) (Table 1). Thus, this model was selected in the present study for impact assessment of climate change on potato productivity and scheduling planting date and selection of suitable cul-

tivar to minimize climatic impact in Gujarat. The model was run for 20 locations in Gujarat excluding Kutch as the area under potato cultivation is negligible in the district.

### *Selection of potato cultivars*

The simulation studies were carried with 3 potato cultivars from 3 different maturity groups, viz. late ('Kufri Badshah'), medium ('Kufri Jyoti') and early ('Kufri Pukhraj'), which are cultivated extensively in Gujarat. The simulation study was carried out for potential yields of potato cultivars planted on 5th November (the normal date of planting in Gujarat) for all the scenarios as described in next section.

### *Weather data*

In the present study, IMD district normals of 1971–2000 for 20 districts of Gujarat (Table 2) were used for baseline scenario (year 2000). Hargreaves-Samani equation was employed for working out total solar radiation. The equation uses maximum and minimum temperature to estimate solar radiation and is reported to be best suited for Indian conditions (Samani *et al.*, 2000; Bandyopadhyay *et al.*, 2008). The weather data were then converted into WOFOST weather file format. The simulation studies were carried out for A1FI high emission scenario of 2020 and 2055. For generation of scenario 2020 and 2055, 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). Projected atmospheric CO<sub>2</sub> concentration based on the Bern-CC model for A1FI scenario was used for incorporating the effect of change in CO<sub>2</sub> concentration in WOFOST model (IPCC, 2001). The figures used in this study for atmospheric CO<sub>2</sub> concentration were 367 ppm (for baseline), 415 ppm (for 2020) and 590 ppm (for 2055).

### *Incorporation of CO<sub>2</sub> impact in the model*

For incorporating the impact of CO<sub>2</sub> in the WOFOST model, changes were made in the parameters, light-use efficiency of single leaf and maximum leaf CO<sub>2</sub> assimilation rate. An increase of 25 to 40% (mean 32.5%) in yield of C<sub>3</sub> plants owing to doubling of CO<sub>2</sub> from 355 ppm to 710 ppm has been reported (Wolf *et al.*, 2010). Based on literature, changes were made in initial angle (+11%) and in the maximum CO<sub>2</sub> assimilation – light response curve (+60%) parameters of WOFOST model for doubling CO<sub>2</sub> conc. from 355 to 710 ppm. Under the experimental conditions with non-limiting supply of water and nutrients, and where temperature is kept near optimum for crop growth, the yield increase for C<sub>3</sub> crops with doubling of CO<sub>2</sub> has been estimated at 30% by various workers (Fuhrer *et al.*, 2003),

therefore, figures have been taken as +10% (30/32.5 X 11) and +55% (30/32.5 X 60) for doubling CO<sub>2</sub> conc. for potato, assuming roughly linear relationship between CO<sub>2</sub> increase and growth processes. Accordingly, these parameters were changed for 2020 and 2055 for A1FI scenario as follows:

Parameter	2020	2055
Change in light-use efficiency of single leaf	$+10\% \times (415-367)/355 = +1.4\%$	$+10\% \times (590-367)/355 = +6.28\%$
Change in maximum leaf CO <sub>2</sub> assimilation rate	$+55\% \times (415-367)/355 = +7.4\%$	$+55\% \times (590-367)/355 = +34.5\%$

In the present study, to assess the impact of temperature, CO<sub>2</sub> and their interaction on crop growth and productivity, WOFOST model was run for 20 locations spread across Gujarat (Table 2), for 3 potato cultivars in baseline situation and for future climates (2020 and 2055).

For adaptation studies, model was run for 3 different locations representing different parts of state, viz. Jamnagar (22.47°N, 70.05 °E), Surendranagar (22.72 °N, 71.64 °E) and Dahod (22.85 °N, 74.12 °E). The model was run for 3 cultivars of potato ('Kufri Badshah', 'Kufri Jyoti' and 'Kufri Pukhraj'), for all the 3 climatic scenarios (baseline -2000, 2020 and 2055) for 10 different dates starting from 1st October at a weekly interval.

### Kriging

*Geomatica* software was used for creation of maps including baseline productivity and change in productivity of different potato cultivars under future climate scenarios. An image of 500 m pixel size was used for generation of GIS maps of Gujarat. A point layer of 20 districts of Gujarat was incorporated using their geographical locations (Table 2). Attribute data of each district containing productivity and change in productivity under future climate scenarios were geo-statistically interpolated using Kriging technique and surface layers of the attributes were produced. Modeling for per cent change in productivity and for estimation of area falling under different class of attributes was done

in EASIPACE.

## RESULTS AND DISCUSSION

The productivity of 'Kufri Badshah', varied from 35.1 (Navasari) to 50.8 t/ha (Banaskantha) within the locations, with a mean productivity of 40 t/ha under the baseline scenario (2000), while the productivity of 'Kufri Jyoti' and 'Kufri Pukhraj' ranged from 30.6 (Navasari) to 46.5 t/ha (Banaskantha) and 31.1 (Jamnagar) to 49.1 t/ha (Banaskantha) in the same scenario, respectively, with a mean productivity of 36 and 37.4 t/ha (Table 3). The extrapolated results have shown the same productivity figures for the 3 varieties. In general, the productivity was high in Northern districts of Banaskantha for all cultivars but reduced on moving towards South and South West. The productivity of potato in general was low in Jamnagar, Porbandar, Junagadh, Bharuch, Navasari and Valsad districts. This was probably due to higher mean temperature in these districts because of their proximity with the sea shore.

### Effect of climate change

The simulation results for 'Kufri Badshah' showed that, increase in temperature alone is likely to bring down the productivity from 7.4 (Narmada) to 18.4 (Bharuch) % with a mean decline of 11.5% in 2020. However, an increase of 48 ppm in CO<sub>2</sub> during 2000–2020 is likely to increase the productivity of 'Kufri Badshah' by 4.9% when the mean is taken across the locations. However, under the combined effect of temperature and CO<sub>2</sub>, the mean productivity of 'Kufri Badshah' is expected to decline by 6.7% in 2020 over 2000. When extrapolation was done for all locations, 7.6% decline in the yield of 'Kufri Badshah' is expected. In case of 'Kufri Jyoti', the decline in productivity due to increase in temperature alone in 2020 is likely to range from 11.1 (Banaskantha) to 25.5 (Bharuch) % with the mean decline of 14.5% in 2020. While the figures for 'Kufri Pukhraj' are 11.6 (Dahod) to 18.6 (Navasari) %, with a mean decline of 14.5%. During the same period, increase in CO<sub>2</sub> is expected to increase the productivity of 'Kufri Jyoti' and 'Kufri Pukhraj' by 5.3% and 5.2% respectively. As potato is a C3 plant and increase in atmospheric CO<sub>2</sub>

**Table 1.** Comparison of measured (actual) and simulated values of some important parameters of potato cultivars

Parameter	'Kufri Badshah'			'Kufri Jyoti'			'Kufri Pukhraj'		
	Mea.	Sim.	Diff.	Mea.	Sim.	Diff.	Mea.	Sim.	Diff.
Emergence (days)	17	15	2 days	15	15	0 days	15	15	0 days
Tuber initiation (days)	37	36	1 days	32	35	3 days	29	36	7 days
Total DM yield (t/ha)	14.6	15.5	5.6%	12.3	12.6	2.5%	13.1	13.1	0.5%
Tuber DM yield (t/ha)	8.7	8.9	2.1%	7.3	7.9	7.5%	8.3	8.3	0.6%

Mea, Measured; sim., simulated; diff., difference; DM, dry-matter

**Table 2.** WOFOST simulated potential productivity of potato cultivars under baseline (2000) and future climate scenarios at different locations under study in Gujarat

Station	‘Kufri Badshah’						‘Kufri Jyoti’						‘Kufri Pukhraj’						
	Baseline yield (t/ha)			Change over baseline yield (%)			Baseline yield (t/ha)			Change over baseline yield (%)			Baseline yield (t/ha)			Change over baseline yield (%)			
	2020	2055	2055	2020	2055	2055	2020	2055	2055	2020	2055	2055	2020	2055	2055	2020	2055	2055	
Ahmadabad	43.2	-10.4	4.7	-6.0	-21.6	20.6	-12.4	5.2	-7.6	-28.2	22.6	-22.4	41.3	-12.0	5.0	-7.4	-32.0	22.1	-24.1
Anand	42.4	-11.1	4.8	-6.6	-23.9	21.1	-13.6	5.3	-8.7	-31.9	23.1	-26.9	40.2	-13.4	5.1	-8.6	-33.7	22.6	-30.3
Banaskantha	50.8	-10.3	4.7	-6.0	-20.9	20.5	-11.1	5.0	-6.5	-24.4	22.1	-15.2	49.1	-12.0	5.0	-7.6	-28.0	22.0	-16.2
Bhavnagar	40.0	-10.3	4.2	-6.0	-20.8	20.3	-12.1	5.1	-7.4	-27.2	22.4	-23.1	37.8	-12.8	5.0	-7.9	-33.0	21.7	-22.7
Bharuch	35.7	-18.4	5.0	-6.9	-28.3	22.1	-30.0	31.0	-25.5	5.8	-18.4	-32.4	25.3	-29.8	32.2	-10.1	-34.3	25.7	-31.3
Dahod	44.1	-10.1	4.8	-5.7	-21.4	21.1	-16.4	40.7	-11.5	5.2	-6.7	-24.4	22.7	-19.3	42.9	-11.6	-6.9	-27.7	22.6
Dang	38.7	-10.7	4.7	-6.3	-21.1	20.3	-12.8	5.2	-8.0	-28.9	22.5	-26.3	36.3	-13.0	5.0	-8.1	-33.7	21.9	-27.2
Gandhinagar	41.4	-10.7	4.7	-6.3	-21.8	20.4	-18.8	37.4	-12.9	5.2	-8.2	-29.2	22.4	-24.6	38.7	-13.1	-8.3	-34.9	21.9
Jamnagar	35.1	-10.4	4.3	-6.4	-15.4	18.7	-14.2	30.8	-10.9	4.8	-6.4	-20.8	20.9	-19.5	31.1	-13.0	-8.2	-24.3	20.4
Junagarh	38.0	-13.4	4.9	-9.0	-26.7	21.3	-23.8	33.1	-20.0	5.6	-13.6	-34.3	24.1	-22.9	34.0	-16.8	-12.8	-34.2	24.5
Mahesana	41.2	-10.7	4.7	-6.3	-21.7	20.3	-18.8	37.2	-12.9	5.2	-8.2	-29.1	22.4	-22.3	38.5	-13.1	-8.3	-34.8	21.8
Narmada	35.6	-7.4	8.6	-3.0	-19.0	24.5	-17.8	33.2	-13.2	5.1	-8.4	-32.2	22.3	-26.8	34.4	-15.5	-10.2	-36.3	21.6
Navsari	35.1	-16.9	5.0	-8.5	-28.6	22.0	-22.0	30.6	-22.9	5.7	-16.3	-31.4	25.0	-23.7	31.8	-18.6	-12.6	-35.6	25.3
Patan	44.8	-10.3	4.7	-6.0	-21.1	20.4	-15.2	40.8	-12.1	5.1	-7.4	-26.6	22.4	-20.0	42.6	-11.8	-7.3	-32.4	22.0
Porbandar	37.6	-10.9	4.6	-6.7	-22.2	19.8	-20.9	33.1	-13.8	5.1	-8.8	-33.2	22.2	-22.8	33.9	-16.5	-10.9	-36.8	21.6
Rajkot	41.9	-11.2	4.8	-6.9	-23.7	20.6	-20.2	37.0	-13.1	5.2	-8.2	-36.5	22.9	-23.2	38.5	-16.1	-10.7	-35.7	22.3
Sabarkantha	36.8	-10.9	4.6	-6.6	-24.0	20.0	-22.8	32.6	-13.7	5.2	-8.7	-35.6	22.4	-23.7	33.6	-17.8	-11.9	-39.3	21.8
Surendranagar	42.5	-10.6	4.7	-6.3	-21.8	20.5	-17.8	38.5	-12.7	5.2	-8.0	-28.9	22.5	-23.5	39.9	-12.2	-7.4	-34.6	22.0
Vadodara	39.5	-14.0	5.0	-9.5	-29.2	21.8	-26.9	35.2	-17.4	5.6	-12.1	-33.4	24.4	-25.8	37.1	-16.3	-14.7	-37.3	23.8
Valsad	36.6	-12.3	4.8	-8.0	-24.5	20.4	-25.0	32.7	-14.9	5.3	-9.8	-32.6	23.1	-24.0	34.0	-15.6	-11.3	-39.4	22.5
Mean	40.0	-11.5	4.9	-6.7	-22.9	20.8	-19.9	36.0	-14.5	5.3	-9.4	-30.1	22.9	-23.3	37.4	-14.3	-9.5	-33.9	22.5

has a fertilization effect on this crop it leads to increased photosynthesis which ultimately promotes its growth and productivity. However, combined effect of temperature and CO<sub>2</sub> is likely to bring down the productivity by 9.4% in case of ‘Kufri Jyoti’ and 9.5% in case of ‘Kufri Badshah’ in 2020.

In 2055, greater decline is expected due to increase in temperature, in the productivity of all the 3 cultivars. The decline expected in the yield due to temperature ranged from 15.4 (Jamnagar) to 29.2 (Vadodra), 20.8 (Jamnagar) to 36.5 (Rajkot) and 24.3 (Jamnagar) to 39.4 (Valsad) % for ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’, respectively, with the respective mean decline of 22.9, 30.1 and 33.9%. The changes in crop production-related climatic variables will possibly have major influences on regional as well as global food production (Abraha and Savage, 2006). Temperature is a primary factor affecting the rate of plant development. Warmer temperatures expected with climate change and the potential for more extreme temperature events will impact plant productivity. Mean increase of 20.8, 22.9 and 22.5% in the productivity of ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’ cultivars is expected owing to positive effect of CO<sub>2</sub> fertilization as CO<sub>2</sub> is expected to reach 590 ppm.

However, this positive effect of CO<sub>2</sub> on productivity of

these potato cultivars is not sufficient to compensate fully the negative impact of associated temperature rise and the model has shown a mean decline of 19.9, 23.3 and 25.6% in the productivity of ‘Kufri Badshah’, ‘Kufri Jyoti’ and ‘Kufri Pukhraj’, respectively, when the mean was taken over 20 locations under study. Lee *et al.* (2020) also reported that, elevated temperature negatively impacts the growth and yield of potato crops, especially towards the late-growth phase; however, the simultaneous and appropriate elevation of CO<sub>2</sub> and temperature could promote potato productivity positively. Potato is a crop of temperate region and for net photosynthesis it requires, minimum (0–7°C), optimum (16–25°C) and maximum (40°C) temperature as reported by Patsalos (2005). Thus, a decline in potato productivity in Gujarat may be attributed to higher than optimum temperature required for optimum growth of potato.

The extrapolated results on the combined effect of CO<sub>2</sub> and temperature are depicted in Fig. 1. It can be observed that, decline in potato productivity across the districts studied, was higher in those which already had low baseline productivity, i.e. southern and south-west districts of Gujarat. This might be a result of higher than the optimal temperature required for potato growth and development under the baseline scenario. A rise in temperature during

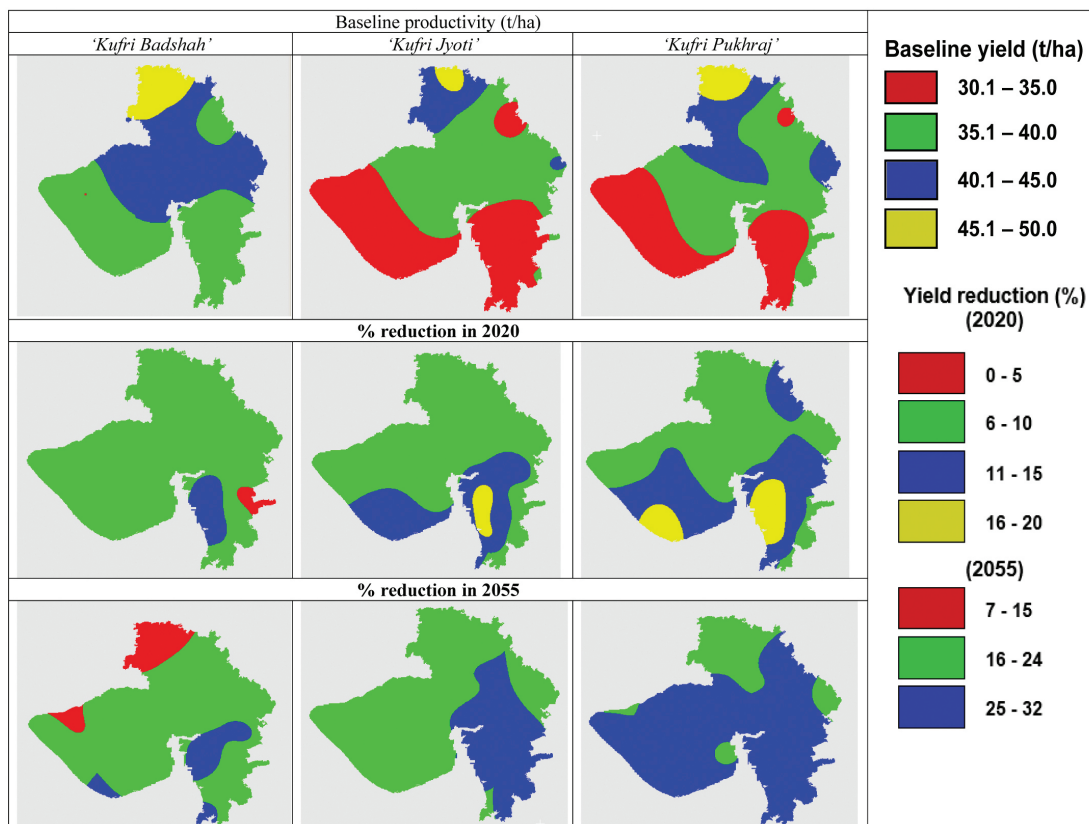


Fig. 1. Potential productivity of different potato cultivars under baseline and changes in future climatic scenario



**Table 4.** Potential productivity of potato cultivars at representative locations in Gujarat under baseline (2000) and future climate scenarios

Location	Normal	Baseline (2000)			2020			2055							
		*Productivity (t/ha) 'Kufri Badshah'	'Kufri Jyoti'	'Kufri Pukhraj'	DoP (t/ha)	Change over baseline mean DoP (days)	Highest yielding cultivar	DoP (t/ha)	Change over baseline mean DoP (days)	Highest yielding variety*					
Jamnagar	5 Nov	35.1	30.8	31.1	32.3	19 Nov	33.5	19 Nov	31.5	19 Nov	'Kufri Badshah'	19 Nov	+14	-2.6	
Surendranagar	5 Nov	42.5	38.5	41.4	40.8	5 Nov	39.8	5 Nov	35.5	12 Nov	'Kufri Badshah'	12 Nov	0	+7	-13.0
Dahod	5 Nov	44.1	40.7	43.4	42.7	5 Nov	41.6	5 Nov	36.9	5 Nov	'Kufri Badshah'	5 Nov	0	0	-13.7
Mean	40.6	36.7	38.6	38.6	38.3	34.6	-9.7	34.6	-9.7						

DoP, Date of planting

**Adaptation**

The simulation results for adaptation are shown in Fig. 2. The results indicated that yield of 'Kufri Badshah' was the highest at all the three locations during beginning of simulation and it increased up to day 12 after planting at Jamnagar, up to 5th November at Surendranagar and up to 20th October at Dahod under the baseline scenario and was also the highest among all the cultivars. However, further delay in planting witnessed a decline in yield of Kufri Badshah at all the locations. It was interesting to see that the yield of 'Kufri Pukhraj' which was low on initial dates of planting increased rapidly and surpassed the yield of 'Kufri Badshah' when planting was delayed beyond 19th November. Figure 2 further shows that under all future climate scenarios the yield of 3 cultivars declined at all 3 locations. Although, more or less it followed the similar trend as of the baseline scenario.

The results of simulation given in Table 4 indicate that by changing the date of planting, effect of climate change on potato productivity in Gujarat can be minimized to some extent. At Jamnagar, i.e. western part of Gujarat, with delaying the planting of 'Kufri Badshah' by 2 weeks can bring down reduction in the yield from 6.4 to 4.6% in 2020 and from 14.2 to 10.3% in 2055. At Dahod, normal date of planting in case of 'Kufri Badshah' was found suitable for all the 3 scenarios. In case of medium-maturing cultivar 'Kufri Jyoti', delaying the planting by 2 weeks at Jamnagar can bring down reduction from 6.4 to 0% in 2020 and from 19.5 to 5.8% in 2055 scenario. Delaying planting of 'Kufri Pukhraj' by 1–2 weeks in 2020 and 2–3 weeks in 2055 can arrest yield decline to a greater extent at all the 3 locations, at Jamnagar even an increase is expected in the yield of 'Kufri Pukhraj' with 2 week delayed planting in 2020.

Further analysis of simulation data (Table 5) showed that by changing the date of planting and selection of suitable varieties, the effect of climate change on potato productivity in 2020 can be completely offset. In 2055, a mean decline of 22.9% can be easily brought down to only 9.7% through selection of suitable varieties and change in the date of planting, as is evident from the mean of 3 locations given in Table 5. The study further indicates that there is a need to develop potato cultivars which have a higher bulk-ing period proportionate to their total crop duration. Our results confirm the findings of Hijmans (2003) who also reported that by changing time of planting, the use of later-maturing cultivars, and a shift of the location of potato production mitigate the negative impacts of climate change on potato production.

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**Table 5.** Geographical area of Gujarat (%) under different yield classes in 2000

Potential productivity (t/ha)	'Kufri Badshah'	'Kufri Jyoti'	'Kufri Pukhraj'
30–35	0.0	44.5	32.8
35.1–40	50.8	45.4	44.6
40.1–45	41.2	8.4	17.9
45.1–50	8.0	1.7	4.7

**Table 6.** Productivity of potato cultivars in baseline year and changes thereof in future climates (interpolated results for total geographical area of Gujarat)

Parameter	'Kufri Badshah'	'Kufri Jyoti'	'Kufri Pukhraj'
Baseline yield (t/ha)	40.0	36.0	37.4
Overall reduction in yield (%)			
2020	7.6	9.7	10.9
2055	19.5	22.1	25.2
Yield reduction classes (%) in 2020	<b>% geographical area of Gujarat</b>		
0–5%	1.7	-	-
6–10%	92.1	72.5	53.8
11–15%	6.2	24.4	36.2
16–20%	-	3.1	10.0
Yield reduction (%) classes in 2055			
7–15%	10.2	-	-
16–24%	79.9	70.4	19.8
25–32%	9.9	29.6	80.2

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