Journal of Agrometeorology 23 (1) : 82-92 (March 2021)

Assessment of climate change impact on different pigeonpea maturity groups in north Indian condition

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ABSTRACT

The CROPGRO-pigeonpea model embedded in DSSAT v4.7.5 was used to assess the impact of climate change on phenology and grain yield of reference genotype of different pigeonpea maturity groups. The impact of climate change delayed reproductive stages (anthesis, maturity) and decreased grain yield of reference genotype of different pigeonpea maturity groups were evident in all scenarios. Short duration genotypes (MN5, ICPL88039, Prabhat, UPAS120) showed progressively higher decrease in yield as compared to medium (Maruti, Asha, ICP7035) and long (Bahar, MAL13) duration genotypes with each successive increase in scenatio from RCP2.6 to RCP8.5 and projected year from 2010 to 2095. Anthesis was delayed 9 days in MN5 to 20 days in Bahar and maturity delayed 15 days in MN5 to 24 days in Bahar with RCP 8.5 in year 2095 in comparison to RCP2.6 in years 2010, whereas, grain yield was decreased 14% in Bahar to 66% in MN5 among genotypes of different maturity groups.

Key words: MarkSim, GCM, RCP, DSSAT, climate change, pigeonpea, maturity group

The Earth's climate is projected to undergo marked changes over the 21stcentury due to natural processes and anthropogenic factors (IPCC, 2014). As known that pigeonpea is second most grain legume stable in India, therefore climate change impacts on its production could have broad and national repercussions on food and nutritional security. The pigeonpea production is highly variable due to climatic variability. There is a great challenge for sustainable pigeonpea production in the country. The RCPs quantitatively describe and provide time and space dependent trajectories of anthropogenic greenhouse gases and pollutants together with their collective radiative forcing, and are used as input to climate models (IPCC, 2014). Global circulation models and process-based crop models have been used in different studies assessing the potential impacts of climate change on crop production. MarkSim DSSAT Weather File Generator, a software that not only downscales but also generates daily weather from general circulation models is used to overcome the coarse resolution of general circulation models (Jones and Thornton, 2013). The generated daily weather data characteristic of future climate scenarios was used to drive the CROPGRO-pigeonpea model.

For assessment of climate change and variability, Patel *et al.*(2018) analyzed 30 years weather data of Varanasi (from 1981 to 2010) and projected for years i.e. 2010, 2035, 2065 and 2095. They observed that the maximum temperature were increased0.5°C to1.9°C (1.5-5.8%), whereas, minimum temperature were also increased 0.5- 2.0°C (2.7-10.3%)for projected years 2010 to 2095. Solar radiation and rainfall would be decreased from 1.4-5.5 MJm^{-2}day^{-1} (7.5-28.0%) and 141.5-542 mm (14.6-56.1%), respectively. The methodology of Patel *et al.*(2018) was adopted in order to study the impacts of climate change on pigeonpea yields. The main objective of present study was simulated projected yield of reference genotype of different pigeonpea maturity group under conditions of changing anticipated future radiation and temperature at Varanasi using MarkSim weather generator.

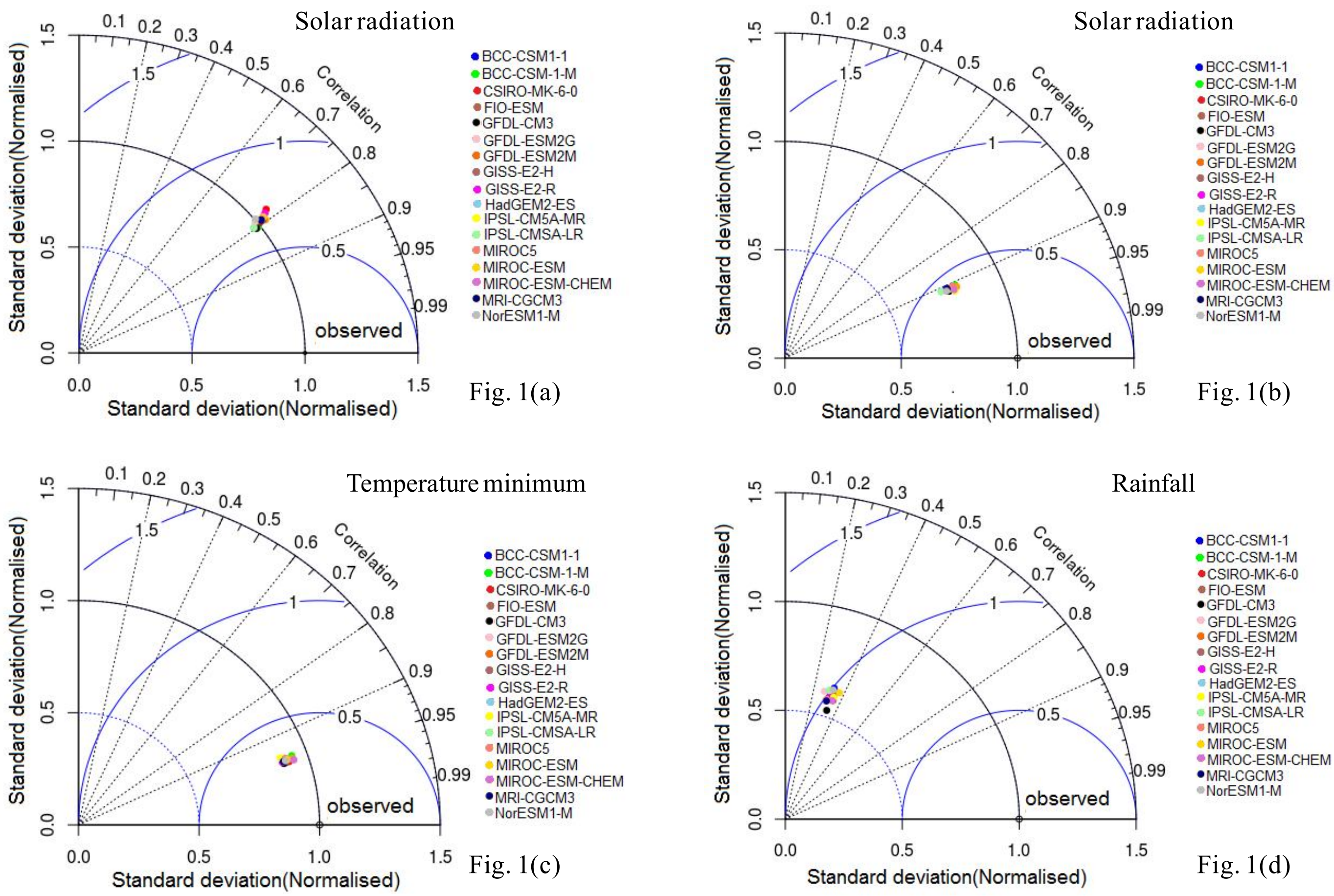

Fig.1 : Taylor diagrams for solar radiation, temperature maximum and minimum and precipitation, comparing observations with the weather generator models of MarkSim GCM at Varanasi for the year 2010.

MATTERIALS AND METHODS

Daily weather data on maximum temperature, minimum temperature, solar radiation and rainfall from the India Meteorological Department(IMD), New Delhi and anthesis, maturity and grain yield data of reference cultivars of different pigeonpea maturity group collected from reports of All India Co-ordinated Pulse Improvement Project(AICPIP)/ All India Co-ordinated Reasearch Project on Pigeonpea(AICRPP) / All India Co-oridinated Research Project on Dryland Agriculture(AICRPDA)/International Crop Research Institute for Semi-Arid Tropic(ICRISAT)/ Indian Institute of Pulse Research(IIPR)/ State Agriculture Universities (SAUs)/ Krishi Vigyan Kendra(KVKs)/State Department of Agriculture(SDAs) and works of many researcher shown in Table 1 were use for calibration and validation. The *n*RMSE of day to anthesis, matrurity and grain yield of reference genotype of different pigeonpea maturity groups were showed its acceptable level viz. less than 10.0% as respective simulated values was closed to observed values (Table 1). The sensitivity analysis were carried out after the calibration and validation(Table 1) of The CROPGRO-pigeonpea model embedded in DSSATv4.7.5 model (Hoogenboom *et al.,* 2019) in respect to anthesis, maturity and grain yield.

The minimum input data required to run the model for the studies of climate change impact includes: daily weather data (solar radiation, rainfall, maximum and minimum temperatures)generated from the website MarkSim DSSAT weather generator (http://gisweb.ciat.cgiar.org/ MarkSimGCM/) for Varanasi (25°182 north latitude, 83°102 east longitude and 76 meters above mean sea level) from 2010-2095 (Jones and Thornton, 2013); data of 99 replications of GFLD-CM3 model, with a spatial resolution of 1.2587 × 2.5 (latitude by longitude) (Dufresne *et al.,* 2013) was selected. Data were downloaded in DSSAT friendly format for the following scenarios: RCP2.6, 4.5, 6.0 and RCP 8.5 with their respective projected years: 2010, 2035, 2065 and year 2095. The generated weather data of year 2010 with RCP 2.6, 4.5, 6.0 and RCP 8.5 were chosen as baseline for assessment of climate change impact in future years (2035, 2065 and 2095).

Table 1: Major pigeonpea maturity groups, reference cultivars, anthesis, maturity and grain yield used in calibration and validation (Data from reports of AICPIP/ AICRPP/ AICRPDA/ ICRISAT/ IIPR/ SAUs/ SDAs and different researcher are used).

ICRISAT maturity group	Maturity group	Reference cultivars	50% Flowering DAP	Obs.	Sim.	Maturity DAP	Obs.	Sim.	Grain yield (t ha^{-1})	Obs.	Sim.
00	Super-early(SE)	MN 5	<50	45	43	85-90	85	82	1.5-2.0	1.1	0.9
0	Extra-short(ES)	ICPL 88039	51-60	50	55	90-110	92	90	1.5-2.0	1.8	1.9
I	Extra-Short(ES)	Prabhat	61-70	65	63	110-120	101	100	1.5-2.5	2.5	2.7
II	Short(S)	UPAS 120	71-80	74	73	120-125	115	115	1.5-2.5	2.6	2.8
III	Short(S)	T 21	81-90	87	86	160-165	140	131	2.0-3.0	2.8	2.9
IV	Short(S)	ICP 6	91-100	90	94	165-170	155	151	2.0-3.5	3.3	3.6
V	Short-medium(SM)	Maruti	101-110	105	105	170-180	175	169	2.0-3.5	3.2	3.6
VI	Medium(M)	Asha	111-130	115	115	180-200	195	206	2.5-4.0	3.8	4.0
VII	Medium(M)	ICP 7035	131-140	136	134	200-210	220	241	2.5-4.0	3.8	4.1
VIII	Medium-long(ML)	Bahar	141-160	145	143	250-260	270	271	2.5-4.5	3.5	3.3
IX	Long(L)	MAL 13	>160	155	156	240-250	285	300	2.5-4.5	4.5	4.8
		RMSE		2.4			9.2			0.3	
		nRMSE		2.5			5.5			8.8	

Obs.: Observed, Sim.: Simulated, References- MN 5:Chauhan *et al*.(1998), Chauhan *et al*.(2002), Vales *et al*.(2012); ICPL 88039: Saxena *et al*.(2006), Vales *et al*.(2012); Prabhat: Kumar Rao and Dart(1987); UPAS 120: Sandhya and Singh(2018), Carberry *et al*.(2001); T 21: Kumar Rao and Dart(1987), Carberry *et al*.(2001), Saxena *et al*.(2019); ICP 6: Chauhan *et al*.(1992); Maruti: Saxena *et al*.(2006), Channabasavanna *et al*.(2015); Asha: Saxena *et al*.(2006), Channabasavanna *et al*.(2015); ICP 7035: Saxena *et al*.(2011); Bahar: Yadav and Singh(2009); MAL 13: Saxena *et al*.(2006)

RESULTS AND DISCUSSION

Performance of models of MarkSim GCM

For the performance of models, downloaded weather data of year 2010 of all 17 models of MarkSim GCM and compared with observed weather data of year 2010 as correlation, RMSE and normalized standard deviation in Taylor diagram. Results from the Taylor diagram suggests a good performance for the solar radiation Fig.1 (a) and temperature Fig.1 (b and c) variable by almost all the 17 models in MarkSim. For solar radiation, the correlation was high and ranged from 0.76 to 0.81, the RMSE was low and ranges from 0.67 to 0.75 MJ/day and the normalized standard deviation was some high and rages from 0.91 to 1.11 MJ/day (Fig.1.a). For maximum temperature, the correlation was high and ranged from 0.90 to 0.93, the RMSE was low and ranges from 0.45 to 0.49 ^{0}C/day and the normalized standard deviation was also low and rages from 0.75 to 0.80 ^{0}C/day (Fig.1.b). For minimum temperature, the correlation was high and ranged from 0.94 to 0.95, the RMSE was low and ranges from 0.35 to 0.39 ^{0}C/day and the normalized standard deviation was also low and rages from 0.84 to 0.90 Deg C/ day (Fig.1.c). For the generated rainfall, the models deviate significantly from observations. For the generated rainfall, the models deviate significantly from observations. The RMSE were large (0.85-0.97 mm/day) and the correlation was weak and ranges from 0.27 to 0.37 (Fig. 1.d). However, the GFDL-CM3 model ensemble performs better than any individual model as it has the largest correlation and least RMSE and normalized standard deviation. GFDL-CM3 is the best-performing individual model, followed closely by several others. Patel *et al.* (2018) also find that model GFDL-CM3 has higher confidence and correlation between observed weather data for India.

Validation of GFLD-CM3 weather generator model

For validation of GFLD-CM3 model, simulated grain yield and phenology of reference genotypes of different pigeon pea maturity groups using GWD of GFLD-CM3 and compared with simulated of observed weather data. Simulated grain yield and phenology were near to simulate using observed weather data and presented in Table 2

Table 2(a): Validation of GFLD-CM3 results against observed weather data of year 2010 of Varanasi district(Extra-short varieties)

Genotype	Scenario	Grain yield (t ha^{-1})		Anthesis days (DAS)		Maturity days (DAS)	
		Pro#	Sim*	Pro#	Sim*	Pro#	Sim*
NM5	RCP (2.6)	0.7	0.9	40	41	75	75
	RCP (4.5)	0.8	0.9	39	41	75	75
	RCP (6.0)	0.8	0.9	40	41	75	75
	RCP (8.5)	0.8	0.9	39	41	74	75
	Mean	0.8	0.9	39	41	75	75
	RMSE	0.1		1.57		0.32	
	nRMSE	7.7		3.83		0.42	
ICPL88039	RCP (2.6)	1.7	1.9	52	53	88	88
	RCP (4.5)	1.8	1.9	52	53	88	88
	RCP (6.0)	1.7	1.9	52	53	88	88
	RCP (8.5)	1.8	1.9	51	53	87	88
	Mean	1.8	1.9	52	53	88	88
	RMSE	0.1		1.16		0.58	
	nRMSE	5		2.19		0.66	
PRABHAT	RCP (2.6)	2.6	2.7	60	61	98	98
	RCP (4.5)	2.6	2.7	60	61	98	98
	RCP (6.0)	2.4	2.7	60	61	98	98
	RCP (8.5)	2.6	2.7	59	61	97	98
	Mean	2.5	2.7	60	61	98	98
	RMSE	0.2		1.49		0.36	
	nRMSE	7		2.44		0.37	

Pro#: Projected, Sim*: Simulated

(a,b&c). The *n*RMSE of day to anthesis and maturity of reference genotype of different pigeon pea maturity groups were showed its acceptable level viz. less than 6.0%. The *n*RMSE of grain yield of reference genotype of different maturity groups was also support to simulation of impact of climate change of pigeonpea crop using generated weather data for future climatology. However, validation has been done with simulated phenology and grain yield using observed weather data of year 2010 only.

Consequences of climate change on pigeon pea yield

Percent changes in yield were evaluated by comparing the future pigeon pea yields of each reference genotype of different maturity groups to the baseline yields of projected year of 2010 with its scenario (Table 3.a). Effect of climate change on pigeon pea grain yield were studied for projected years i.e. 2035, 2065 and 2095, yield decreased prevail at all scenario viz. RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. Short duration genotypes (MN5, ICPL88039, Prabhat, UPAS120) showed progressively higher decrease in yield as compared to medium (Maruti, Asha, ICP7035) and long (Bahar, MAL13) duration genotypes with each successive increase in scenatio from RCP 2.6 to RCP 8.5 and projected year from 2010 to 2095. The maximum yield decreased in the scenario RCP 8.5, which ranged from -66%(MN5) to -14% (Bahar) were more extreme than emission scenarios (RCP 2.6, 4.5 and 6.0), which were between -3%to -41% in genotype MN5 to 3% to -12% in genotype Bahar. These results show RCP 8.5 (-14%) as the most resilient scenario, and RCP 2.6 (-5%) as least resilient scenario to climate change on average yield basis. Projected year 2035 (-7%) was the least vulnerable and year 2095(19%) the most vulnerable under all emission scenario. Yadav *et al.* (2016) and Patel *et al*. (2018b) found that substantial pigeonpea

Table 2(b): Validation of GFLD-CM3 results against observed weather data of year 2010 of Varanasi district (short and short-medium varieties)

Genotype	Scenario	Grain yield (t ha^{-1})		Anthesis days (DAS)		Maturity days (DAS)	
		Pro#	Sim*	Pro#	Sim*	Pro#	Sim*
UPAS120	RCP (2.6)	2.8	2.8	70	71	113	113
	RCP (4.5)	3.0	2.8	70	71	113	113
	RCP (6.0)	2.8	2.8	70	71	114	113
	RCP (8.5)	3.0	2.8	69	71	113	113
	Mean	2.9	2.8	70	71	113	113
	RMSE	0.1		1.16		0.36	
	nRMSE	3		1.63		0.32	
T 21	RCP (2.6)	3.0	2.9	84	84	129	129
	RCP (4.5)	3.1	2.9	84	84	129	129
	RCP (6.0)	3.0	2.9	84	84	129	129
	RCP (8.5)	3.1	2.9	83	84	129	129
	Mean	3.1	2.9	84	84	129	129
	RMSE	0.1		0.41		0.31	
	nRMSE	5		0.49		0.24	
ICP6	RCP (2.6)	3.3	3.6	92	92	150	149
	RCP (4.5)	3.2	3.6	91	92	150	149
	RCP (6.0)	3.4	3.6	91	92	150	149
	RCP (8.5)	3.3	3.6	91	92	150	149
	Mean	3.3	3.6	91	92	150	149
	RMSE	0.2		0.62		1.03	
	nRMSE	7		0.67		0.69	
MARUTI	RCP (2.6)	3.7	3.6	103	103	168	167
	RCP (4.5)	4.0	3.6	103	103	169	167
	RCP (6.0)	3.5	3.6	103	103	168	167
	RCP (8.5)	3.5	3.6	103	103	169	167
	Mean	3.7	3.6	103	103	103	103
	RMSE	0.2		0.16		1.16	
	nRMSE	5		0.16		0.75	

Pro#: Projected, Sim*: Simulated

grain yield decreased with increasing maximum and minimum temperature from normal temperature. Devasirvatham *et al.* (2012) explained that the high temperatures (40/25) reduced pod set and seed number by reducing pollen viability and pollen production per flower, per cent pollen germination. High temperature during reproductive stage causes abnormal development of the male/ female reproductive tissues, poor production of growth regulators in sink tissues, reduced supply of photosynthates, pollen production, pollen viability, fertilization, pod, seed-set; all of which lead to poor productivity in pigeonpea (Kesava Rao *et al.*, 2013).

Consequences of climate change on phenology of pigeonpea crop

The traditional varieties of pigeonpea grown are mainly medium and long-duration types. Reproductive phase of development coincides with the period when temperatures are cool and day length is short. Consequently, it is tempting to overlook the effect of temperature and conclude that

Table 2(c): Validation of GFLD-CM3 results against observed weather data of year 2010 of Varanasi district(medium to long varieties)

Genotype	Scenario	Grain yield (t ha^{-1})		Anthesis days (DAS)		Maturity days (DAS)	
		Pro#	Sim*	Pro#	Sim*	Pro#	Sim*
ASHA	RCP (2.6)	4.2	4.0	113	113	199	204
	RCP (4.5)	4.1	4.0	113	113	190	204
	RCP (6.0)	4.5	4.0	112	113	198	204
	RCP (8.5)	4.0	4.0	112	113	196	204
	Mean	4.2	4.0	112	113	196	204
	RMSE	0.3		0.55		8.59	
	nRMSE	7		0.49		4.21	
ICP7035	RCP (2.6)	4.1	4.1	134	132	239	239
	RCP (4.5)	4.2	4.1	134	132	238	239
	RCP (6.0)	3.9	4.1	134	132	239	239
	RCP (8.5)	4.2	4.1	134	132	241	239
	Mean	4.1	4.1	134	132	239	239
	RMSE	0.1		2.04		1.11	
	nRMSE	2		1.55		0.46	
BAHAR	RCP (2.6)	3.5	3.3	146	141	268	269
	RCP (4.5)	3.2	3.3	146	141	273	269
	RCP (6.0)	3.0	3.3	146	141	271	269
	RCP (8.5)	3.2	3.3	147	141	271	269
	Mean	3.2	3.3	146	141	271	269
	RMSE	0.2		5.28		2.42	
	nRMSE	5		3.74		0.90	
MAL 13	RCP (2.6)	4.5	4.8	162	154	290	298
	RCP (4.5)	4.6	4.8	163	154	297	298
	RCP (6.0)	4.4	4.8	161	154	286	298
	RCP (8.5)	4.7	4.8	164	154	294	298
	Mean	4.6	4.8	162	154	292	298
	RMSE	0.3		8.54		7.16	
	nRMSE	5		5.54		2.40	

Pro#: Projected, Sim*: Simulated

flowering is triggered only by short days. If sensitivity in phenology leads to a delay in maturity, it is likely to result in yield reduction in those areas where rainfall duration is short or where the crop depends on residual soil moisture. Both the extra-short and short-duration genotypes flowered within 100 days from sowing but the medium and long-duration genotypes flowered later. The extra-short duration genotype has the highest optimum temperature while the long-duration genotype has the lowest optimum temperature. The extra-short and short-duration genotypes had high optimum temperature for time to flower with cool temperatures lengthening and warm temperatures shortening the duration. For medium-duration genotypes (Maruti, Asha, ICP7035), temperatures during the vegetative stages are high but low during the reproductive phases. By contrast, the long-duration genotype (Bahar, MAL13) was insensitive

Table3(a): Simulation of climate change impact on grain yield (t/ha) of reference genotype of pigeon pea of different maturity group at Varanasi, India (right column) shows change in % grain yield of the genotype against RCP2.6-2010)

Scenario		ICRISAT Maturity group																					
	Year\	0		0		I		II		III		IV		V		VI		VII		VIII		IX	
	Reference	SE		ES		ES		S		S		S		SM		M		M		ML		L	
	genotype	MN5		ICPL88039		PRABHAT		UPAS120		TYPE21		ICP6		MARUTI		ASHA		ICP7035		BAHAR		MAL13	
RCP2.6	2010	0.73	0	1.73	0	2.56	0	2.80	0	3.01	0	3.33	0	3.71	0	4.16	0	4.07	0	3.53	0	4.54	0
	2035	0.71	-3	1.63	-6	2.41	-6	2.54	-9	2.95	-2	3.24	-3	3.61	-3	3.99	-4	3.99	-2	3.42	-3	4.41	-3
	2065	0.66	-10	1.55	-11	2.27	-11	2.39	-15	2.88	-4	3.20	-4	3.48	-6	3.79	-9	3.89	-4	3.32	-6	4.35	-4
	2095	0.64	-12	1.44	-17	2.20	-14	2.22	-21	2.72	-10	2.91	-13	3.39	-9	3.83	-8	3.72	-9	3.25	-8	4.25	-6
RCP4.0	2010	0.82	12	1.84	7	2.62	2	2.98	6	3.11	3	3.21	-4	3.97	7	4.07	-2	4.20	3	3.18	-10	4.63	2
	2035	0.63	-14	1.57	-9	2.28	-11	2.66	-5	2.87	-5	3.08	-7	3.62	-3	4.11	-1	3.89	-4	3.37	-4	4.32	-5
	2065	0.57	-22	1.49	-14	2.11	-17	2.49	-11	2.67	-11	3.00	-10	3.42	-8	3.92	-6	3.78	-7	3.29	-7	4.27	-6
	2095	0.45	-38	1.27	-27	1.83	-29	2.07	-26	2.33	-23	2.77	-17	3.13	-16	3.60	-14	3.53	-13	3.19	-10	4.14	-9
RCP6.5	2010	0.81	12	1.74	1	2.42	-6	2.85	2	3.00	-1	3.43	3	3.53	-5	4.51	8	3.95	-3	3.04	-14	4.43	-2
	2035	0.67	-8	1.53	-12	2.11	-18	2.44	-13	2.97	-2	3.17	-5	3.35	-10	4.01	-4	3.83	-6	3.32	-6	4.24	-6
	2065	0.56	-23	1.38	-20	2.01	-22	2.01	-28	2.33	-23	2.66	-20	3.30	-11	3.75	-10	3.73	-8	3.25	-8	4.20	-8
	2095	0.43	-41	1.11	-36	1.68	-35	1.93	-31	2.09	-31	2.38	-29	3.07	-17	3.49	-16	3.46	-15	3.14	-11	4.07	-10
RCP8.5	2010	0.82	12	1.81	4	2.56	0	3.00	7	3.11	3	3.28	-2	3.50	-6	4.02	-4	4.20	3	3.23	-8	4.69	3
	2035	0.58	-20	1.40	-19	2.22	-14	2.47	-12	2.58	-14	2.97	-11	3.26	-12	3.78	-9	3.86	-5	3.16	-10	4.05	-11
	2065	0.43	-40	1.18	-32	1.78	-30	2.10	-25	2.36	-22	2.77	-17	3.16	-15	3.68	-12	3.52	-13	3.09	-12	3.95	-13
	2095	0.25	-66	0.72	-58	1.30	-49	1.67	-41	2.07	-31	2.32	-30	2.97	-20	3.38	-19	3.30	-19	3.03	-14	3.88	-15

Note: SE: Super-early, ES: Extra-short, S: Short, SM: Short-medium, M: Medium, ML: Medium-long, L: Long

Table3(b): Simulation of climate change impact on anthesis(days)of reference genotype of pigeon pea of different maturity group at Varanasi, India(right column shows change in days to anthesis of the genotype against RCP2.6-2010)

Scenario		ICRISAT Maturity group																					
	Year\	0		0		I		II		III		IV		V		VI		VII		VIII		IX	
	Reference	SE		ES		ES		S		S		S		SM		M		M		ML		L	
	genotype	MN5		ICPL88039		PRABHAT		UPAS120		TYPE21		ICP6		MARUTI		ASHA		ICP7035		BAHAR		MAL13	
RCP2.6	2010	40	0	52	0	60	0	70	0	84	0	92	0	103	0	113	0	134	0	146	0	162	0
	2035	40	1	53	1	62	2	72	2	86	2	95	3	106	3	116	4	137	4	149	3	162	0
	2065	41	2	55	3	63	3	74	4	88	4	97	5	108	5	118	6	138	5	149	3	163	1
	2095	41	2	54	2	63	3	74	4	88	4	97	5	108	5	118	6	138	5	149	3	164	2
RCP4.0	2010	39	0	52	0	60	0	70	0	84	0	91	0	103	0	113	0	134	0	146	1	163	1
	2035	41	1	54	2	62	2	73	3	87	3	95	4	107	4	117	5	139	5	150	4	165	3
	2065	42	3	56	4	65	5	77	7	90	7	100	8	111	8	122	9	142	9	152	7	166	4
	2095	44	4	58	6	67	7	78	8	92	8	102	10	113	10	124	11	145	11	155	9	169	6
RCP6.5	2010	40	0	52	0	60	0	70	0	84	0	91	0	103	0	112	0	134	0	146	0	161	-1
	2035	40	1	53	1	61	1	72	2	86	2	94	2	105	2	115	3	137	3	149	3	165	2
	2065	42	3	56	4	64	5	76	6	89	6	99	7	110	7	121	8	141	7	151	5	165	3
	2095	44	5	59	7	69	9	81	11	95	11	105	13	116	13	127	15	147	13	156	11	169	7
RCP8.5	2010	39	0	51	-1	59	-1	69	-1	83	0	91	0	103	0	112	0	134	1	147	1	164	2
	2035	41	1	54	2	62	2	73	3	87	3	96	4	107	4	117	5	138	4	149	3	164	2
	2065	45	5	59	7	69	9	81	11	95	11	105	13	116	13	127	14	147	14	157	11	170	8
	2095	49	9	66	14	77	17	90	20	103	19	115	23	126	23	139	26	158	24	166	20	177	15

Note: SE: Super-early, ES: Extra-short, S: Short, SM: Short-medium, M: Medium, ML: Medium-long, L: Long

Table 3(c): Simulation of climate change impact on maturity(days)of reference genotype of pigeon pea of different maturity group at Varanasi, India (right column shows change in days to maturity of the genotype against RCP2.6-2010).

Scenario		ICRISAT Maturity group																							
	Year\	0		0		I		II		III		IV		V		VI		VII		VIII		IX	
	Reference	SE		ES		ES		S		S		S		SM		M		M		ML		L	
	genotype	MN5		ICPL88039		PRABHAT		UPAS120		TYPE21		ICP6		MARUTI		ASHA		ICP7035		BAHAR		MAL13	
RCP2.6	2010	75	0	88	0	98	0	113	0	129	0	150	0	168	0	199	0	239	0	268	0	290	0
	2035	76	1	89	2	100	2	116	3	132	2	153	3	170	2	202	3	240	1	268	0	291	1
	2065	77	2	91	3	102	4	118	4	133	3	154	4	171	3	204	5	240	1	271	3	293	3
	2095	77	2	91	3	102	4	118	4	133	4	154	4	171	3	205	6	241	2	272	4	295	5
RCP4.0	2010	75	0	88	0	98	0	113	0	129	0	150	0	169	1	190	-9	238	-1	273	5	297	7
	2035	77	2	90	2	101	3	116	3	132	3	153	4	171	3	202	3	240	1	274	6	297	7
	2065	79	4	93	6	105	6	121	8	135	6	157	7	174	6	209	10	244	5	275	7	299	9
	2095	81	6	95	8	107	9	123	10	137	8	159	9	176	8	209	10	245	6	277	9	301	11
RCP6.5	2010	75	0	88	0	98	0	114	0	129	0	150	0	168	0	198	-1	239	0	271	3	286	-4
	2035	76	1	89	1	100	2	116	2	131	2	152	2	170	2	201	2	242	3	271	3	294	4
	2065	79	4	93	5	104	6	120	6	134	5	156	6	173	5	207	8	242	3	274	6	295	5
	2095	83	8	98	10	110	12	126	13	139	10	162	12	178	10	212	13	245	6	275	7	299	9
RCP8.5	2010	74	-1	87	-1	97	-1	113	-1	129	0	150	0	169	0	196	-3	241	2	271	3	294	4
	2035	77	2	90	2	101	3	117	3	132	3	154	4	171	3	205	6	241	2	274	6	297	7
	2065	83	8	98	10	110	11	126	12	139	10	162	12	178	10	212	13	246	7	274	6	298	8
	2095	90	15	107	20	120	22	137	24	148	19	171	21	187	19	220	21	255	16	291	23	310	20

Note: SE: Super-early, ES: Extra-short, S: Short, SM: Short-medium, M: Medium, ML: Medium-long, L: Long

to variation in temperature likely because it is a land race from northern India where temperatures during the crop's growth cycle vary from>40°C to sub-zero. This study also showed that with the exception of genotypes from northern India, pigeonpea has specific and narrow adaptation. For photoperiod, the long duration genotypes (Bahar, MAL13) were the most sensitive, followed by medium-duration genotypes (Maruti, Asha and ICP 7035), which were intermediate in sensitivity. The short-duration genotype (UPAS120, T 21 and ICP6) was insensitive and extra-short-duration genotype (MN5 and ICPL 88039, Prabhat) was the least sensitive to photoperiod. In similar studies, medium- and long-duration cultivars delayed flowering by 150 days in response to photoperiod (Carberry *et al*., 2001).

In our study, model simulated phenology viz. days to anthesis and days to maturity reveal how RCPs and their projected years would lengthen critical crop stages, all of which are detrimental for plant and grain size due to enhanced respiration and poor translocation of assimilate from source to sink (Harrison *et al.,* 2011). The impact of delayed reproductive stages anthesis (Table 3.b), maturity(Table 3.c) were evident in all scenarios (RCP 2.6, 4.5, 6.0 and RCP 8.5) and increased with increasing projected years. Yadav *et al.* (2016) and Patel *et al*. (2018b) found that days to anthesis and maturity increased when increasing maximum and minimum temperature from normal temperature. Highest increase of days to anthesis and days to maturity at RCP 8.5 during 2095 while, lowest in at RCP 2.6 during 2010. In all scenarios, increased maximum and minimum temperature delaying on anthesis and maturity phase irrespective of genotypes.

CONCLUSIONS

The present investigation was to assessment of impact of climate change on reference genotype of different pigeon pea maturity group using generated weather data of MarkSim GCM of RCP scenario of IPCC and their projected years for Varanasi region. The study concluded that climate change could potentially result in decreasing yield of all reference genotypes in different pigeon pea maturity groups at Varanasi (Uttar Pradesh), north India. Maximum grain yields were decrease with RCP8.5 at all projected years, which show most vulnerable RCP in comparison to others RCP. Also, the study of climate change showed adverse effect on the physiology. There lies threat of climate change and its anticipated effect on pigeon pea yield in this region as revealed in this study. Agriculture scientists, therefore, should keep this information in mind while developing new variety, technology and management etc. for pigeon pea growing in this region. Information generated in this study can also be utilised for decision support system and making planning at large scale.

REFERENCES

Carberry, P.S.; Ranganathan, R.; Reddy, L.J.; Chauhan,Y.S. and Robertson, M.J. (2001). Predicting growth and development of pigeonpea: Flowering response to photoperiod. *Field Crops Research* 69:151-162

Channabasavanna, A.S.; Kitturmath, M.S. and Rajakumar, H.(2015). Standardization of sowing date and genotypes of pigeon pea [*Cajanus cajan* (L.) Millsp.] under erratic rainfall conditions in northern dry zone of Karnataka. *Karnataka J. Agric. Sci.,* 28(4): 604-605.

Chauhan, Y.S.; Johansen, C.; Jung-Kyung Moon, Yeong-Ho Lee and Suk-Ha Lee(2002). Photoperiod responses of extra-short-duration pigeon pea lines developed at different latitudes. *Crop Sci.* 42:1139–1146.

Chauhan, Y.S.; Wallace, D.H.; Johansen, C. and Singh, Laxman (1998). Genotype-by-environment interaction effect on yield and its physiological bases in short-duration pigeon pea. *Field Crops Research* 59:141-150.

Chauhan, Y.S.; Johansen, C. and Venkataratnam, N.(1992). Effect of phosphorous deficiency on phenology and yield components of short-duration pigeon pea. *Trop. Agric.(Trinidad)* 69(3):335-338.

Devasirvatham, V.; Gaur, P.M.; Mallikarjuna, N.; Tokachichu, R.N.; Trethowan, R.M. and Tan, D.K. (2012). Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. *Fun. Plant Biol.*, 39(12): 1009-1018.

Dufresne, J.L.; Foujols, M.; Denvil, S. ; Caubel, A.; Marti, O.; Aumont, O. and Vuichard, N. (2013). Climate change projections using the IPSL-CM5 earth system model: from CMIP3 toCMIP5. *Climate Dynamics*, 40.

Harrison, L.; Michaelsen, J.; Funk, C. and Husak, G. (2011). Effects of temperature changes on maize production in Mozambique. *Climate Research* 46 (3):211–222.

Hoogenboom, G.; Jones, J.W.; Wilkens, P.W. ; Porter, C.H.; Boote, K.J.; Hunt, L.A.; Singh, U.; Lizaso, J.I.; White, J.W.; Uryasev, O.; Ogoshi, R.; Koo, J.; Shelia, V. and Tsuji, G.Y. (2019). Decision Support System for Agrotechnology Transfer (DSSAT) Version v4.7.5 (http://dssat.net). DSSAT Foundation, Prosser, Washington.

International Panel on Climate Change (IPCC) (2014). Summary for Policy Makers. Climate Change 2014: Impacts, Adaptation and Vulnerability-Contributions of the Working GroupII to the Fifth Assessment Report.

Jones, P.G. and Thornton, P.K. (2013). Generating downscaled weather data from a suite of climate models for agricultural modelling applications. *Agric. Syst.* 114:1-5.

Kesava Rao, A.V.R.; Wani, S.P.; Komuravelly, S.; Singh, P.; Bairagi, S.D. and Ramadevi, O. (2013). Assessing impacts of projected climate on pigeonpea crop at Gulbarga. *J. Agrometeorol.*, 15(Special Issue-II): 32-37.

Kumar Rao, J.V.D.K. and Dart, P.J.(1987). Nodulation, nitrogen fixation and nitrogen uptake in pigeonpea (*Cajanus cajan* (L.) Millsp) of different maturity groups. *Plant & Soil* 99:255-266.

Patel, C.; Nema, A.K.; Singh, R.S.; Yadav, M.K.; Singh, K.K.; Singh, S.K.; Rai, P.K. and Singh, S.M. (2018a). Assessment of climate change impact on wheat crop using MarkSim GCM for Varanasi region of Uttar Pradesh (India). *J. Agrometeorol.* 20(3):216-218.

Patel, D. D.; Pandey, Vyas; Gurjar, Ramesh and Patel, H. P.(2018b). Effect of intra-seasonal variation in temperature and rainfall on seed yield of pigeon pea cultivars using CROPGRO model. *J. Agrometeorol.* 20(4):286-292.

Received : April 2020 ; Accepted : February 2021