Coupled multi-model climate and climate suitability change predictions for major cassava growing regions of India under two representative concentration pathways

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Abstract

Changes in suitability of crops under climate change studies are a pre-requisite to achieve sustainable utilization of available land resources and to attain food security. This study attempts ensembled multi-model prediction of change in climate and climate suitability of cassava by 2030 and 2050 in major cassava growing regions of India under 4.5 and 8.5 representative concentration pathways (RCP). Suitability of cassava was modelled using EcoCrop model in Diva GIS 7.5. Climate and suitability changes were analysed using Diva GIS 7.5 and Arc GIS 10.1. The study showed a general warming of climate over the major cassava growing regions by 2030 and 2050 under RCPs 4.5 and 8.5. The mean temperature of major cassava growing regions in 2030 will increase by 1.18 - 1.55^{0}C and 1.29 - 1.49^{0}C for RCPs 4.5 and 8.5; and 1.62 - 1.78^{0}C and 2.03 - 2.28^{0}C for RCPs 4.5 and 8.5 in 2050. The precipitation in 2030 will increase by 13.57 - 92.40 mm and 25.27-103.70 mm for RCPs 4.5 and 8.5; and in 2050 it will change by -1.91 to 73.4 mm and 5.31 to 56.60 mm for RCPs 4.5 and 8.5. The climate suitabilty will change by -1 to 8 % and -1.34 to 12.02 % in 2030 for RCPs 4.5 and 8.5; and -1.27 to 11.67% and -3.76 to 6.59% for RCPs 4.5 and 8.5 in 2050**.** Districts in Kerala, Tamil Nadu and Andhra Pradesh showing highest positive and negative impacts on climate suitability of cassava for RCP 4.5 and RCP 8.5 in 2030 and 2050 were identified. Districts showing no negative impact were also predicted. The results showed cassava's comparative advantage in climate resilence compared to other major food crops such as rice and wheat.

Keywords: Cassava, Climate change, Climate suitability, Representative concentration pathways.

Introduction

The safe existence of the living system including human beings depends wholly on the abiotic factor climate, which is a combination of influx of temperature and precipitation. The phenomenon of climate change is realized as a future threat to this living system. Decline in the productivity of agriculture in the world was projected to be between 3 and 16% by 2080 (Katherine et al., 2011; Anupama, 2014). Average temperatures of developing countries are near or above crop tolerance levels, and it is predicted that they would face an average decline of 10 - 25% in agricultural productivity by 2080. Reduction of crop duration due to increase in mean temperature also reduces final yield (Anupama, 2014). The yield of crops in areas experiencing temperature close to physiological maxima will be affected due to warming (IPCC, 2007). Thus India will also have to face the consequences of climate change for which various adaptation strategies must be developed based on scientific studies.

Cassava *(Manihot esculenta* Crantz*),* is grown in 103 countries across the globe mostly by small and marginal farmers in the tropics who are the most vulnerable to climate change (Sabitha et al., 2016). The ideal environment for cassava is an annual

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rainfall of more than 1000 mm, mean annual temperature above 18^{0}C and a mean solar radiation level higher than 16 MJ m^{-2} and it is cultivated mainly in the tropical and subtropical latitudes between 30^0 N and S of the equator and elevations upto 2300 m above mean sea level (Cock, 1983; Ekanayake et al., 1998). A few studies are available on the impact of future climate on cassava in other parts of the globe but not in India except that of Sabitha et al. (2016) where they used SRES - A1B dataset. Ceballos et al. (2011) and Jarvis et al. (2012) have done important studies done in African countries.

According to Hijmans et al. (2001) suitability assessment of crop species, where there was insufficiency in agronomic data to run more complex, process-based models, could be done with the Ecocrop which is a simple empirical modelling approach. Liu et al. (2008) assessed impacts on production of cassava and other five crops across sub-Saharan Africa under various SRES scenarios using the GIS based Environmental Policy Integrated Climate (GEPIC) model.

The EcoCrop model (Hijmans et al., 2001) is one of the most widely used tools to study the climate suitability changes of crops (Beebe et al., 2011; Jarvis et al., 2012; Vermeulen et al., 2013; Villegas et al., 2013; Sabitha et al., 2016; Piikki et al., 2017). Hence this study aimed at predicting the changes in future climate and climate suitability of cassava in major growing environments of India at two representative concentration pathways (RCP) of 4.5 and 8.5 by 2030 and 2050 using ten different coupled global climate models (GCMs) of coupled model intercomparison project (CMIP5).

Materials and Methods

Study area

The study area included current cassava growing regions of India. The presence point map of cassava in India developed by Sabitha et al. (2016) was modified by including 3652 additional points in the various cassava growing regions. The presence point map was prepared based on expert knowledge of scientists working in ICAR-CTCRI, Thiruvananthapuram, Kerala; All India Coordinated Research Project on Tuber Crops (AICRP-TC) centers and available literature. The geographic coordinates of these regions at 30 seconds spatial resolution using the district boundary shape file of each growing area (Figure 1) were extracted and a total of 13705 coordinates as cassava presence points were obtained covering 12 states (42 districts) in India, *viz,*. Andhra Pradesh, Arunachal Pradesh,

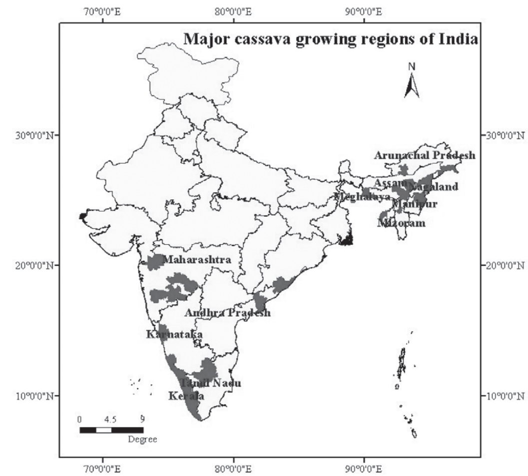

Figure 1. Presence points map of major cassava growing regions in India

Assam, Karnataka, Kerala, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Tamil Nadu and Tripura.

Current climate data

The spatial data of current climate were obtained from the WorldClim dataset, at the spatial resolution of 30 arc-second equivalent to about 0.86 km^2 at the equator, commonly referred to as '1- km' resolution to depict current climatic conditions (Hutchinson,1995; Hijmans et al., 2005; http://www.worldclim.org). The data included monthly time series of minimum, maximum and mean temperature and precipitation. The WorldClim spatial dataset was developed using data from ~

47,000, 23,000 and 13,000 weather stations (globally) for monthly information on precipitation, mean temperature and diurnal temperature range data respectively. The data were processed using a quality checking algorithm and then developed into a continuous climate surface using thin plate spline algorithm with elevation, latitude and longitude as independent variables (Hutchinson and Hoog, 1985; Hijmans, 2003). The database includes precipitation, mean temperature, minimum and maximum temperature from 47554 , 24542 and 14835 locations respectively (Challinor et al., 2010).

Future climate data

The downloaded future climate data included monthly time series data of maximum, minimum and mean temperature and total monthly precipitation for 4.5 and 8.5 Representative Concentration Pathways (RCP) for 2030 and 2050 from 10 different coupled global climate models (GCMs) of coupled model inter-comparison project 5 (CMIP5) (Table 1) used in the IPCC Fifth Assessment Report (AR5) (Pravat et al., 2015). The model selection was based on the availability of data for both RCPs 4.5 and 8.5 for 2030 and 2050 and also based on optimum model ranking for climate change projections for Indian monsoon precipitation (IPCC, 2014) considering that the models would be more precise to predict future suitability and suitability change of cassava in India.

The emission scenarios were based on total anthropogenic radiative forcing at the end of the 21st century. Different paths were taken by the economic models to reach four different radiative forcings that were correspondent to different concentration paths of the green house gases, the so-called RCPs. Considering the possibility that green house gas emission would be at an intermediate level in future due to various strategies and also considering the future hidden threat from uncontrolled high green house gas emissions, the two green house gas emission scenarios of RCPs 4.5 and 8.5 were considered. The RCP 4.5 corresponds approximately to B1 scenario in fourth assessment report of IPCC (AR4); the radiative forcing grows almost linearly upto about the year 2060 and then slows down the growth rate until the end of the century where it stabilizes. The radiative forcing in RCP 8.5 corresponds approximately to A2 scenario in AR4; it grows almost linearly during the 21st century, but with higher radiative forcing

Table 1. Details of the coupled model inter-comparison project 5 (CMIP5) models selected for the study

Sl. No.	Model	Spatial Resolution (Long ^{0} x Lat ^{0})	Modelling Centre	Country
1	CCSM4	1.25 x 0.9424	National Centre for Atmospheric Research	USA
2	CESMI-CAM5	1.25 x 0.9424	National Centre for Atmospheric Research	USA
3	GFDL-CM3	2.5 x 2	NOAA Geophysical Fluid Dynamics Laboratory	USA
4	MIROC-ESM CHEM	2.8125 x 2.7673	Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, Japan Agency for Marine-Earth Science and Technology	Japan
5	NorESMI-M	2.5 x 1.8947	Bjerknes Centre for Climate Research Norwegian Meteorological Institute	Norway
6	INM-CM4	2 x 1.50	Institute for Numerical Mathematics	Russia
7	GFDL-ESM2M	2.5 x 1.5169	NOAA Geophysical Fluid Dynamics Laboratory	USA
8	FIO-ESM	2.815 x 2.7673	The First Institute of Oceanography,	China
9	MIROC MIROC 5	1.4063 x 1.389	Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, Japan Agency for Marine-Earth Science and Technology	Japan
10	MPI-ESM-LR	1.25 x 0.9424	Max Planck Institute for Meteorology	Germany

values (Sin et al., 2014). The RCP 4.5 corresponds to the radiative forcing of 4.5 Wm^{-2} and RCP 8.5 to 8.5 Wm^{-2}. This study did not account for the carbon dioxide fertilization effects in the simulations. The spatially downscaled (delta method) GCM predicted future climate data were downloaded from http://www.ccafs-climate.org/data. The model resolution was 30 arc seconds.

GCM ensemble based climate change prediction

The changes in annual minimum, maximum and mean temperature and precipitation under RCPs 4.5 and 8.5 scenarios for 2030 and 2050 were predicted by ensembling the ten GCMs in Diva-GIS 7.5 platform. The data were restricted to the areas where cassava was reported to be cultivated as mentioned in an earlier section.

Current and future suitability modelling and suitability change detection

Crop suitability modelling involves the evaluation of the model and the usage of the selected ecological parameter set(s) to run the model using certain climate scenario(s) (IPCC, 2014). All the suitability analysis was carried out using Diva GIS 7.5 and Arc GIS 10.1 softwares. The suitability of cassava was predicted by inputting the calibrated ecological parameters (Table 2) along with the current climate scenario (for current suitability) and for two different future climate scenarios (RCPs 4.5 and 8.5) for the ten CMIP5 models (for future climate suitability).

Table 2. Ecological parameters used to calibrate the EcoCrop model for cassava

Sl.No	Parameter	Calibrated value
1	Tkill	5 ^{0}C
2	Tmin	18 ^{0}C
3	Tmax	48 ^{0}C
4	Topmin	20 ^{0}C
5	Topmax	30 ^{0}C
6	Rmin	400 mm
7	Ropmin	600 mm
8	Ropmax	2000 mm
9	Rmax	3300 mm

Source: Sabitha et al., 2016

The suitability change was then calculated for each model and the following impact matrices were derived for cassava growing regions for each GCM specific predictions.

a. Average climate suitability change (%) in cassava growing regions
b. Average climate suitability change (%) in positively impacted areas
c. Average climate suitability change (%) in negatively impacted areas

Estimation of climate suitability and suitability change

The output suitability map which is in raster format in default consisted of six classifications. They are : not suited (0%), very marginal (1-20%), marginal (21-40%), suitable (41-60%), very suitable (61-80%) and excellent (81-100%). Presence points (containing the information of state and district) in the vector format - each placed one square kilometre apart- were laid over the suitability map. Using the tool 'extract value by points' in Diva GIS, the concerned suitability value was extracted. The average value of all the points is accounted as suitability of a district.

The GCM model performance of future suitability of cassava for each scenario for 2030 and 2050 was studied using Taylor diagrams (Sin et al., 2014). Taylor diagrams are the most convenient method to compare the performance of different models using three related parameters, standard deviation, correlation and centered root mean square (RMS) distance with observed value data (Taylor, 2001). Statistics of predicted future suitability in cassava growing regions were computed and a colour was assigned to each model considered. The position of each point appearing on the plot quantified how closely that simulated future suitabilty using a model matches predicted current suitability. The changes in annual minimum, maximum and mean temperature, total precipitation and suitability were also analysed .

Table 3. Predicted climate change in major cassava growing regions of India

	Tmin (^{0}C)				Tmax (^{0}C)				Tmean (^{0}C)				Rainfall (mm)			
RCP	2030		2050		2030		2050		2030		2050		2030		2050	
Year	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5
Andhra Pradesh	1.49	1.50	1.78	2.46	1.14	1.34	1.66	2.30	1.38	1.47	1.76	2.25	15.95	32.32	19.66	64.73
Kerala	1.32	1.68	1.60	1.79	0.93	1.26	1.45	2.03	1.18	1.36	1.62	2.03	25.66	25.27	11.32	5.31
Karnataka	1.49	1.47	1.75	2.40	1.14	1.34	1.63	2.26	1.39	1.46	1.73	2.21	13.57	34.02	-1.91	35.13
Maharashtra	1.50	1.52	1.81	2.50	1.14	1.36	1.69	2.34	1.39	1.49	1.78	2.28	16.07	32.79	24.58	75.13
NE	1.80	1.39	1.85	2.55	1.07	1.13	1.62	2.42	1.55	1.29	1.78	2.21	92.40	103.70	93.90	56.60
Tamil Nadu	1.49	1.49	1.74	2.41	1.14	1.33	1.61	2.26	1.38	1.46	1.73	2.21	14.68	31.32	6.40	44.01

Results and Discussion

Projected climate change in cassava growing regions

Minimum temperature (Tmin)

Model ensembled predicted change in climate at RCPs 4.5 and 8.5 for 2030 and 2050 is shown in Table 3. The Tmin of major cassava growing environments in 2030 is predicted to increase from 1.32 (Kerala) to 1.80^{0}C (north eastern states) and 1.38 (Kerala) to 1.52^{0}C (Maharashtra) for RCPs 4.5 and 8.5, and the corresponding values for 2050 were 1.60 (Kerala) to 1.85^{0}C (north eastern states) and 1.79 (Kerala) to 2.55^{0}C (north eastern states) respectively. For both the scenario and for the years, Kerala showed the lowest increase in Tmin. The changes in Tmin by individual GCMs were in the range of 0.6 (MIROC-ESM CHEM) to 1.9^{0}C (CESMI-CAM5 and GFDL-CM3) for RCP 4.5 and 0.9 (MIROC-ESM CHEM) to 1.8^{0}C (GFDL-ESM2M and FIO-ESM) for RCP 8.5 in 2030; 0.7 (MIROC-ESM CHEM) to 2.5^{0}C (GFDL-CM3) for RCP 4.5 and 1.7 (MIROC-ESM CHEM) to 3.3^{0}C (GFDL-CM3) for RCP 8.5, in 2050.

Maximum temperature (Tmax)

Tmax in 2030 were projected to increase from 0.93 (Kerala) to 1.14^{0}C (Tamil Nadu, Andhra Pradesh, Maharashtra and Karnataka) and 1.13 (north eastern states) to 1.36^{0}C (Maharashtra) for RCPs 4.5 and 8.5 and the corresponding values for 2050 were 1.45 (Kerala) to 1.69^{0}C (Maharashtra) and 2.03 (Kerala) to 2.42^{0}C (north eastern states). The changes in Tmax by individual GCMs were 0.40 (CESMI-CAM5 and GFDL-CM3) to 1.44^{0}C (GFDL-CM3) for RCP 4.5 and 0.93 (MIROC-ESM CHEM) to 1.76^{0}C (GFDL-ESM2M) for RCP 8.5 by 2030. The changes in 2050 for RCP 4.5 were from 2.31 (GFDL-CM3) to 0.92^{0}C (MIROC MIROC 5) and for RCP 8.5 the corresponding values were 1.52 (MIROC-ESM CHEM) - 3.28^{0}C (GFDL-CM3) .

Mean temperature (Tmean)

The Tmean of major cassava growing environments in 2030 were projected to increase by 1.18 (Kerala) - 1.55^{0}C (north eastern states) and 1.29 (north eastern states) - 1.49^{0}C (Maharashtra) for RCPs 4.5 and 8.5 and the corresponding values for 2050 were 1.62 (Kerala) to 1.78^{0}C (Maharashtra and north eastern states) and 2.03 (Kerala) to 2.28^{0}C (Maharashtra) respectively. The individual GCM predicted changes in Tmean were in the range of 0.68 (MIROC-ESM CHEM) - 1.72^{0}C (GFDL-CM3) and 0.99 (MIROC-ESM CHEM) - 1.87^{0}C (GFDL-ESM2M) for RCPs 4.5 and 8.5 in 2030. The corresponding values in 2050 ranged from 0.95 (MIROC-ESM CHEM) to 2.47^{0}C (GFDL-CM3) and 1.61 (MIROC-ESM CHEM) to 3.14^{0}C (GFDL-CM3).

Annual rainfall

In 2030, the rainfall would change from 13.57 (Karnataka) to 92.40 mm (north eastern states) and 25.27 (Kerala) to 103.70 mm (north eastern states) for RCPs 4.5 and 8.5. The corresponding values for 2050 were -1.91 (Karnataka) to 73.9 mm (north eastern states) and 5.31mm (Kerala) to 56.60 mm (north eastern states). The individual GCM predicted changes in rainfall varied from -2.49 (FIO-ESM) to 122 mm (CESMI-CAM5) for RCP

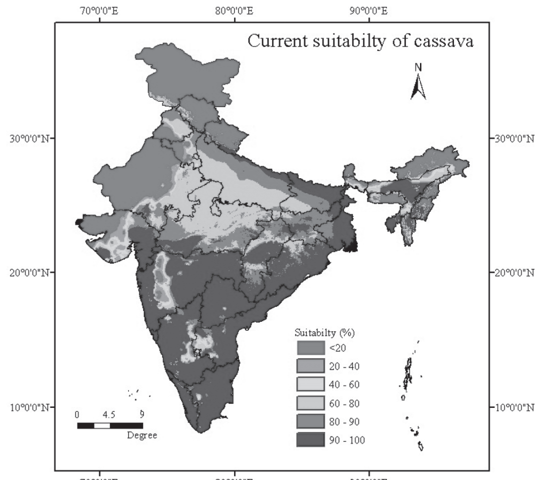

Figure 2. Current climate suitability of cassava by EcoCrop model

4.5 and -4.55 (MIROC-ESM CHEM) to 191.62 mm (NorESMI-M) for RCP 8.5 in 2030. In 2050, it would be from -82.98 (MPI-ESM-LR) to 136.66 mm (CESMI-CAM5) for RCP 4.5 and 2.59 (NorESMI-M) to 170.91 mm (MPI-ESM-LR) for 8.5.

Current climate suitability of cassava

With the calibrated ecological parameters, the current climate suitability of cassava was modelled using EcoCrop model in DIVA-GIS 7.5 (Figure 2). The results showed an average suitability between 52.26 and 99.89% in major cassava growing regions. Tamil Nadu (98.78 %), Kerala (97.18%), Andhra Pradesh (99.82%), Maharashtra (81.66%) and Karnataka (99.89%) showed excellent (>80%)

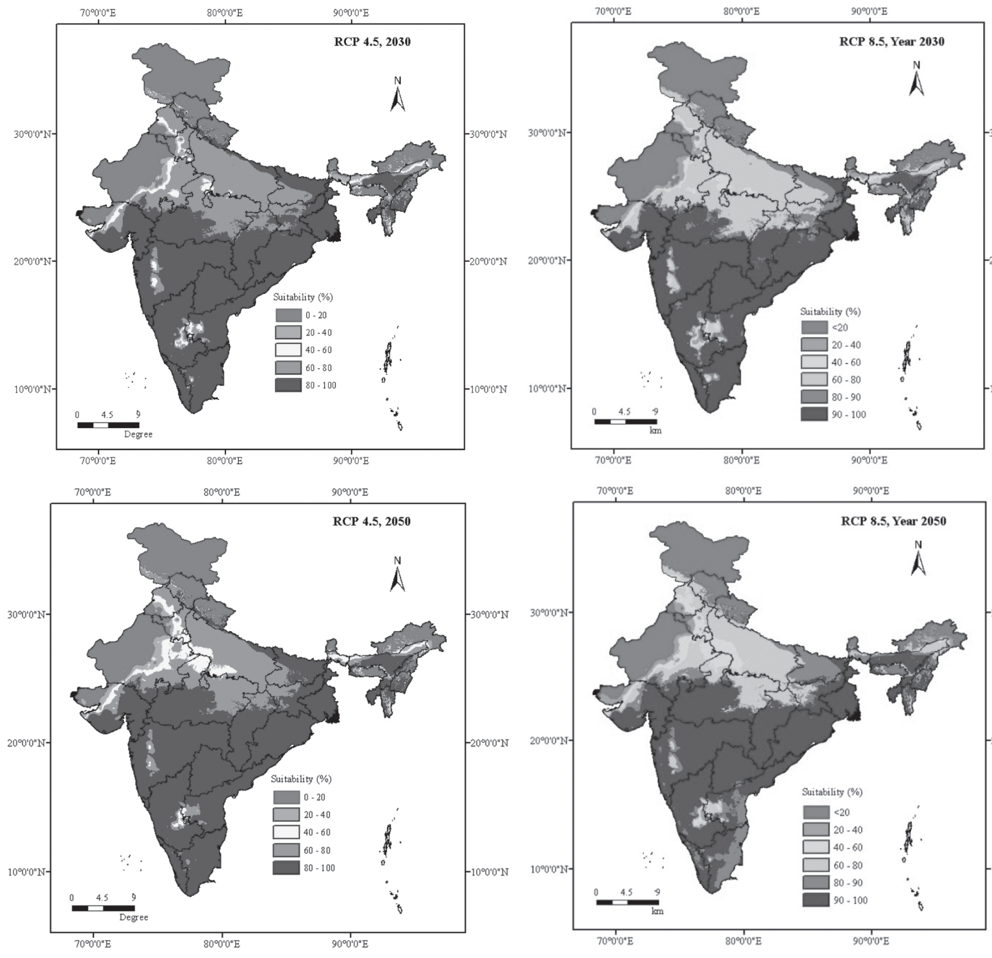

Figure 3. Predicted future suitabilities of cassava as average of the 10 GCMs studied

suitability while north eastern states showed suitability of 52.26 % .

Future climate suitability of cassava

Predicted future suitability of cassava in major growing regions of India is shown in Figure 3. In 2030, it is predicted to be 97.60% for Tamil Nadu, 95.88% for Kerala, 99.74% for Andhra Pradesh, 93.11% for Maharashtra, 97.99% for Karnataka and 61.58% for north eastern states for RCP 4.5. For RCP 8.5, the values would be 96.82% for Tamil Nadu, 95.85% for Kerala, 99.57% for Andhra Pradesh, 95.84% for Maharashtra, 98.33% for Karnataka and 62.40% north eastern states. For RCP 4.5 in 2050, the future suitabilty was found to be 96.73% for Tamil Nadu, 95.28% for Kerala, 99.14% for Andhra Pradesh, 95.04% for Maharashtra, 97.91% for Karnataka and 64.17% for north eastern states. For RCP 8.5, the suitabilties would be 96.78% for Tamil Nadu, 93.71% for Kerala, 96.99% for Andhra Pradesh, 96.57% for Maharashtra, 95.63 % for Karnataka and 70.97% for north eastern states.

Comparison of predicted future climate sutability by models to current climate sutability

The performance of 10 different models was studied using Taylor diagrams (Fig. 4 and Table 4). A comparative assessment on predicted future suitability of cassava by individual GCMs for RCP 4.5 in 2030 using Taylor diagram showed that the models NorESMI-M (SD 13.286, R 0.979, RMSE <5), MIROC-ESM CHEM (SD 14.264, R 0.976, RMSE <5) and MIROC MIROC 5 (SD 15.329, R 0.969, RMSE <5) matched more with the current suitability. For RCP 8.5, MIROC-ESM CHEM (SD 14.907, R 0.976, RMSE < 5) fit best to the observed value. For RCP 4.5 in 2050, MIROC-ESM CHEM (SD 12.596, R 0.987, RMSE <5) , MIROC MIROC 5 (SD 13.891, R 0.977, RMSE btw10-5), and GFDL-ESM2M (SD 11.578, R 0.985, RMSE btw10-5) matched more and for RCP 8.5 FIO-ESM (SD 12.107, R 0.875, RMSE btw 10-5) , MIROC-ESM CHEM (SD 14.907, R 0.935, RMSE btw 10 to 5) and MPI-ESM-LR (SD 15.831, R 0.904, RMSE 10 to 5) tied more.

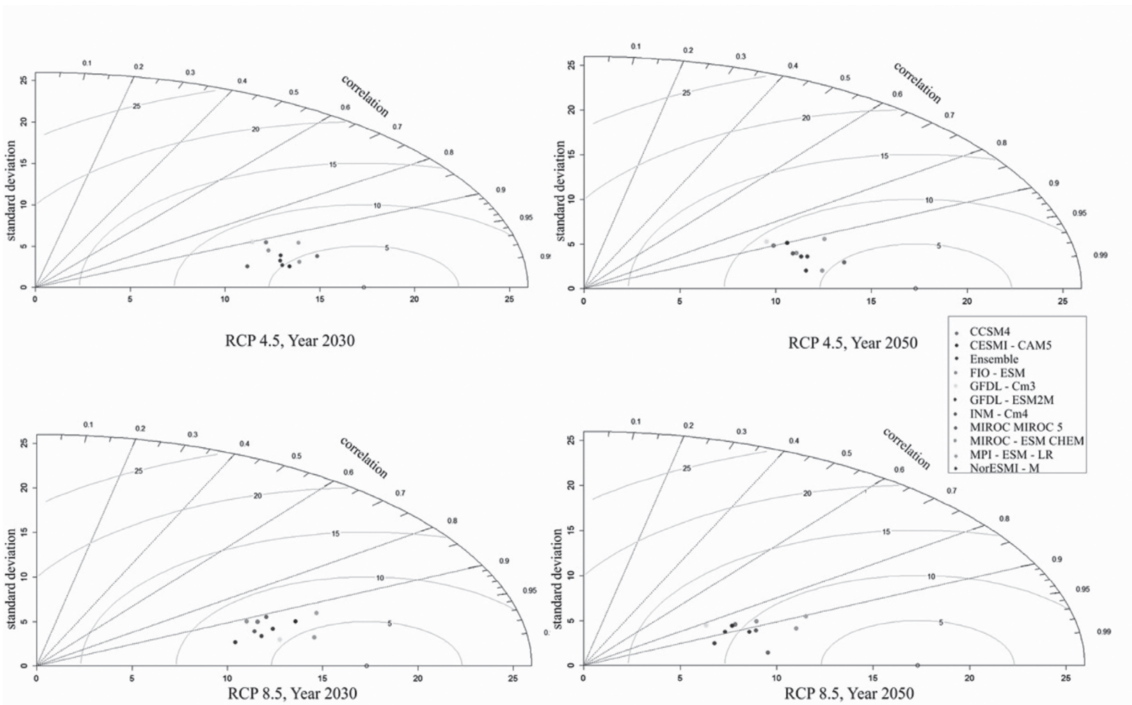

Figure 4. Taylor diagram showing relation between current suitability and predicted future suitability by each model

Table 4. Correlation and standard deviation of predicted current climate suitability and future suitability of each models in major growing areas of cassava

Sl.No	Model	Correlation				Standard deviation			
		2030		2050		2030		2050	
		4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5
1	CCSM5	0.913	0.919	0.899	0.865	13.326	12.605	10.994	9.085
2	CESMI-CAM5	0.982	0.938	0.901	0.866	13.642	14.476	11.759	8.879
3	FIO-ESM	0.939	0.909	0.941	0.875	13.082	12.107	11.777	10.222
4	GFDL-CM3	0.901	0.974	0.874	0.816	12.677	13.097	10.896	7.756
5	GFDL-ESM2M	0.957	0.968	0.985	0.891	13.493	10.749	11.759	8.211
6	INM-CM5	0.975	0.947	0.940	0.915	11.466	12.071	11.578	9.742
7	MIROC MIROC 5	0.969	0.909	0.977	0.989	15.329	13.253	13.891	9.643
8	MIROC-ESM CHEM	0.976	0.976	0.987	0.935	14.264	14.907	12.596	11.765
9	MPI-ESM-LR	0.932	0.926	0.914	0.904	14.876	15.831	13.715	12.741
10	NorESMI-M	0.979	0.962	0.955	0.938	13.286	12.254	12.198	7.222

Change in climate suitability and impacts on cassava at different scenarios

The changes in *Cs* of cassava under RCPs 4.5 and 8.5 by 2030 and 2050 are shown in Figure 5, and their impacts in Table 5. The model ensembled results under RCP 4.5 showed that in 2030 there would be decrease in mean suitability by -1 and -2% for Tamil Nadu and Karnataka respectively.

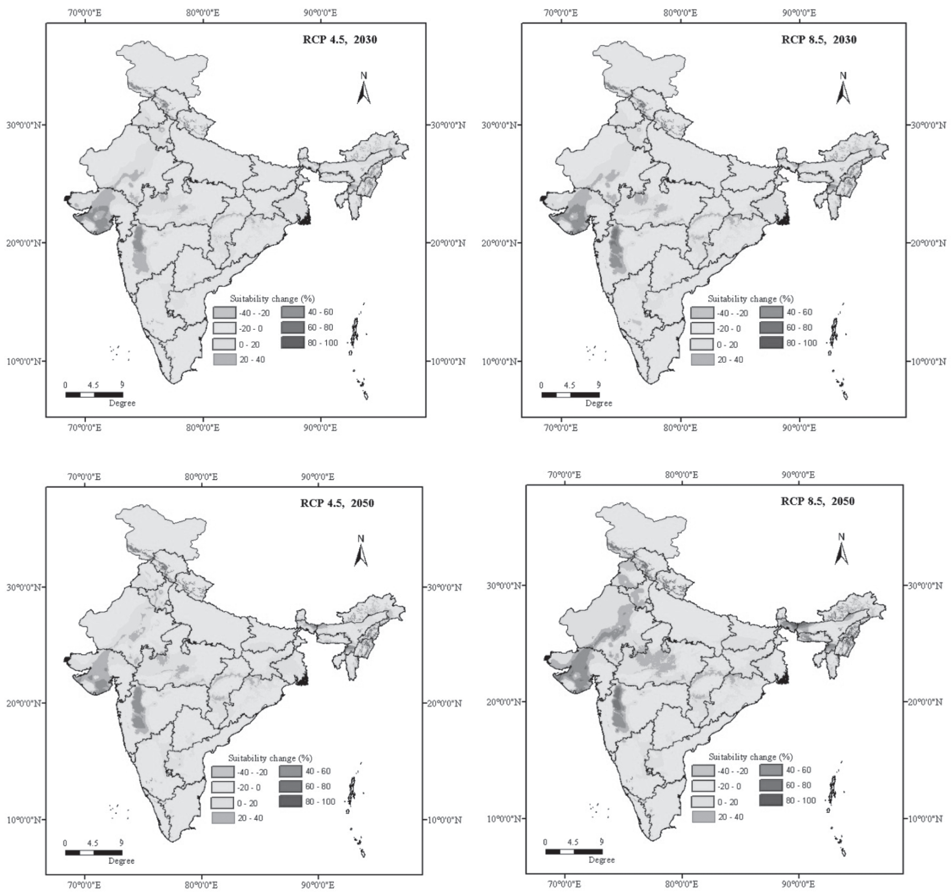

Figure 5. Changes in cassava climate suitability as average of the 10 GCMs studied

Table 5. Regional changes in cassava climate suitability for individual GCMs studied

GCM	RCP 4.5, Year 2030			RCP 8.5, Year 2030			RCP 4.5, Year 2050			RCP 8.5, Year 2050		
	OSC*	SCPIA*	SCNIA*	OSC	SCPIA	SCNIA	OSC	SCPIA	SCNIA	OSC	SCPIA	SCNIA
CCSM4	6.21	36.83	-8.37	6.68	36.83	-7.88	8.30	38.18	-6.59	9.46	42.82	-6.43
CESMI-CAM5	3.62	33.81	-13.16	4.48	33.65	-10.41	7.42	39.52	-8.43	9.87	41.08	-5.41
GFDL-CM3	6.15	33.68	-5.97	3.71	28.51	-9.23	7.01	37.86	-7.09	8.66	43.24	-8.32
MIROC ESM-CHEM	3.15	27.72	-9.07	0.87	21.27	-10.11	3.91	29.15	-8.74	6.17	36.54	-6.51
NorESMI-M	4.21	21.70	-5.79	5.13	33.82	-9.95	5.27	31.67	-7.56	7.86	39.22	-8.18
INM-CM4	6.50	34.08	-8.00	5.43	33.44	-8.58	7.19	38.99	-7.54	8.71	40.04	-6.65
GFDL-ESM2M	4.59	33.75	-8.36	6.47	34.42	-6.89	4.32	29.22	-8.70	7.84	40.07	-7.98
FIO-ESM	4.53	35.47	-8.90	7.00	39.40	-7.03	5.70	36.02	-7.32	7.87	42.14	-8.99
MIROC MIROC 5	-3.49	30.14	-16.06	5.15	38.73	-10.08	0.65	30.30	-13.36	3.68	31.38	-9.02
MPI-ESM-LR	3.94	31.97	-8.58	2.89	33.87	-12.66	5.78	37.37	-12.67	6.51	38.22	-9.83
Mean	3.94	31.92	-9.23	4.78	33.39	-9.28	5.56	34.83	-8.80	7.66	39.48	-7.73

OSC* - Overall suitability change, SCPIA - Suitabilty change in positively impacted areas,
SCNIA - Suitabilty change in negatively impacted area.

Maharashtra showed an increase of 8% (highest) followed by Andhra Pradesh (5 %) and north eastern states (5%). Kerala showed no change. Individual GCM predicted changes in cassava growing regions ranged from -3.49 (MIROC MIROC 5) to 6.50% (INM-CM4). Under RCP 8.5 in 2030, change in future suitability in Kerala and Karnataka would be -1.29 and -1.34% respectively. Maximum increase in suitabity would be in Maharashtra (12.02%). Tamil Nadu, Andhra Pradesh and north eastern states showed increased suitabilities of 0.07, 2.98 and 5.60% respectively. Studies with individual GCMs showed variabilities from 0.87 (ESM CHEM) to 6.68% (CCSM4) for RCP 8.5, 2030.

The predicted changes in climate suitability in districts of major cassava growing states – Kerala, Tamil Nadu and Andhra Pradesh showed that, for RCP 4.5 in 2030, Wayanad (13%) in Kerala, Kanyakumari (0.30%) in Tamil Nadu and Srikakulam (13%) in Andhra Pradesh showed highest positive impact, while Ernakulam (-4%) in Kerala, Namakkal (-3%) in Tamil Nadu and East Godavari (-1%) in Andhra Pradesh showed highest negative impact. For RCP 8.5 in 2030 Wyanad and Idukki (2%) in Kerala, Kanyakumari (0.30%) in Tamil Nadu, Vizhianagalam (9%) in Andhra Pradesh showed highest positive impact; while Ernakulam and Thrissur (-4%) in Kerala, Salem (-6%) in Tamil Nadu showed highest negative impact. No negative impact is predicted for the cassava growing districts in Andhra Pradesh under 8.5 RCP for 2030.

For RCP 4.5 in 2050, individual GCM predicted changes would be from 0.65 (MIROC MIROC 5) to 8.30% (CCSM4). Model ensembled results for the same showed a decrease in suitability by -1.27% in Kerala. Maharashtra showed the highest value of 11.67% followed by north eastern states (8.26%). Andhra Pradesh, Karnataka and Tamil Nadu showed 8.10, 7.07 and 4.50% of increase respectively. For RCP 8.5 in 2050, the individual GCMs showed variability from 6.51 (MPI-ESM-LR) to 9.87% (CCSM4). Kerala showed decrease in suitability of –3.76%, north eastern states showed an increase of 6.59% (highest) followed by Karnataka (6.39%), Tamil Nadu (5.81%), Maharashtra (5.76%) and Andhra Pradesh (4.2%). In the districts of major cassava growing states for RCP 4.5 in 2050, Kasargod (5.15%) in Kerala, Dharmapuri (6%) in Tamil Nadu, Vizhianagalam (9%) in Andhra Pradesh showed highest positive impact, while Ernakulam and Thrissur (-5%) in Kerala, and Srikakulam (-0.15%) in Andhra Pradesh showed highest negative impact. No negative impact is shown in cassava growing districts of Tamil Nadu under this RCP for 2050. For RCP 8.5 in 2050, Idukki (4%) in Kerala, Dharmapuri (4%) in Tamil Nadu and Vizhianagalam (6%) in Andhra Pradesh showed highest positive impact in cassava suitabilty while Thrissur (-8%) in Kerala, Namakkal

(-6%) in Tamil Nadu and Srikakulam (-3.21%) in Andhra Pradesh showed highest negative impact.

Overall suitability change (OSC) is predicted to be positive for both the years and scenarios. The OSC for RCPs 4.5 and 8.5 in 2030 were 4 and 4.78% and the corresponding values in 2050 were 5.56 and 7.66%. Positively impacted areas would be more for RCP 4.5 in 2050 and minimum area would have positive impact for RCP 4.5 in 2030. For both RCPs of 4.5 and 8.5 in 2030 and 2050, the result showed that the negative impact would be less than 10%.

Warming of the atmosphere, mere increase in total rainfall and climate suitability of cassava are predicted under RCPs 4.5 and 8.5 in 2030 and 2050 (Figure 6). Despite the changing climate, a profound change in climate suitability of cassava could not be observed. Jarvis et al. (2012) studied climate change and change in suitability of cassava in the north and sub - Saharan Africa using SRES - A1B emissions scenario (IPCC, 2000) of 24 different GCMs. The results explain that major decrease in cassava climate suitability is not expected for the majority of areas in Africa. Sabitha et al. (2016) studied the change in climate and climate suitability of cassava using SRES-A1B emission scenario for major growing regions of India with 22 GCMs in 2030.

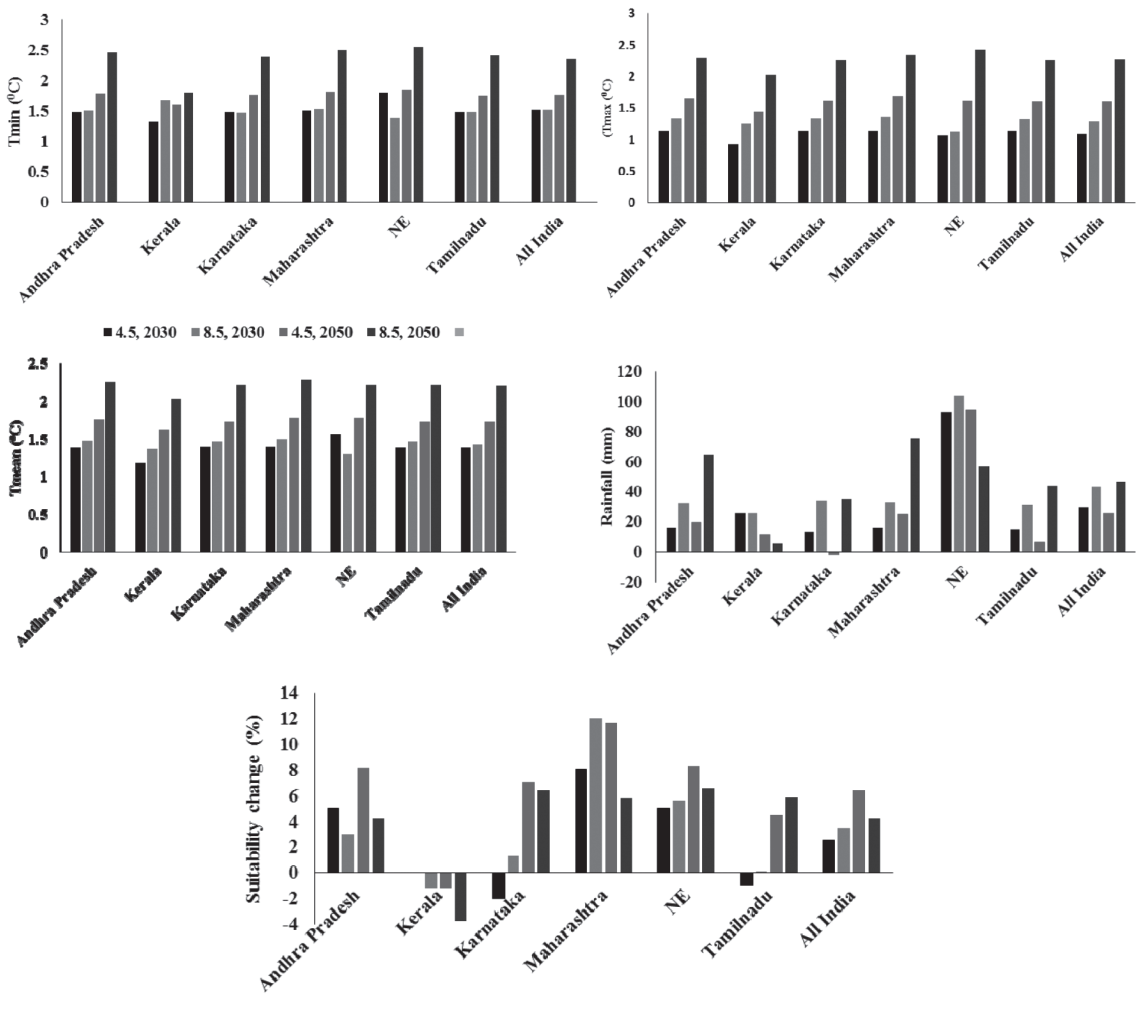

Figure 6. Change in climate and climate suitability in cassava growing regions

Our studies agree with the findings of Liu et al. (2008) , Lobell et al. (2008), Schlenker and Lobel (2010), Ceballos et al. (2011), Jarvis et al. (2012) and Sabitha et al. (2016), all of whom reported increase in cassava suitability in the scenario of changing climate. IPCC (2014) had reported that increase of local temperature by 2°C or more above late-20th-century levels would negatively impact production of crops like wheat, rice and maize in tropical and temperate regions where adaptation is absent, though some locations may benefit. Rosenzweig and Parry (1994), Fischer et al. (2002), IPCC (2013) and Parry et al. (2004) had reported that without adaptation there was a possibility of 10-40 % loss in crop production in India by 2080–2100 due to global warming despite beneficial aspects of increased CO_2. For wheat , the production might decline by 4-5 million tons for every 1^0C rise in temperature during the growth period under present land use (Aggarwal, 2008)

The studies thus explain the climate resilence of cassava and its importance in food security. Our study did not account for the carbon dioxide fertilization, soil type etc., and consideration of these features may contribute much more accurate results.

The results of the present study showed that irrespective of the scenario, 2030 and 2050 were predicted to be warmer than current climate, and 2050 under RCP 8.5 scenario would be the warmest. No accountable changes in precipitation were predicted by both scenarios for both time periods. The cassava suitability at RCPs 4.5 and 8.5 by 2030 and 2050 showed that there would not be considerable change in the suitability of cassava. The individual GCMs predicted results at two different scenarios for the two time periods, showing that though there were negatively impacted areas, the overall suitability was positive, or predicted to increase by all the GCMs except MIROC MIROC 5 which predicted a mere reduction of -3.49% (RCP 4.5, 2030). The overall suitability would increase by a maximum of 7.66 %, which indicated no profound change in suitabilty. Under the same RCP, positive shift in suitability was noticed from 2030 to 2050. The high altitudinal districts of Kerala such as Wayanad and Idukki are going to be more positively impacted, while coastal districts like Ernakulam and Thrissur negatively impacted. But no such spatial relation was observed in growing districts of Tamil Nadu and Andhra Pradesh. When many staple crops were facing the threat of decreased production due to climate change, cassava seemed to be a promising crop which could bring an answer to future food security.

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