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Change in climate and climate suitability of major taro [*Colocasia esculenta* (L.) schott] growing regions of India

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Abstract

Root and tuber crops such as taro [*Colocasia esculenta* (L.) schott] play a vital role in food security and livelihoods and yet neglected in climate change impact studies and large-scale crop improvement programs. This study attempts ensembled multi-model prediction of change in climate and climate suitability of taro in major taro growing regions of India by 2030 and 2050 under 4.5 and 8.5 representative concentration pathways (RCP). Climate, suitability (EcoCrop model) and suitability changes were analysed using Arc GIS 10.1 and Diva GIS 7.5. According to the study, under RCPs 4.5 and 8.5, the major taro growing regions will experience warming of the climate by 2030 and 2050. The mean temperature of major taro growing regions in 2030 will increase by 1.15- 1.49°C and 1.58 – 2.09°C for RCPs 4.5 and 8.5; and 1.35 - 1.70°C and 2.02 - 2.68°C for RCPs 4.5 and 8.5 in 2050. The precipitation in 2030 will increase by -2.01 – 82.07 mm and 2.84 - 128.02 mm for RCPs 4.5 and 8.5; and in 2050 it will change by 13.48 to 16.98 mm and 1.09 to 108.54 mm for RCPs 4.5 and 8.5. The climate suitability will change by -12.31 to 5.17% and -14.29 to 7.63% in 2030 for RCPs 4.5 and 8.5; and -18.26 to 6.57% and -24.1 to 9.39% for RCPs 4.5 and 8.5 in 2050.

Keywords: Taro, Climate change, Climate suitability, Representative concentration pathways, EcoCrop model

Introduction

Feeding a growing global population in a changing climate presents a significant challenge to society (Ericksen et al., 2009). Numerous issues, including rising demand, greater input costs, soil degradation, need to reduce greenhouse gas emissions, and increasing competition for land and water from non-food uses have an impact on food security (Hertel, 2011). Additionally, it is anticipated that yields will be impacted by climate change greatly (Tubiello et al., 2007). Root and tubers are the second most important group of food crops in the developing world after cereals, contributing to diets of over 2 billion people across the tropics and subtropics with annual production of about 800 million tons. They are crucial for the rural people's supply of calories and nutrients and help to lower food insecurity and malnutrition (Tadele, 2019), and it includes cassava, sweet potato, cocoyam and yams. These roots and tubers, however, are underexploited as there is a lack of genetic variety, biotechnology applications, and scientifically valid assessments of their adaptability (Mabhaudhi et al., 2019). Due to this, many root and tuber crops, including cocoyam, are categorized as neglected and under-utilized crops (Tumuhimbise, 2015).

Taro [*Colocasia esculenta* (L.) Schott], is an annual herbaceous plant belonging to the family Araceae (Prajapati et al., 2011) and is cultivated in 50 countries with 88.69% production concentrated in Africa.

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Globally, taro (cocoyam) is cultivated in an area of 1.79 m ha with a total production of 12.37 m tons and the average productivity is 6.91 t ha^{-1} (www.fao.org/faostat). According to Gananca et al. (2015), taro has a high moisture demand and thrives on the edges of wet fields and next to streams. It prefers regions with significant annual rainfall (>1,500 mm) and even distribution (Mwenye 2009). Lim (2015) claims that low rainfall inhibits corm growth because occasional moisture stress results in low yields, corms with a dumbbell form, and corms of poor quality. Addressing temperature, it can withstand maximum temperatures of at least 21°C and minimum temperatures of at least 10°C. As a result, it is colder tolerant than other tuber crops because it can withstand temperatures as low as 10°C. However, freezing temperatures harm the leaves and reduce yield (Lim 2015; Raemaekers, 2001). According to the FAO (1994), the crop matures over a long period of time between 180 and 300 days.

The most widely used tools to study the climate suitability changes of crops is EcoCrop model (Hijmans et al., 2001; Beebe et al., 2011; Jarvis et al., 2012; Vermeulen et al., 2013; Villegas et al., 2013; Sabitha et al., 2016; Piikki et al., 2017, Remya et al., 2018, Shiny et al., 2019). The basic mechanistic model (EcoCrop) implemented uses environmental ranges as inputs to determine the main niche of a crop and then produces a suitability index as output. The model was originally developed by Hijmans et al., (2001) and named EcoCrop since it was based on the FAO-EcoCrop database. The impact of future climate on suitability of taro in India is not yet studied by EcoCrop model. Hence, the present study was aimed at understanding whether taro really is a crop of merit for adaptation to climate change. Hence, this study used ten different coupled global climate models (GCMs) of the coupled model intercomparison project (CMIP5) to predict changes in the future climate and the climate suitability of taro in the major growing environments of India at two representative concentration pathways (RCP) of 4.5 and 8.5 by 2030 and 2050.

Materials and Methods

Study area

The study area included current taro growing regions of India. The presence point map of taro in India was developed according to expert knowledge of scientists working in ICAR-CTCRI and AICRP-TC (All India Coordinated Research Project on Tuber Crops) centers and based on available literature, identified principal regions where taro is cultivated currently. The geographic coordinates of these regions at 30 seconds spatial resolution using the district boundary shape file of each growing area (Fig. 1) were extracted and a total of 64,393 coordinates as taro presence points were obtained covering 10 states (157 districts) in India, *viz.,* Andhra

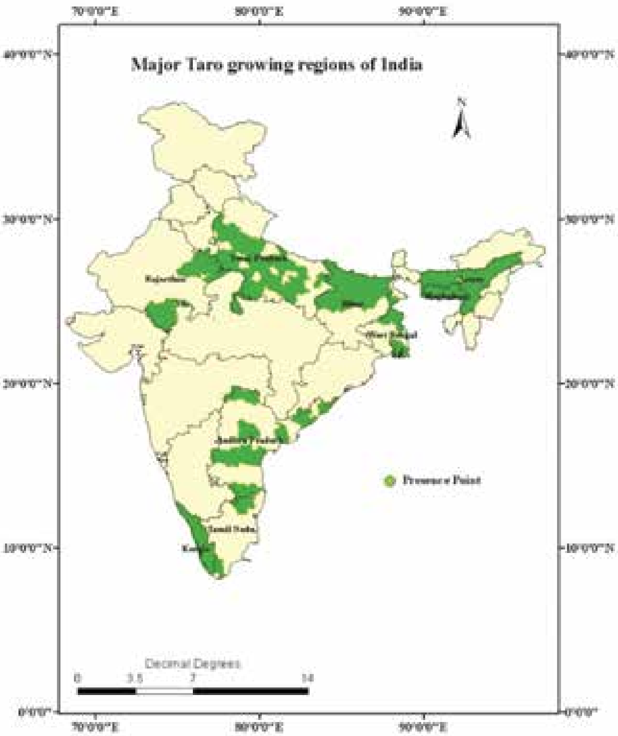

Fig. 1. Presence points map of major taro growing regions in India

Pradesh, Assam, Bihar, Kerala, Meghalaya, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh and West Bengal.

Current climate data

The spatial data of current climate were obtained from the WorldClim dataset (Hijmans et al., 2005; http://www.worldclim.org) 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 (Hutchinson, 1995) to depict current climatic conditions. The data include 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 was processed using a quality checking algorithm and then developed a continuous climate surface using thin plate spline algorithm (Hutchinson and Hoog, 1985; Hijmans, 2003), with elevation, latitude and longitude as independent variables. (http://www.ccafs-climate.org/data). The database includes precipitation, mean temperature, minimum and maximum temperature from 47554, 24542 and 14835 locations respectively (Challinor et al., 2010).

Future climate data

Representative Concentration Pathways (RCPs) are essential for assessing potential future climate changes and their impacts. It is used in climate modeling to project future greenhouse gas concentrations and associated radiative forcing (Vuuren et al., 2011). 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 will be more precise to predict future suitability and suitability change of taro 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 forcing that were correspondent to different concentration paths of the green house gases, the so-called RCPs. Considering the possibility that green house gas emission will be at an intermediate level in future due to various strategies and 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. RCP 4.5 corresponds approximately to B1 scenario in fourth assessment report of IPCC (AR4); the radiative forcing grows almost linearly up to 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 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 above 10 GCMs in Diva-GIS 7.5 platform. The data were restricted to the areas where taro is 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 sets to run the model using certain climate scenarios (IPCC 2014). All the suitability analysis were carried out using Diva GIS 7.5 and Arc GIS 10.1 software's. Initially, inputting the calibrated ecological parameters

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

Sl. No.	Model	Spatial Resolution (Long ^{0} × Lat $^{0)}$	Modelling Centre	Country
1	CCSM4	1.25 × 0.9424	National Centre for Atmospheric Research	USA
2	CESMI-CAM5	1.25 × 0.9424	National Centre for Atmospheric Research	USA
3	GFDL-CM3	2.5 × 2	NOAA Geophysical Fluid Dynamics Laboratory	USA
4	MIROC-ESM CHEM	2.8125 × 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 × 1.8947	Bjerknes Centre for Climate Research Norwegian Meteorological Institute	Norway
6	INM-CM4	2 × 1.50	Institute for Numerical Mathematics	Russia
7	GFDL-ESM2M	2.5 × 1.5169	NOAA Geophysical Fluid Dynamics Laboratory	USA
8	FIO-ESM	2.815 ×2.7673	First Institute of Oceanography, MNR	China
9	MIROC MIROC 5	1.4063 ×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 × 0.9424	Max Planck Institute for Meteorology	Germany

(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 10 CMIP5 models (for future climate suitability), the suitability of taro was predicted. Table 2 shows that crop would die at a temperature ≤0°C, and is not suited for temperature below 10°C, the crop grows optimally in the range of 21 to 28°C and will not grow if temperature is above 35°C. In the case of precipitation, the crop will be harmfully stressed if the total precipitation during the growing season is less than 1000 mm (drought stress) or above 3000 mm (excess water) and grows optimally in the range of 1500 to 2500 mm precipitation.

Table 2. Ecological parameters used to calibrate the Eco Crop model for taro

Sl. No.	Parameter	Calibrated value
1	Tkill	0°C
2	Tmin	10°C
3	Tmax	35°C
4	Topmin	21°C
5	Topmax	28°C
6	Rmin	1000 mm
7	Ropmin	1500 mm
8	Ropmax	2500 mm
9	Rmax	3000 mm

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

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

The taro presence points were used for extraction of data from the resultant raster maps. Presence points (containing the information of state and district) in the vector format - each placed one square kilometer 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.

Results and Discussion

Projected climate change in taro growing regions

Minimum temperature (T_{min})

The spatial pattern of annual change in minimum temperature at RCPs 4.5 and 8.5 for 2030 and 2050 is shown in Table 3. The T_{min} of major taro growing environments in 2030 is predicted to increase from 1.25 (Tamil Nadu) to 1.65 °C (Assam) and 1.61 (Kerala) to 2.03°C (Rajasthan) for RCPs 4.5 and 8.5, and the corresponding values for 2050 were 1.37 (Kerala) to 1.74°C (Rajasthan) and 2.16 (Kerala) to 2.83°C (Rajasthan), respectively. For both the scenario and for the years, Kerala and Tamil Nadu showed the lowest increase in T_{min}. The changes in T_{min} by individual GCMs were in the range of 0.41(GFDL-CM3) to 2.04°C (FIO-ESM) for RCP 4.5 and 0.98 (GFDL-CM3) to 2.04°C (MIROC MIROC 5) for RCP 8.5 in 2030; 0.47 (GFDL-CM3) to 2.72°C (FIO-ESM) for RCP 4.5 and 1.81 (GFDL-CM3) to 3.51°C (FIO-ESM) for RCP 8.5, in 2050.

Maximum temperature (T_{max})

T_{max} in 2030 were projected to increase from 0.87 (Meghalaya) to 1.32°C (Rajasthan) and 1.43 (Tamil Nadu) to 2.07°C (Uttar Pradesh) for RCPs 4.5 and 8.5 and the corresponding values for 2050 were 1.17 (Andra Pradesh) to 1.59°C (Uttar Pradesh) and 2.02 (Kerala) to 2.79°C (Uttar Pradesh). The changes in T_{max} by individual GCMs were 0.36 (CESMICAM5)

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

	Change in minimum temperature (°C)				Change in maximum temperature (°C)				Change in mean temperature (°C)				Change in precipitation (mm)			
RCP	4.5		8.5		4.5		8.5		4.5		8.5		4.5		8.5	
Year	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Andhra Pradesh	1.30	1.71	1.43	2.37	1.01	1.62	1.17	2.21	1.21	1.73	1.35	2.17	22.22	42.81	13.51	61.71
Assam	1.65	1.95	1.63	2.68	0.87	1.51	1.31	2.35	1.31	1.78	1.52	2.43	82.07	128.02	15.19	108.54
Bihar	1.42	1.76	1.56	2.67	1.10	1.75	1.38	2.55	1.30	1.82	1.52	2.47	19.06	22.10	15.19	52.67
Kerala	1.31	1.61	1.37	2.16	0.93	1.44	1.26	2.02	1.18	1.59	1.36	2.02	24.86	7.37	13.60	1.09
Meghalaya	1.47	1.81	1.54	2.59	0.87	1.51	1.21	2.32	1.22	1.72	1.43	2.32	69.50	77.90	14.26	9.29
Rajasthan	1.56	2.03	1.74	2.83	1.32	2.02	1.55	2.62	1.49	2.09	1.70	2.68	15.71	14.67	16.98	90.23
Tamil Nadu	1.25	1.62	1.38	2.20	0.94	1.43	1.21	2.11	1.15	1.58	1.35	2.05	38.06	57.72	13.48	91.22
Telangana	1.49	1.90	1.60	2.70	1.18	1.88	1.38	2.56	1.40	1.97	1.54	2.41	9.08	41.55	15.38	97.99
Uttar Pradesh	1.49	1.89	1.67	2.81	1.32	2.07	1.59	2.79	1.45	2.04	1.68	2.68	-2.01	2.84	16.80	49.29
West Bengal	1.36	1.67	1.41	2.52	1.11	1.73	1.27	2.48	1.29	1.77	1.39	2.28	35.14	28.34	13.90	56.04

to 1.671°C (FIO-ESM) for RCP 4.5 and 1.06 (GFDL-CM3) to 1.925°C (MIROC-ESM CHEM) for RCP 8.5 by 2030. The changes in 2050 for RCP 4.5 were from 1.15 (MPI-ESM-LR) to 2.49°C (FIO-ESM) and for RCP 8.5 the corresponding values were 1.63 (NorESMI-M) - 3.76°C (FIO-ESM).

Mean temperature (T_{mean})

The T_{mean} of major taro growing environments in 2030 were projected to increase by 1.15 (Tamil Nadu) - 1.49°C (Rajasthan) and 1.58 (Tamil Nadu) – 2.09°C (Rajasthan) for RCPs 4.5 and 8.5 and the corresponding values for 2050 were 1.35 (Tamil Nadu and Andra Pradesh) to 1.70°C (Rajasthan) and 2.02 (Kerala) to 2.68°C (Rajasthan and Uttar Pradesh), respectively. The individual GCM predicted changes in Tmean were in the range of 0.70 (GFDL-CM3) - 1.91°C (FIO-ESM) and 1.07 (GFDL-CM3) – 2.04°C (MIROC MIROC 5) for RCPs 4.5 and 8.5 in 2030. The corresponding values in 2050 ranged from 1.02 (GFDL-CM3) to 2.65°C (FIO-ESM) and 1.73 (GFDL-CM3) to 3.53°C (FIO-ESM).

Annual rainfall

In 2030, the rainfall would change from -2.01 (Uttar Pradesh) to 82.07 mm (Assam) and 2.84 (Uttar Pradesh) to 128.02 mm (Assam) for RCPs 4.5 and 8.5. The corresponding values for 2050 were 13.48 (Tamil Nadu) to 16.98 mm (Rajasthan) and 1.09 mm (Kerala) to 108.54 mm (Assam). The individual GCM predicted changes in rainfall varied from -26.6 (MIROC-ESM CHEM) to 102.66 mm (NorESMI-M) for RCP 4.5 and -22.2 (GFDL-CM3) to 99.68 mm (GFDL-ESM2M) for RCP 8.5 in 2030. In 2050, it would be from -99.7 (MPI-ESM-LR) to 159.59 mm (NorESMI-M) for RCP 4.5 and 1.00 (MIROC MIROC 5) to 217.51 mm (CEMI-CAM5) for 8.5.

Current climate suitability of taro

With the calibrated ecological parameters, the current climate suitability of taro was modelled using Ecocrop model in DIVA-GIS 7.5 (Fig. 2). The results showed an average suitability between 10.75 and 85.95% in major taro growing regions. Kerala (85.95%) showed excellent suitability (>80%) whereas Assam (77.65%) and West Bengal (66.92%) were very suitable for taro cultivation, while Meghalaya and Bihar showed suitability of 56.23 and 51.02%, respectively.

Future climate suitability of taro

Predicted future suitability of taro in major growing regions of India is shown in Fig. 3. In 2030, the result showed an average future suitability between 12.66 and 76.34% in major taro growing regions; it is predicted to be 76.34% for Kerala, 72.64% for Assam, 61.38% for Meghalaya, 54.60% for West Bengal and rest of states shows future suitability below 50% for RCP 4.5. For

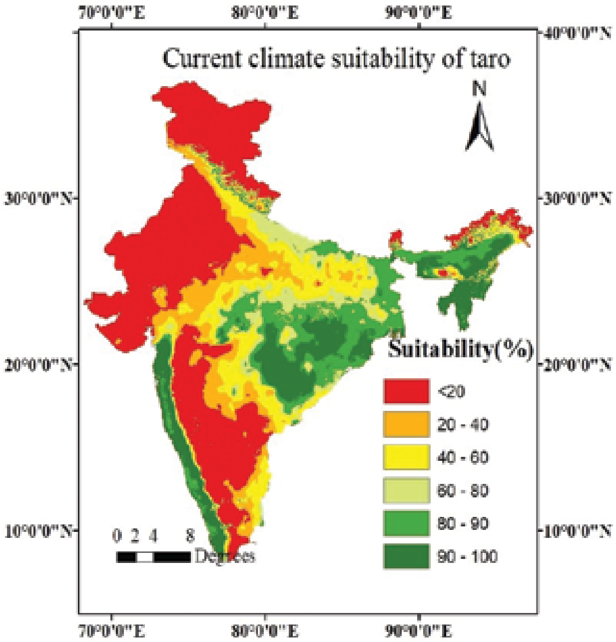

Fig. 2. Current climate suitability of taro by EcoCrop model

RCP 8.5, the predicted values would range between 13.74 and 73.69%, and it would be 73.69% for Kerala, 72.52% for Assam, 63.85% for Meghalaya, 52.64% for West Bengal and rest of states shows future suitability below 50% for both the RCPs. For RCP 4.5 in 2050, the future suitability was in the range 12.82 to 72.83% and it will be 72.83% for Kerala, 69.59% for Assam, 62.79% for Meghalaya, 95.04%. For RCP 8.5, the suitability's would range between 16.70 and 69.51%, which will be 69.51% for Kerala, 66.48% for Assam, 65.61% for Meghalaya and all other states show future suitability below 50% for both RCPs.

The changes in current suitability of taro under RCPs 4.5 and 8.5 by 2030 and 2050 are shown in Fig. 4 and their impacts in Table 4. The model ensembled results under RCP 4.5 in 2030 ranged from -12.31 (West Bengal) to 5.17% (Meghalaya). Decrease in suitability was observed for West Bengal (-12.31%), Kerala (-9.61%), Assam (-5.02%), Bihar (-3.5%) and Uttar Pradesh (-2.38%) and Andra Pradesh (0.4%), Telangana (0.47%), Tamil Nadu (1.5%), Rajasthan (1.92%) and Meghalaya (5.17%) showed a suitability increase. Individual GCM predicted changes in taro growing regions ranged from -7.91 (MIROC-ESM CHEM) to 5.13% (NorESMI-M). Under RCP 8.5 in 2030, the decrease in future suitability was observed in West Bengal (-14.29%), Kerala (-12.27%), Assam (-5.13%), Uttar Pradesh (-3.03) and Bihar (-2.91%). Rajasthan, Tamil Nadu, Andhra Pradesh, Telangana and Meghalaya showed increased suitabilities of 2.98, 3.38, 3.81, 3.97 and 7.63% respectively. Studies with individual GCMs showed variabilities from -5.74 (GFDL-CM3) to 2.94% (NorESMI-M) for RCP 8.5, 2030.

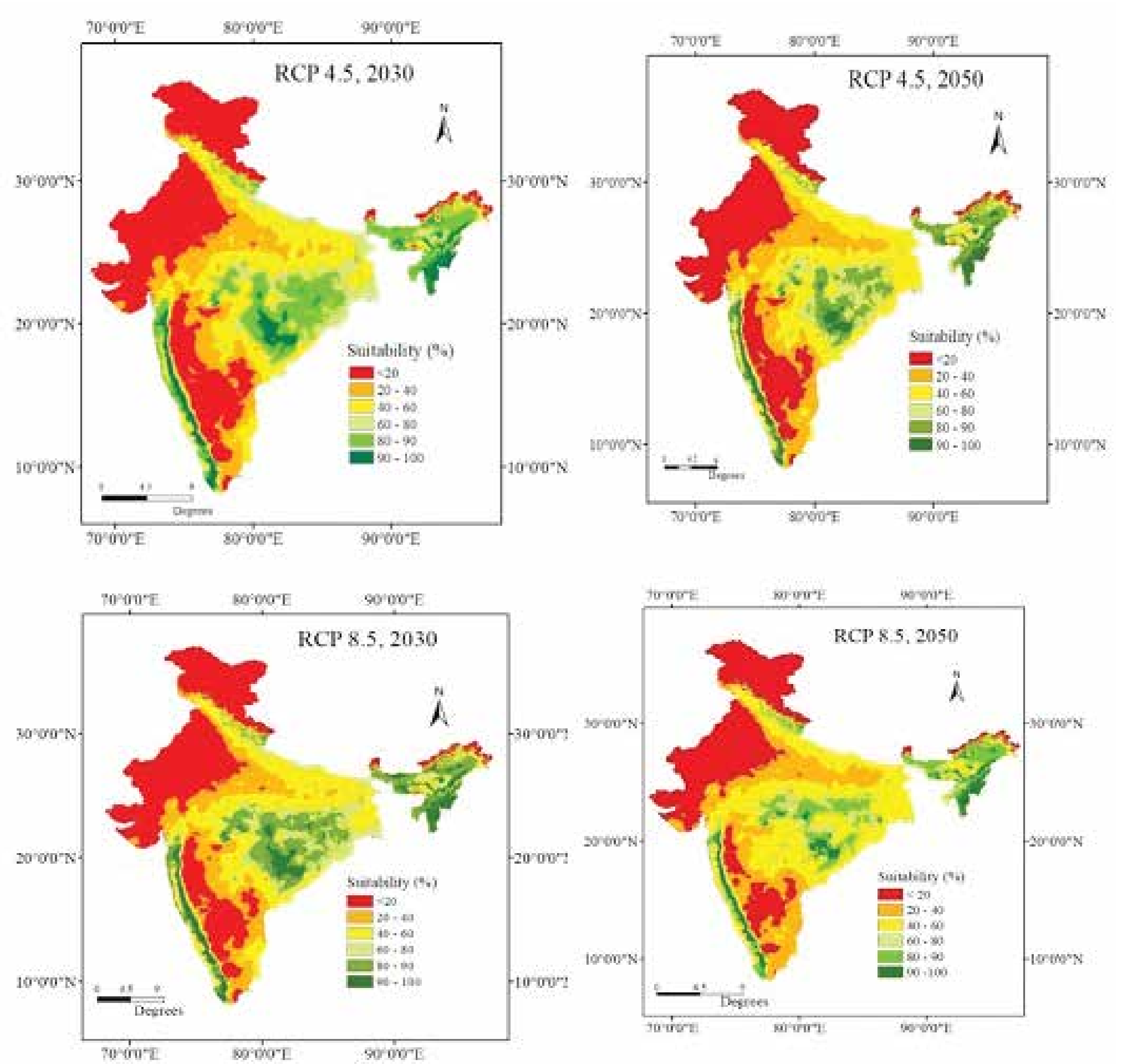

Fig. 3. Predicted future suitabilities of taro as average of the 10 GCMs studied

Change in climate suitability and impacts on taro at different scenarios

The predicted changes in climate suitability in districts of major taro growing states – Andhra Pradesh, Assam, Kerala, Meghalaya, Tamil Nadu and Uttar Pradesh have showed that, for RCP 4.5 in 2030, Vishakhapatnam (5.60%) in Andhra Pradesh, Tinsukia (14.70%) in Assam, Kozhikode (11%) in Kerala, West Khasi Hills (15%) in Meghalaya, Tirunelveli (9.70%) in Tamil Nadu and Sharanpur (13.90%) in Uttar Pradesh showed highest positive impact. While Chittoor (-12.90%), N.C. Hills (-17.20%), Kannur (-21.30%), West Garo Hills (-15.70%), Vellore (-7.60%) and Mau (-13.7%) in Andhra Pradesh, Assam, Kerala, Meghalaya, Tamil Nadu and Uttar Pradesh, respectively showed highest negative impact. For RCP 8.5 in 2030 Chittoor (10.90%), Chirang (17.40%), Kozhikode (13.5%), West Khasi Hills (19%), Tirunelveli (11.40%) and Bunor (17%) in Andhra Pradesh, Assam, Kerala, Meghalaya, Tamil Nadu and Uttar Pradesh showed highest positive impact; while West Godavari (-14.10%) in Andhra Pradesh, Karbi Analog (-20%) in Assam, Malappuram (-26.40%) in Kerala, Ri Bhoi (-18.40%) in Meghalaya, Vellore (-9.60%) in Tamil Nadu and Sharanpur (-23%) in Uttar Pradesh showed highest negative impact.

For RCP 4.5 in 2050, individual GCM predicted changes would be from -13.49 (MPI-ESM-LR) to 4.96% (NorESMI-M). Model ensembled results for the same showed a decrease in future suitability in West Bengal (-18.26%), Kerala (-13.13%), Assam (-8.07%), Bihar (-7.37%) and Uttar Pradesh (-5.01%). Andhra Pradesh,

Table 4. Regional changes in taro 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	1.25	7.16	-10.87	-0.72	7.96	-9.23	-1.18	7.61	-11.03	-6.79	8.97	-14.67
CESMI-CAM5	-2.50	7.58	-6.29	0.57	6.27	-7.46	-3.89	8.05	-9.88	-2.34	20.82	-13.50
GFDL-CM3	-4.92	6.28	-10.62	-5.76	9.55	-10.81	-7.65	7.74	-16.36	-4.61	15.69	-11.92
MIROC ESM-CHEM	-3.19	4.87	-5.29	-5.67	9.50	-10.18	-6.47	3.92	-9.17	-6.27	8.88	-12.60
NorESMI-M	-1.76	6.10	-7.79	-1.25	6.32	-8.43	0.89	9.58	-13.43	-3.60	9.76	16.22
INM-CM4	-2.17	6.14	-6.88	-1.65	5.75	-7.44	-0.26	7.37	-9.54	-3.90	7.63	12.61
GFDL-ESM2M	-2.97	3.92	-7.42	0.05	9.43	-8.48	-8.88	6.17	-12.55	-12.95	8.06	-17.99
FIO-ESM	-7.94	4.77	-11.22	-4.92	6.68	-9.40	-7.77	6.12	-11.82	-12.42	10.61	-17.75
MIROC MIROC 5	-5.15	3.50	-7.00	-2.69	5.08	-9.56	-13.54	5.57	-16.27	-6.99	5.55	-14.63
MPI-ESM-LR	5.15	9.15	-6.81	2.95	10.52	-12.51	4.98	10.49	-9.26	4.03	11.85	12.10
Mean	-2.42	5.95	-8.02	-1.91	7.706	-9.35	-4.38	7.26	-11.93	-5.58	10.78	-6.21

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

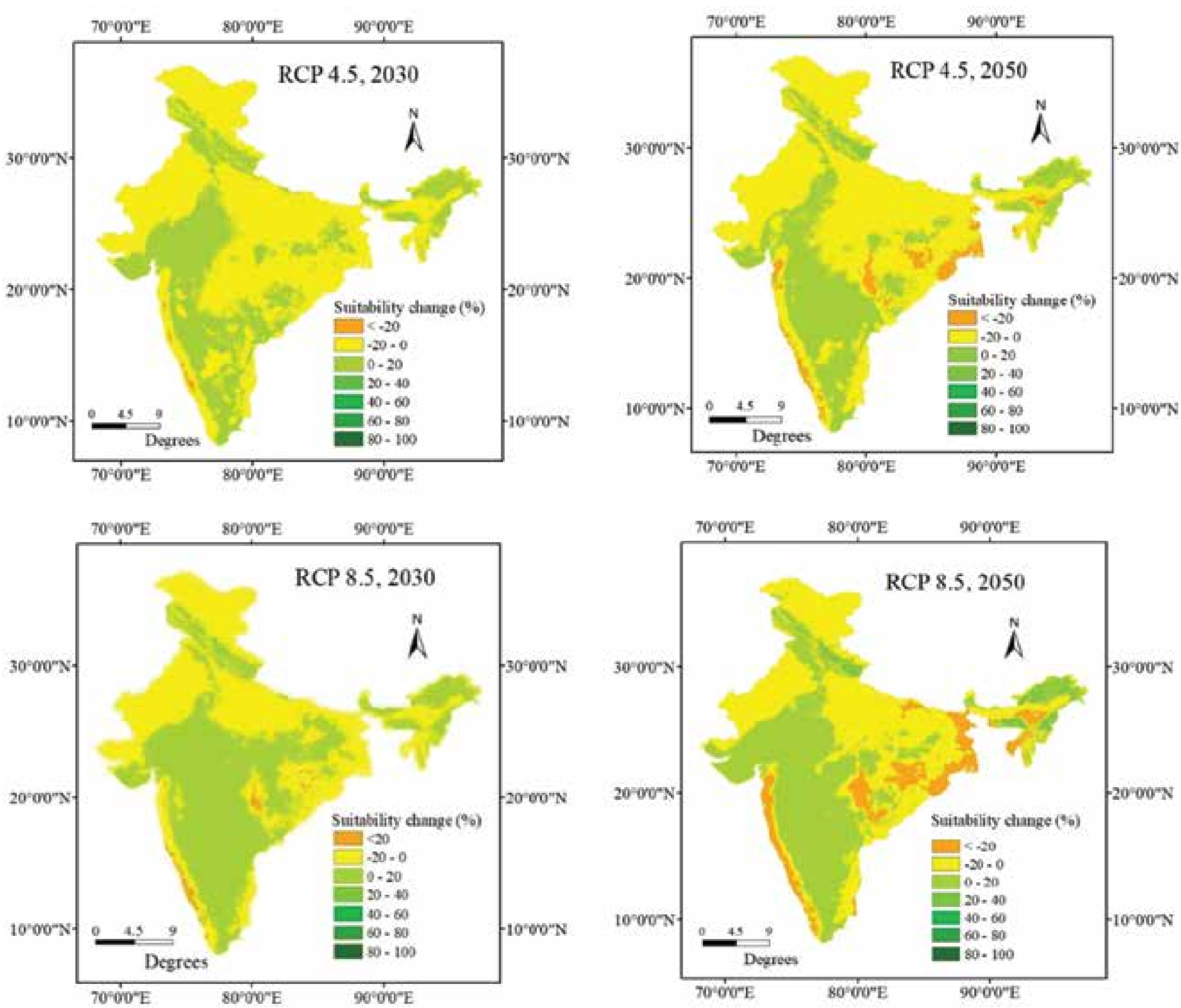

Fig. 4. Predicted changes in taro climate suitabilities as average of the 10 GCMs studied

Tamil Nadu, Rajasthan, Telangana and Meghalaya showed increased suitabilities of 0.85, 1.41, 2.08, 2.48 and 6.57% respectively. For RCP 8.5 in 2050, the individual GCMs showed variability from -12.9 (MIROC MIROC 5) to 4.02 % (NorESMI-M). West Bengal (-24.1%), Kerala (-16.45%), Bihar (-12.5%), Assam (-11.17%) and Uttar Pradesh (-6.01%) showed decrease in suitability, whereas Andhra Pradesh (1.66%), Tamil Nadu (2.01%), Telangana (3.73), Rajasthan (5.95%) and Meghalaya (9.39%) showed an increase of suitability for taro.

In the districts of major taro growing states for RCP 4.5 in 2050, Chittor (7.2%) in Andra Pradesh, Tinsukia (19.70%) in Assam, Malappuram (15.30%) in Kerala, West Khasi Hill (19.9%) in Meghalaya, Tirunelveli (11.9%) in Tamil Nadu and Sharanpur (18.5%) in Uttar Pradesh showed highest positive impact, while West Godavari (18.6%), Karbi Analog (-22.30%), Ernakulam (-25%), West Garo Hills (-22.5%), Vellore (-13.5%) and Mau (-18.9%) in Andhra Pradesh, Assam, Kerala, Meghalaya, Tamil Nadu and Uttar Pradesh showed highest negative impact. For RCP 8.5 in 2050, Chittoor (12.6%) in Andra Pradesh, Karbi Analog (28.60%) in Assam, Wayanad (18.80%) in Kerala, East Khasi Hills (33.40%) in Meghalaya, Tirunelveli (18.70%) in Tamil Nadu and Sharanpur (21.90%) in Uttar Pradesh showed highest positive impact in taro suitability while West Godavari (-28.50%) in Andra Pradesh, Dhubri (-28.30%) in Assam, Kannur (-32.30%) in Kerala, West Garo Hills (33.40%) in Meghalaya, Vellore (-17.4%) in Tamil Nadu and Deoria (-24.0%) in Uttar Pradesh showed highest negative impact. Overall suitability change (OSC) is predicted to be negative for both the years and scenarios, except for CCSM4 (1.25%) and MPI-ESM-LR (5.15 %) for 4.5 scenario and 0.57, 0.05 and 2.95% for CESMI-CAM5, GFDL-ESM2M AND MPI-ESM-LR, respectively for 8.5 scenario in the year 2030. In 2050, the OSC for models Nor ESMI-M (0.89%) and MPI-ESM-LR (4.98%) in 4.5 scenario and in 8.5, MPI-ESM-LR (4.03%) were predicted to be positive. Positively impacted areas would be more for RCP 8.5 in 2030 and minimum area would have positive impact for RCP 8.5 in 2050. For both RCPs of 4.5 and 8.5 in 2030 and 2050, the result showed that the positive impact would be less. Warming of the atmosphere, mere increase in total rainfall and climate suitability of taro are predicted under RCPs 4.5 and 8.5 in 2030 and 2050 (Fig. 5). Kodis et al., (2018) studied ecological niche modeling for a cultivated plant species: a case study on taro (*Colocasia esculenta*) in Hawaii using two ecological niche models. The findings also imply that climate change will have an impact on the geographic regions that are projected to be suitable for taro, with more extreme future climatic scenarios showing less overlap between these regions and

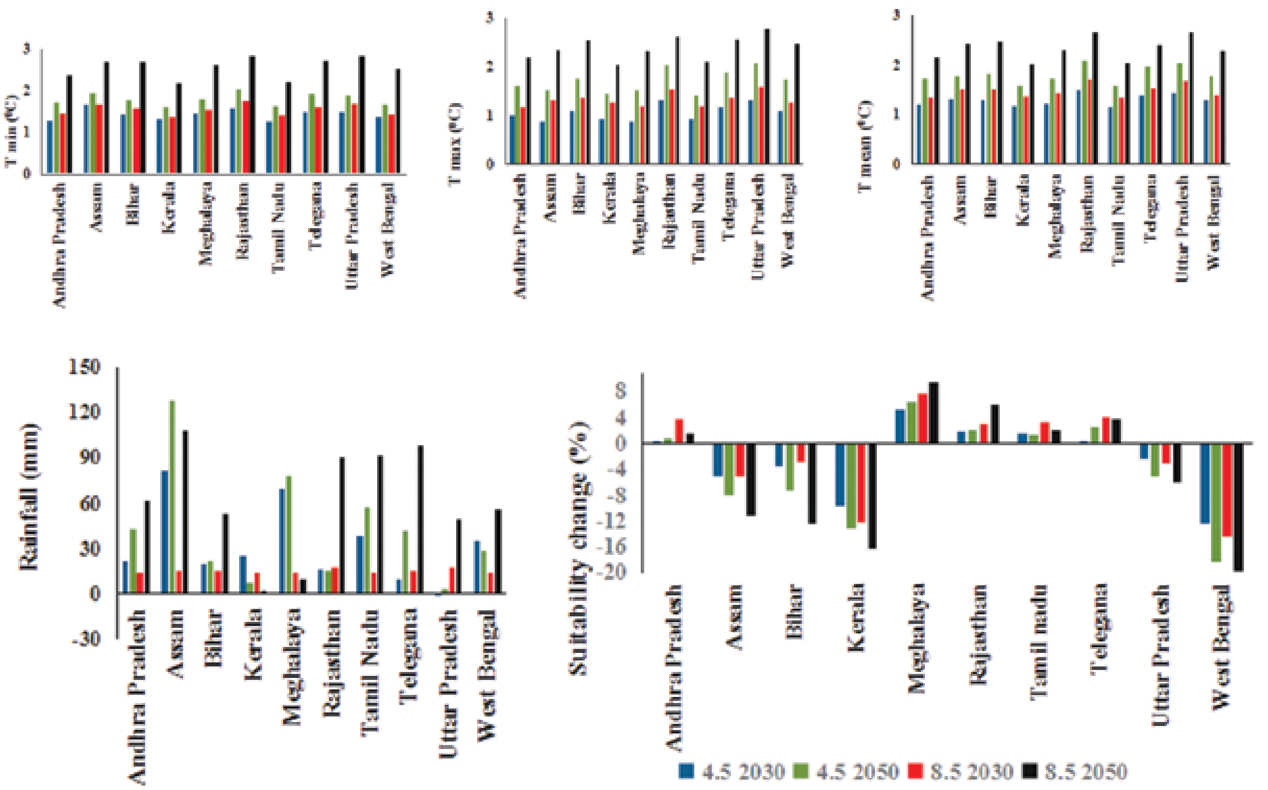

Fig. 5. Comparison of climate change and climate suitability change in the taro growing regions under RCP for 2030 and 2050

existing habitat. Pushpalatha et al., (2023) studied the future climate suitability of underutilized tropical tuber crops by using MaxEnt model, suggested that taro was highly suitable in southern peninsular and north- eastern regions in near future (2030) which was in accordance with our result.

Conclusion

According to the results of the current study, 2050 under the RCP 8.5 scenario would be the warmest and 2030 under any scenario were anticipated to be warmer than the current climate. No accountable changes in precipitation were predicted by both scenarios for both time periods. The mean temperature of major taro growing regions in 2030 will increase by 1.15- 1.49°C and 1.58 – 2.09°C for RCPs 4.5 and 8.5; and 1.35 - 1.70°C and 2.02 - 2.68°C for RCPs 4.5 and 8.5 in 2050. The precipitation in 2030 will increase by -2.01 – 82.07 mm and 2.84 - 128.02 mm for RCPs 4.5 and 8.5; and in 2050 it will change by 13.48 to 16.98 mm and 1.09 to 108.54 mm for RCPs 4.5 and 8.5. The climate suitability will change by -12.31 to 5.17% and -14.29 to 7.63% in 2030 for RCPs 4.5 and 8.5; and -18.26 to 6.57% and -24.1 to 9.39% for RCPs 4.5 and 8.5 in 2050. The suitability of taro under RCPs 4.5 and 8.5 by 2030 and 2050 indicated that there would be a significant change in suitability. The individual GCMs predicted results at two different scenarios for the two time periods, showing that though there were positively impacted areas, the overall suitability was negative, or predicted to decrease by most of the GCMs.

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