DIVA-GIS and MaxEnt based diversity indices help in understanding trait and geographic diversity in maize in India

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Keywords: *Diversity, richness, DIVA-GIS, MaxEnt, maize.*

Abstract

A total of 62 diverse late maturing hybrids of maize (*Zea mays* L.) both from public and private sector were evaluated during Rainy (*Kharif*) 2018 across four diverse geographic locations (centres) of the peninsular region of India, *viz.*, Coimbatore, Dharwad, Karimnagar and Hyderabad. The data, *viz.*, plant height, cob height, days to 50% anthesis, days to 50% silking, days to 75% maturity and cob weight was analysed for diversity and richness indices using DIVA-GIS software. The objective was to identify the trait (s), which showed more diversity or richness among the hybrids and to identify the geographical region which was more efficient resolving the diversity and richness in the hybrids. Ecological niche modelling using Maximum Entropy method was analysed to identify the potential regions for growing the elite maize hybrids. The study was able to conclude that the trait plant height recorded maximum diversity index among all the traits, the Hyderabad location was most suitable for resolving diversity among the hybrids and also based on MaxEnt it was concluded that regions in the states of Andhra Pradesh, Assam, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Pondicherry, Tamil Nadu, Telangana and Tripura were the potential regions, under current climatic conditions, suitable for these hybrids under testing.

Abbreviations

AUC: Area under curve
DIVA-GIS: Geographic information system
EC: Electrical conductivity
ppm: parts per million
RH: Relative humidity

Introduction

Maize (*Zea mays*. L) is a principal cereal crop in many developed and developing countries of the world. It was reported to have wide adaptability to climatic conditions ranging from Chile at 40S to Russia and Canada at 50N; from sea level to 3400m elevation (Bouchet *et al*.. 2013). It is widely used for animal feed and industrial raw material in the developed countries whereas it serves as food-providing nutritional security and feed, and in the developing regions of the world *viz.*, sub-Saharan Africa, Asia and Latin America (Prasanna *et al*.. 2021). Population growth and increased demand for animal products, more so in the developing countries, further the continued increased demand for maize, including for, its use as industrial raw material apart from food, feed and bio fuel (Andorf *et al*.. 2019) . In India, maize is the third most prominent position with an annual production of around 27 mt covering 9.0 m ha ranks fifth in area being next to rice, wheat, sorghum and pearl millet. Maize recorded increasing trend for cropped area from 3.2 m ha (1950-51) to 9.5 m ha (2017-18) but declined to 9.0 m ha during 2018-19 (Chauhan *et al*.. 2020). Surplus maize has been produced in India and 0.92 mt were exported in the year 2020 (Chauhan *et al*.. 2020). A systematic programme for maize research in India was started in 1957, with commencement of All India Coordinated Research Project (AICRP) on Maize by the Indian Council of Agricultural Research (ICAR) with mandate for enhancing the productivity, profitability and competitiveness of maize and maize-based farming systems with economic and environmental sustainability. The Project with network of 34 centres in 23 states, released >360 cultivars having different genetic makeup including double cross hybrids, synthetics, composites and recently highly productive single cross hybrids for various regions and end-uses.

Keeping in the importance of single cross hybrids in maize, every year hundreds of hybrids developed by both public institutions and private companies are being evaluated for their production potential along with pest tolerance through a well established AICRP system involving multi-location testing in well demarcated agro-ecological zones. Development of adapted varieties/hybrids for these environmental conditions with diverse eco-geographic and environmental conditions is a challenge and a continual activity. Also, the vagaries of climate change/ variability needs to be addressed and as climatic conditions change at particular experimental sites and maize producing regions, mega environment assignments to be re-assessed to guide breeders to appropriate new germplasm and target environments (Cairns *et al*.. 2012) and develop more climate resilient maize systems (Cairns *et al*.. 2013). Cairns *et al*.. (2013) professed the significance of Geographic information systems (GIS) in targeting breeding programs by predicting regions of vulnerability, targeting germplasm movement and identifying future climates for agricultural production environments. Howden *et al*.. (2007) reported that adaptation to climate change requires cross-disciplinary solutions. Cairns *et al*.. (2013) underscored the urgent need to identify the most vulnerable regions so that the breeding programs are able to deliver improved genotypes to offset potential losses under climate change. Tao and Zang (2010) had suggested testing with such adapted cultivars and to ascertain as to what fraction of the yield variation was contributed by life cycle length compared to other direct effects of temperature on assimilation and grain-set.

Evaluation of hybrids from diverse ecosystems might be good source for productive lines with better adaptation to the climate variability. Under changing climatic scenario, it was felt to test efficiency of the locations in resolving the diverse hybrids, and in bringing out the best expression of hybrids and also the traits that can be easily relied on for resolving the diverse hybrids. It also helps in the identification of the possible regions or areas from one can further source inbred to be used in the crop improvement using the single cross hybrid technology. With this in view a diverse set of hybrids sourced from all over India were characterized and evaluated and the extent of diversity being among traits and locations was studied using the DIVA-GIS. Further, MaxEnt was used in the assessment of suitability of various areas of these hybrids under the present environmental conditions and future scenario.

Material and methods

Maize hybrids and Experimental sites

Sixty-two, late maturing, diverse maize hybrids from both public and private sectors were evaluated during *Kharif* (rainy) 2018 at four centres, *viz.*, Coimbatore, Dharwad, Karimnagar and Hyderabad across India. The experiment was laid out in two rows of 4m length with a spacing of 60 cm x 20 cm. The crop was raised under supplemental irrigation with fertilizer as per recommendations for zone. Standard descriptor and descriptor states were used for recording six quantitative traits on maize hybrids *viz.*, Plant height (cm), rounded to 0 decimal, Days to 50% Anthesis, Days to 50% Silking, Days to maturity – 75% dry husk/appearance of black layer at the base of the kernel, Cobs count at harvest (No./plot), Cobs weight at harvest (Kg/plot). Four presence points (GPS coordinates) recorded from four sites were used for the present study.

Soils and Weather during Kharif (rainy), 2018 Coimbatore

The crop was grown in fertile black soil. During the crop growth period (June’18-November’18), the average relative humidity (RH) recorded was 86.2% (morning) and 61.6% (evening) and month-wise relative humidity% (morning & evening) was – June-83.7% & 67.1%, July-84.0% & 63.8%, August-84.9% & 60.4%, September-87.0% & 53.2%, October-88.8% & 60.6% and November-89.0 %& 61.0%. Average temperature (°C) recorded was 30.6°C (maximum) and 22.7°C (minimum) respectively. Month-wise maximum and minimum temperature (°C) recorded was June-33.3°C & 23.7°C, July-30.3°C & 32.3°C, August-30.2°C & 23.0°C, September-32.8°C & 22.7°C, October-30.4°C & 21.9°C and November- 29.8°C & 21.5°C. Rainfall (mm) received maximum in the month of October (151.6 mm) and minimum in the month of November (39.9 mm). Month-wise rainfall received is June-54 mm, July-70.8 mm, August-60.4 mm, September-115.7 mm, October-151.6 mm and November-39.9 mm. intermittent rainy showers were received during the crop growth and the total rainfall recorded was 492 mm during the cropping season.

Dharwad

At Dharwad centre the soils are medium deep black type with neutral pH (6.5 to 7.3), non-saline in nature with EC ranging from 0.0 to 0.5 ds/m. The soils are high in available "K" with >330.0 kg/ha and Manganese (Mn) > 1.0 pp. But, however they are medium in soil organic carbon content (0.5 to 0.75%) and deficient in available "P" (<23.0 kg/ha), Iron (Fe) of < 4.5 ppm and Zinc (<0.6 ppm). During *Kharif*, 2018 at Dharwad there was 462.6 mm rainfall from June to October from 45 rainy days. The July month being the wettest month with 128.4 mm rainfall. The maximum RH was observed during July 90.1 % followed by August 89.7 %. Similarly, the maximum temperature ranged from 25.8°C (July) to 31.6°C (October) with an average minimum temperature of 20 °C.

Karimnagar

At Karimnagar research station soils are red sandy loam soils with neutral pH (7.35), EC-(0.31 ds/m, non saline), available organic carbon percentage is medium (0.67%), Available nitrogen contents were low (276 kg/ha), available phosphorous and potassium contents were medium (44 kg/ha) and high (431 kg/ha) respectively.

Weather conditions recorded for total rainfall (mm), Number of rainy days, maximum and minimum temperatures from June month to December month. Total rainfall received maximum was in the month of August (319 mm). Month wise rainfall (mm) received was June-133 mm, July-187 mm, August-319 mm and December-17.0 mm. Highest number of rainy days observed in the month of August (13). Month wise number of rainy days recorded was June-8, July-10, August-13, September-3 and December-2. Month wise maximum and minimum temperature (°C) recorded was June -38.1°C & 24.2°C, July- 36.1°C & 22.1°C, August-36.4°C & 22.3°C, September-36.6°C & 24.2°C, October-35.8°C & 20.5°C, November- 34.9°C & 12.4°C and December – 33.5°C & 13.5°C

Hyderabad

At Hyderabad, the crop was grown in light fertile black soil. During the *Kharif* season warm and humid weather has prevailed throughout the season. There was a deficit rainfall in the season (-44.49%). Month-wise rainfall received was – June 51.6 mm (-53.30%), July 87.6 mm (-39.84%), August 159.6 mm (-12.74%), September 43.4 mm (-69.59) and October 43.2 mm (-61.63). The maximum temperature (°C) was observed in the month of October (32.4°C), month-wise maximum-minimum temperature(°C) recorded was – June (34.7°C & 22.6°C), July (30.6°C & 21.4°C), August (29.4°C & 20.8°C), September (31.4°C & 19.9°C) and October (32.4°C & 16.5° C). Maximum relative humidity (%) was recorded in the month of September (90.2%). Month-wise maximum-minimum relative humidity (%) recorded was June (85.3% & 58.2%), July (88.8% & 70.1%), August (88.4% & 71.0%), September (90.2% & 58.1%) and October (86.1% & 39.0%). The maximum and minimum evaporation (mm) was observed in the month of June (6.5 mm) and September (4.1 mm) respectively. Month-wise evaporation (mm) recorded June-6.5 mm, July-5.1 mm, August-4.5 mm, September-4.1 mm and October-4.4 mm. Number of sunshine hours recorded in the month-wise were – June (5.6 hrs), July (3.3 hrs), August (3.8 hrs), September (5.9 hrs) and October (7.4 hrs). Maximum number of rainy days was recorded in the month of August (10). The month-wise rainy days recorded were June-6.0, July-6.0, August-10.0, September-3.0 and October-2.0. Maximum normal rainfall (mm) received in the month of August (182.9) and minimum normal rainfall received in the month of June (110.5).

Environmental variables for MaxEnt

Nineteen bioclimatic predictor variables (BC) were selected for building the ecological niche models which represent annual trends, seasonality and extreme or limiting environmental factors. Environmental layers used (all continuous): bio1 (Annual mean temperature); bio2 (Mean diurnal range); bio3 (Isothermality); bio4 (Temperature seasonality); bio5 (Max temperature of warmest month); bio6 (Min temperature of coldest month); bio7 (Temperature annual range); bio8 (Mean temperature of wettest quarter); bio9 (Mean temperature of driest quarter); bio10 (Mean temperature of warmest quarter); bio11 (Mean temperature of coldest quarter); bio12 (Annual precipitation); bio13 (Precipitation of wettest month); bio14 (Precipitation of driest month); bio15 (Precipitation seasonality); bio16 (Precipitation of wettest quarter); bio17 (Precipitation of driest quarter);bio18 (Precipitation of warmest quarter); bio19 (Precipitation of coldest quarter). Bioclimatic variables were selected based on species ecology (Pascual *et al.*. 2009). For the current and future climate (baseline) of India were used monthly data from the WorldClim (WC) database sourced from global weather station. The variables, including annual mean temperature, mean diurnal range, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation and precipitations of the wettest and driest months were downloaded from the WorldClim dataset – (freely available at http://www.worldclim.org). The WorldClim data provides interpolated represents long term (1950-2000) monthly means of maximum, minimum, mean temperatures and total rainfall as generic 2.5 arc-min grids.

Model building

MaxEnt 3.3.3k software (www.cs.princeton.edu/~schapire) was used as it requires only presence records and its efficacy has been well recognized (Elith *et al*.. 2006; Phillips *et al*.. 2006; Phillips and Dudik 2008). These models included the regularization multiplier (1), maximum number of iterations (500), maximum number of background points (10 000) and convergence threshold (0.00001) and 25 % of the data were reserved to test the model. The outputs of ten replicates were combined to give a mean output. A logistic output for constructing the predictive models was selected as it is the easiest to comprehend, giving a value between 0 and 1 as the probability of occurrence of grass species (Phillips and Dudik 2008). Jackknife analyses and mean area-under-curve (AUC) plots were created using MaxEnt. AUC is commonly used as a test of the overall performance of the model (Elith *et al*.. 2006) and it remains a handy indication of the usefulness of a model (Elith *et al*.. 2006, 2011). A value of 1.00 is an exact agreement with the model, while a value of 0.50 represents a random fit. Jackknife analysis indicates which variable has the greatest stimulus on the model and the overall success of the model

DIVA-GIS Analysis

DIVA-GIS software version 7.5, freely downloadable software from www.diva-gis.org was used to generate the potential distribution map with input ASCI file obtained in MaxEnt analysis (maximum entropy method). Diversity analysis among maize hybrids for several traits *viz*., plant height, days to 50%pollen shedding, days to 50% silking, days to 75% maturity, number of cobs and cob weight analysed using DIVA-GIS. India districts shape file was used for generating grid maps. Point Shape files for the above mentioned traits of maize hybrids created from excel file using 'import points to shape file' in the 'Data menu' of DIVA-GIS window. Diversity analyses for maize traits carried out using the analytical functionality in DIVA-GIS. In the 'Analysis' menu 'point to grid' option was chosen to create grid files with diversity indices from the points shape file. Analysis/Point to Grid menu allows us to take point data in a shape file and create grid files. Grid files were generated for individual traits taken for diversity analysis. All these analyses were carried out in 'Data' view window and the grid maps generated were saved as images using the Design view of the main DIVA-GIS window.

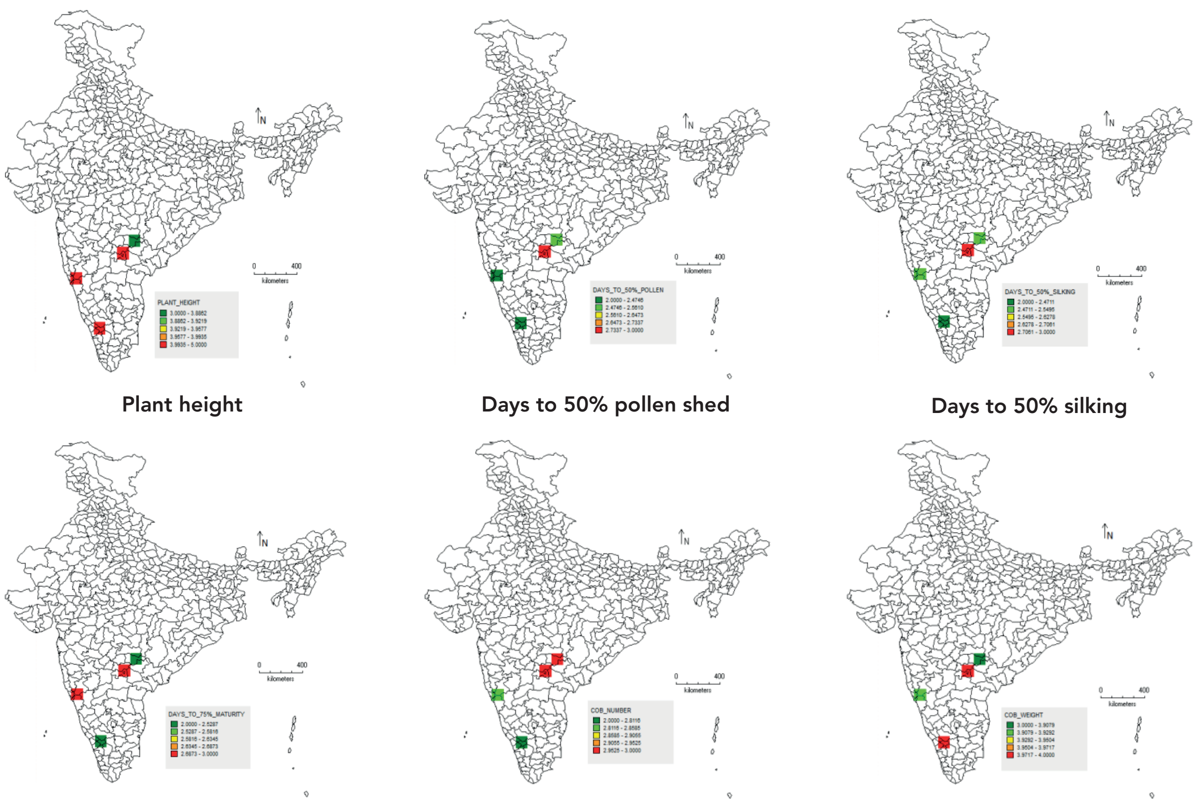
Results and discussion

The mean data of the traits recorded in the four locations is presented in the Table 1. The mean data of each hybrid is presented in Supplementary Table 1. The results of DIVA-GIS analysis, grid maps generated for diversity analysis of the six characters, *viz*., plant height, days to 50% Anthesis, days to 50% silking, days to 75% maturity, cob number and cob weight, which enables identification of the diversity existing among the different traits of the hybrids are presented in Fig.1. The colours of the grids are indicative of the extent of diversity of the maize hybrids recorded as diversity index. High Shannon diversity index was recorded the trait plant height (3.99-5.00), days to 50% Anthesis (2.73-3.00), days to 50% silking (2.73-3.00), days to 75% maturity (2.69-3.00), cob number (2.95-3.00) and cob weight (3.97-4.00). This shows us the highly responsive traits to ecosystem. High diversity index values were recorded for the trait, plant height among all the centres except Karimnagar. Among the locations, Coimbatore recorded low diversity indices for cob number (2.00-2.81), days to 50% anthesis and silking (2.00-2.53) and days to 75% maturity (2.00-2.53) and Karimnagar for plant height (3.00-3.88) and cob weight (3.00-3.91). Interestingly, Hyderabad and Dharwad recorded high and Coimbatore and Karimnagar recorded low diversity indices for all the traits studied. Hyderabad emerged as the location that was able to resolve the diversity better among the hybrids with high diversity Indices for all the traits. The plausible explanation for this could be that the constitution of singly cross hybrid (SCH) involves, crossing between two fixed inbred lines to express maximum hybrid vigour. The two inbred parents involved in the constitution of the hybrids may involve/ germplasm from temperate background and tropical inbred lines- which are highly likely to report high yields by maximized hybrid vigour. In such scenarios, the better resolution or expression of the hybrids constituted by temperate x tropical inbred lines is thereby facilitated by optimum temperature range that is suitable for both temperate and tropical origin genetic material. The temperature recorded at Hyderabad location during the crop growing season ranged from 16.5-37.0°C which is optimum for maize growth, which is resulted optimum expression of growth and development among the all the hybrids hence helping in efficient resolution of diversity, as the hybrids may be having both temperate and tropical blood, whereas the maximum and minimum temperatures recorded at Karimnagar location ranged from 27-33.0°C, at Dharwad it was 20-32.0°C and at Coimbatore 23-34.0 °C. The similarity of diversity of centres is mainly related to the temperature variations in that specific location. The present study highlighted the use of DIVA-GIS tool could be employed in the identification of geographic regions which could be most suitable for maize. Further, an international CGIAR organization working on maize-

Table 1 - Diversity indices range recorded for traits of maize hybrids

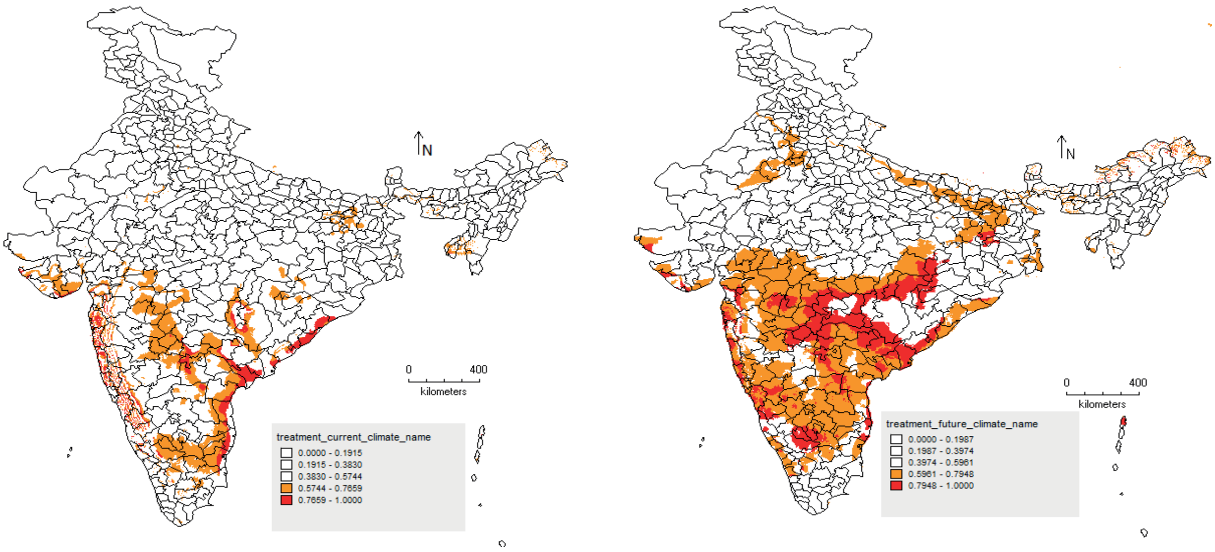
Trait	Coimbatore	Dharwad	Hyderabad	Karimnagar
Plant height	3.99 - 5.00	3.99 - 5.00	3.99 - 5.00	3.00 - 3.88
Cob number	2.00 - 2.81	2.81 - 2.86	2.95 - 3.00	2.95 - 3.00
Days to 50% Pollen	2.00 - 2.47	2.00 - 2.47	2.73 - 3.00	2.47 - 2.56
Days to 50% Silking	2.00 - 2.47	2.47 - 2.55	2.71 - 3.00	2.47 - 2.55
Days to 75% maturity	2.00 - 2.53	2.69 - 3.00	2.69 - 3.00	2.00 - 2.53
Cob weight (g)	3.97 - 4.00	3.91 - 3.93	3.97 - 4.00	3.00 - 3.91

CIMMYT has an office at Hyderabad, India possibly because of this reason. The present study also highlights resolving extent of variability among the traits from varied ecosystems in maize, which can be used for delivering improved cultivars in general and specifically by geographic location, which could be more relevant so in the light of challenge due to climate change. Cairns (2013) reported that maize systems to future climates require the ability to accurately predict future climate scenarios in order to determine agricultural responses to climate change and set priorities for adaption strategies. DIVA-GIS mapping may be effectively used for diversity analysis, distribution pattern and for developing new strategies for conservation, particularly in the wake of recent international developments related to food and nutritional security. GIS mapping has been successfully used in assessing biodiversity and in identifying areas of high diversity in Phaseolus bean (Jones *et al*.. 1997), wild potatoes (Hijmans *et al*.. 2000, 2003), horse gram (Sunil *et al*. 2008), Jatropha curcas (Sunil *et al*.. 2009), linseed (Sivaraj *et al*.. 2009), black gram (Abraham *et al*.. 2010), Canavalia fatty acids (Sivaraj *et al*. 2010), onion (Kamala Venkateswaran *et al*. 2011), medicinal plants (Varaprasad *et al*. 2007) and agro biodiversity (Varaprasad *et al*. 2008).



Plant height — Days to 50% pollen shed — Days to 50% silking — Days to 75% maturity — Number of cobs — Cob weight

Fig. 1 - Diversity analysis among maize hybrids for various traits



A B

Fig. 2 - MaxEnt model generated for identifying climate suitable locations for growing maize hybrids, Current Climate (A) and Future Climate, 2050

MaxEnt Analysis

Maximum Entropy (MaxEnt) is a niche modelling approach that has been developed linking species distribution information built only on identified presences and is a general-purpose method for making predictions or inferences from incomplete information. MaxEnt can take the environmental conditions at occurrence locations and produce a probability distribution that can then be used to assess every other location for its likely occurrence. The result is a map of the probability of conditions being favourable to occurrence. It estimates target probability climate suitable sites for cultivation developed maize hybrids in India by finding the highest probability of climate suitability of the maximum entropy (i.e., most spread out or closest to uniform with indication to a set of bioclimatic variables).

Fig. 2 depicts the MaxEnt model for potential climate suitable sites for cultivation of all the 62 maize hybrids based on the present and future climate scenario, respectively in India. Warmer colours indicate the highest probability of suitable climate location in India for maize cultivation. Parts of Andhra Pradesh, Assam, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Pondicherry, Tamil Nadu, Telangana and Tripura are the potential regions under current climatic conditions (Fig. 2A). In addition, parts of Arunachal Pradesh, Bihar, Sikkim and Rajasthan would be the highly suitable regions for growing maize hybrids in future as inferred from MaxEnt niche modeling (Fig. 2B).

Maximum entropy (MaxEnt) is considered as the most accurate model performing extremely well in predicting occurrences in relation to other common approaches (Elith *et al.* 2006; Hijmans and Graham, 2006), especially with incomplete information. MaxEnt is a niche modelling method that has been developed involving species distribution information based only on known presences. MaxEnt is a niche modelling method and was selected to model potential current and future climate suitability for cultivation of maize hybrids in the present study. MaxEnt has been successfully used by many researchers earlier to predict distributions such as stony corals (Tittensor *et al.* 2009); green bottle blue fly (Williams *et al.* 2014); (macro fungi (Wollan *et al.* 2008); seaweeds (Verbruggen *et al.* 2009); forests (Carnaval and Moritz, 2008); rare plants (Williams *et al.*, 2009) and many other species (Elith *et al.*, 2006). Several articles describe its use in ecological modelling and explain the various parameters and measures involved (Philips *et al.* 2004, 2006; Elith *et al.* 2011). Reddy *et al.* (2015 a, b) presents a novel approach to assess the potential areas for extending the cultivation of Roselle and Ceylon spinach using MaxEnt with regional-level occurrence data. The identified districts/states in the present study could be targeted for selection of cultivation sites of maize hybrids based on climate suitability and for managing other related genetic resources activities.

Conclusions

The use DIVA-GIS and MaxEnt generated models to identify most suitable geographic locations and diverse traits; predicting the potential growing regions of maize hybrids is highly desirable to enhance productivity, expansion of crop area and management opportunities in the country.

Acknowledgments

The authors are thankful to the Director, ICAR-IIMR, Ludhiana and Project Coordinator AICRP on Maize for providing the necessary facilities and support for carrying out the above work

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Supplementary Table 1

Sno.	TREATMENT NAME	Coimbatore (Latitute: 11 .1.23.1595; Longitute: 76.55.42.599)						Dharwad (Latitute :15.48; Longitude: 74.98)						Hyderabad (Latitute: 17.32; Longitude: 78.40)						Karimnagar (Latitute: 18.30; Longitute: 79.15)					
		Plant height (cm)	Cob number	Days to 50% Pollen	Days to 50% Silking	Days to 75% maturity	Cob weight per plot (g)	Plant height (cm)	Cob number	Days to 50% Pollen	Days to 50% Silking	Days to 75% maturity	Cob weight per plot (g)	Plant height (cm)	Cob number	Days to 50% Pollen	Days to 50% Silking	Days to 75% maturity	Cob weight per plot (g)	Plant height (cm)	Cob number	Days to 50% Pollen	Days to 50% Silking	Days to 75% maturity	Cob weight per plot (g)
1	QMH 1590	192,50	29,33	56,00	59,33	98,67	5,83	190,07	39,33	62,00	65,33	107,33	4,21	173,67	36,67	60,67	63,00	102,33	3,09	106,33	29,67	60,67	63,67	105,67	2,58
2	AH 8323	203,50	32,00	55,67	58,33	97,33	7,28	211,60	37,67	62,00	64,00	105,33	6,01	188,00	40,00	60,33	62,33	102,00	4,80	128,00	32,50	61,00	63,50	105,50	3,14
3	GK3124	198,40	32,33	56,67	59,00	98,00	6,95	200,80	38,67	62,00	63,67	106,00	5,69	200,00	37,00	57,00	59,00	99,33	5,02	115,00	30,67	59,33	62,00	104,00	3,21
4	PM18106L	212,30	33,67	57,33	60,00	98,33	7,96	201,13	39,67	63,33	65,33	107,00	6,52	219,33	35,67	62,33	64,33	103,33	5,55	129,33	36,00	60,67	63,33	105,33	4,74
5	Filler (DHM-117)	208,50	30,00	56,67	59,00	97,67	6,58	206,60	41,50	62,00	64,50	107,50	4,79	206,33	36,00	61,67	64,67	104,33	4,26	128,33	34,00	60,00	63,00	105,00	3,02
6	JH 16224	202,40	32,33	57,67	61,00	100,67	6,70	214,07	38,33	62,67	64,67	106,67	5,25	201,33	40,33	62,67	65,00	104,67	5,94	121,00	37,67	59,00	62,00	104,00	3,25
7	PM18105L	207,87	31,00	55,67	59,33	97,67	7,45	202,60	39,67	63,67	66,00	108,00	5,24	183,47	37,67	60,67	62,67	102,00	4,83	129,33	32,67	62,33	65,00	107,00	4,01
8	NK 6240 ©	198,97	32,67	55,00	57,67	96,67	7,08	204,40	40,00	61,50	64,50	106,00	4,82	184,33	39,67	59,67	62,00	101,67	4,70	122,33	31,67	60,33	63,33	105,33	3,31
9	AH 8087	198,40	30,33	57,00	60,00	98,67	6,60	212,07	39,00	63,67	66,00	108,33	5,48	190,00	40,00	61,33	63,33	103,00	4,53	129,67	31,33	59,67	62,67	104,67	4,02
10	STARX-5	204,43	29,67	56,00	58,67	97,67	6,57	189,00	38,50	63,50	66,00	108,50	4,64	191,00	35,33	58,00	60,67	100,67	5,27	105,33	31,00	62,67	65,67	107,67	3,32
11	X5873	198,63	33,00	55,33	59,00	98,00	8,12	194,80	34,00	61,50	64,50	105,50	4,05	195,00	39,00	59,00	60,33	100,33	6,17	112,00	32,00	61,00	63,67	105,67	2,86
12	CP808 SUPER	187,63	29,00	54,67	58,33	97,00	6,48	182,93	34,67	63,67	65,67	108,67	3,59	176,80	38,33	61,67	64,00	104,00	5,18	110,33	32,67	61,67	64,33	106,33	2,77
13	QMH1571	187,33	29,67	56,67	59,67	99,00	6,44	192,60	39,00	63,33	64,67	106,33	4,75	189,00	32,00	61,33	63,67	103,67	2,94	111,50	32,00	59,00	61,50	103,50	3,30
14	DH-315	174,07	26,67	57,67	60,67	100,33	5,89	230,27	38,33	63,33	65,33	108,00	6,92	180,67	38,33	61,00	63,67	103,67	4,47	115,00	30,33	62,00	65,00	107,00	2,98
15	SUPER-4050	202,07	33,00	55,33	58,67	97,67	7,74	236,50	39,50	65,00	66,00	105,50	5,82	199,00	37,67	58,33	60,33	100,33	6,03	126,00	29,00	60,67	63,33	105,33	3,63
16	SYN816514	206,77	33,33	58,00	61,33	100,33	7,82	242,00	38,33	64,33	66,33	106,00	7,10	182,47	39,33	63,33	65,67	105,33	4,63	144,33	32,33	61,00	63,33	105,33	3,82
17	PM18102L	221,73	32,67	58,33	60,67	100,00	7,68	225,33	39,33	63,67	65,33	109,00	4,33	194,33	35,33	61,67	64,00	104,33	5,32	125,00	30,33	61,33	64,33	106,33	2,97
18	CMH 08-287 ©	199,20	32,00	56,67	58,67	97,33	7,43	213,00	37,00	62,00	63,50	105,00	5,37	214,33	39,00	61,00	63,00	103,00	6,16	127,67	31,33	61,33	64,33	106,33	3,55
19	KNMH-4185	206,40	33,00	56,33	59,33	97,67	7,08	221,30	40,00	63,50	65,50	108,00	5,63	201,00	31,00	62,33	64,33	104,33	4,29	118,00	32,33	60,67	63,33	105,33	3,33
20	AH 1625	209,20	32,33	55,67	58,67	97,33	7,42	211,67	38,33	63,33	65,33	105,00	5,85	206,33	39,00	61,67	63,67	103,00	5,84	110,67	31,67	62,33	64,67	106,67	2,98
21	CMH14-722	191,17	31,33	57,33	60,00	99,00	6,71	206,13	38,33	65,00	66,33	109,00	4,85	188,13	39,67	60,67	62,67	102,67	5,11	116,67	30,33	60,67	63,67	105,67	3,46
22	OMH 17-2	203,30	30,67	56,67	59,67	98,00	7,27	208,87	38,67	63,33	65,33	108,00	6,63	202,00	35,67	60,67	63,00	102,00	4,24	125,67	32,33	60,00	62,33	104,33	4,36
23	HT18007	195,87	31,67	56,67	59,67	98,67	6,92	216,00	38,00	62,50	66,00	109,50	4,24	183,00	33,67	62,67	64,67	104,67	3,98	114,00	31,33	60,33	62,67	104,67	3,52
24	PM18101L	207,07	33,67	56,00	58,67	97,33	8,57	211,60	30,67	63,33	65,00	105,33	5,20	181,67	37,67	59,67	61,67	101,67	5,61	128,67	32,00	58,33	61,33	103,33	4,26
25	MM9207	202,87	31,00	55,67	58,67	97,67	6,67	209,87	38,00	62,67	64,00	105,67	5,96	198,33	35,67	59,67	62,33	102,33	5,28	127,00	31,67	59,00	62,00	104,00	3,49
26	BH416112	201,97	27,33	56,00	58,67	97,67	5,60	213,47	36,00	63,67	65,67	106,33	6,34	201,87	32,00	60,00	62,00	102,33	5,70	134,00	28,67	62,00	64,33	106,33	3,41
27	JH 17029	207,10	30,33	55,00	58,00	97,00	7,70	207,33	35,00	63,67	65,67	109,00	4,81	194,33	39,33	59,33	61,67	101,67	4,93	128,33	29,33	60,67	63,00	104,67	3,66
28	JKMH1581	201,83	30,67	56,67	59,67	98,33	6,92	201,60	40,00	62,00	64,33	106,00	3,85	211,33	30,67	62,00	64,33	104,00	5,37	100,33	29,67	58,67	61,33	103,33	2,50
29	IMHSB-17K-08	207,07	29,33	59,33	62,00	101,00	6,75	242,73	40,33	64,33	67,00	107,33	6,63	195,60	32,00	61,33	63,33	103,33	4,59	118,33	34,67	60,67	63,67	105,67	4,12
30	MAH-14-239	192,17	31,33	55,67	58,67	97,00	6,34	212,47	37,67	63,00	65,33	106,33	5,71	171,00	31,00	57,00	59,00	99,00	3,40	113,00	33,33	59,33	61,67	103,67	3,93

Supplementary Table 1

31	BLH137	208,77	33,67	57,00	60,00	99,00	8,32	222,80	38,50	63,50	66,50	105,50	5,63	199,67	39,33	61,33	63,67	103,00	6,42	125,00	30,67	61,00	63,67	105,67	3,30
32	KNMH-4187	178,97	29,67	55,33	58,33	97,33	6,56	211,60	39,33	64,00	66,67	109,33	5,54	192,93	34,50	58,00	60,50	101,50	5,74	110,33	34,00	59,33	62,00	104,00	3,33
33	KMH-005	214,07	32,67	58,33	61,33	101,33	8,77	221,50	39,50	65,00	67,00	110,00	6,33	211,20	38,33	61,67	63,67	103,67	5,68	126,67	31,67	62,33	64,67	106,67	4,00
34	BIO 534	198,40	33,00	56,00	58,67	98,00	7,92	231,33	40,33	63,67	66,00	110,00	7,00	195,33	39,00	58,67	60,33	100,33	5,84	134,67	32,00	61,00	63,00	105,00	4,27
35	JH 15002	213,10	32,33	58,00	61,00	100,67	7,68	197,60	40,67	62,00	65,67	106,67	5,11	212,33	33,67	62,67	64,67	104,33	6,21	100,33	31,67	58,67	62,00	104,00	2,52
36	PM18103L	225,97	33,33	57,67	60,67	100,00	8,06	232,33	36,00	62,00	64,67	105,67	5,97	211,33	38,67	62,33	64,00	102,67	5,49	137,00	31,33	58,67	61,67	103,67	3,70
37	Rasi 70197	180,87	31,00	55,33	57,67	96,33	7,36	220,60	39,00	64,33	66,33	109,00	6,90	178,00	36,00	59,00	61,33	101,67	4,82	122,00	29,00	60,67	63,00	105,00	3,12
38	CMH 08-282 ©	202,10	32,33	56,33	59,00	98,00	7,54	189,87	39,00	63,33	66,00	107,33	7,60	204,00	36,67	58,00	60,33	100,33	5,55	103,33	30,00	60,00	63,00	105,00	3,12
39	MM2033	197,50	32,67	55,00	58,00	97,00	8,04	202,93	39,33	63,33	65,33	105,33	5,84	195,67	29,33	60,67	63,33	103,33	4,85	113,67	34,33	60,00	62,67	104,67	5,21
40	KMH-1(CAH1612)	173,17	28,67	57,00	59,67	98,67	6,29	225,00	38,67	62,00	64,00	105,33	6,17	176,00	37,67	59,67	62,00	102,33	5,79	124,67	33,67	58,33	61,00	103,33	3,89
41	Rasi 4992	184,00	32,00	56,33	59,00	97,67	7,88	199,40	30,00	62,33	65,67	107,33	4,14	208,67	40,00	60,67	62,67	103,00	6,89	119,00	31,00	58,67	61,33	103,33	3,47
42	JH 16026	208,53	31,33	55,33	57,67	96,67	7,47	194,80	39,67	63,67	65,67	106,00	5,67	180,33	39,33	59,00	61,00	100,33	4,65	109,00	34,00	60,67	63,33	105,33	3,09
43	BRMH-16039	185,63	27,67	56,33	59,33	98,67	5,72	220,07	39,67	63,67	65,67	108,33	6,56	192,00	35,67	57,33	59,67	99,67	4,91	125,33	30,67	60,33	63,33	105,33	3,42
44	MM2828	187,17	30,33	56,00	58,33	97,00	7,90	204,93	38,67	63,33	66,67	108,00	5,85	170,67	33,67	60,00	62,00	102,00	3,60	105,67	33,00	60,33	63,33	105,33	3,15
45	BIO 536	189,83	31,00	58,00	61,00	99,67	6,58	222,00	39,33	63,00	65,33	109,00	7,77	190,33	38,67	60,00	62,33	102,33	4,80	132,00	29,33	62,33	64,67	107,00	4,32
46	PHM1801 (CAH1801)	183,30	31,00	56,33	59,00	97,67	6,78	205,07	38,33	64,67	66,00	106,67	4,85	171,00	40,67	61,00	63,33	102,67	4,92	106,33	33,00	60,33	62,67	104,67	3,84
47	PM18104L	197,97	29,67	58,33	61,33	100,67	7,10	199,40	39,50	62,50	64,50	108,00	4,85	216,00	38,33	63,00	65,00	104,67	5,13	108,00	34,33	60,33	63,00	105,00	4,09
48	BIO 9682 ©	182,83	33,00	55,67	58,67	97,33	8,18	188,60	38,50	63,00	66,50	105,50	4,49	178,67	40,00	59,67	62,00	102,00	5,89	103,33	32,33	62,00	64,67	106,67	3,66
49	X5826	175,30	30,33	55,67	58,00	96,67	7,55	230,53	37,00	64,00	65,33	107,67	5,21	174,87	33,33	61,33	64,00	104,00	4,72	118,00	28,67	60,00	63,00	105,00	3,05
50	IMHVS-005	186,00	33,67	56,00	58,00	97,00	8,29	234,27	39,00	62,33	65,00	106,33	6,02	180,67	38,67	63,00	65,00	103,33	4,78	131,00	33,33	61,33	64,00	106,00	4,66
51	TS2601	204,93	31,00	58,00	60,67	100,33	7,03	198,13	31,33	64,67	67,00	105,33	3,03	190,67	39,33	61,00	63,67	103,67	4,41	116,33	31,67	60,67	63,33	105,33	2,54
52	BLH135	201,40	31,67	56,67	59,33	98,33	7,29	218,07	39,00	62,33	64,33	105,33	5,61	211,00	40,00	62,00	64,67	104,33	4,92	135,33	31,00	59,67	62,33	104,67	3,86
53	HKH-366	202,77	29,00	55,33	58,33	96,67	6,06	197,73	37,33	63,67	65,33	107,33	6,33	189,33	36,00	61,67	64,00	104,00	3,27	110,33	29,33	60,67	63,33	105,33	3,46
54	JH 17026	220,03	32,00	56,00	58,67	97,67	7,42	192,73	30,67	63,00	65,33	106,00	3,34	213,67	37,33	60,00	62,33	102,33	5,13	89,67	28,00	58,67	61,33	103,33	3,02
55	ADV 7132	196,77	31,00	57,33	60,33	99,67	7,53	206,87	39,67	60,33	43,67	106,00	4,78	188,67	35,67	61,33	64,00	102,67	4,69	124,00	33,00	59,33	61,67	103,67	3,89
56	MFH18-14	182,27	28,00	55,67	59,00	97,67	5,36	193,20	39,00	64,00	65,67	107,33	4,67	186,27	32,33	56,00	58,00	98,00	4,45	105,00	30,67	60,33	63,33	105,33	2,73
57	GK3164	207,40	32,33	56,33	59,67	98,33	7,59	198,53	40,00	64,33	66,00	107,67	3,67	196,00	38,33	58,00	60,33	100,33	5,74	102,67	33,67	63,33	63,00	105,00	3,96
58	TS2505	195,53	32,33	56,67	59,00	97,67	7,62	215,13	38,33	62,33	63,67	105,67	5,37	192,33	35,00	62,00	63,67	103,67	3,83	138,33	30,67	58,67	61,33	103,33	3,02
59	FAUJI	181,63	32,33	55,00	58,33	97,33	7,48	188,60	39,00	62,33	64,33	105,67	4,14	186,33	40,00	61,33	64,00	104,00	5,23	118,67	30,67	59,33	61,67	103,67	3,18
60	JH 17014	197,07	31,00	55,33	58,33	97,33	6,59	214,87	37,67	63,67	66,00	106,33	5,34	183,33	37,33	58,33	60,33	100,67	3,58	128,00	31,67	59,00	62,00	104,00	3,72
61	MAH-14-138	182,17	30,33	56,33	59,33	98,00	6,75	214,13	38,67	64,00	65,00	106,33	5,97	175,33	36,67	60,00	62,00	102,33	3,67	126,50	32,33	61,00	63,67	105,00	3,89
62	CMH14-716	199,20	33,00	56,67	59,33	98,33	8,14	214,00	36,00	64,00	66,50	107,00	4,94	209,33	35,33	59,33	61,67	102,00	6,31	127,00	31,00	61,00	64,00	106,00	3,39