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ECOLOGICAL *NICHE* MODELING TO IDENTIFY CULTIVATION AREAS FOR PINEAPPLE IN THE REPUBLIC OF BENIN

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ABSTRACT

Pineapple is one of the most important tropical fruit species, widely cultivated and economically important in Benin. This study aimed to identify potentially favorable areas for the cultivation of pineapple under current and future environmental conditions in Benin. The two cultivars of pineapple grown in Benin were separately considered: Sugarloaf and Smooth Cayenne. Five (05) modeling algorithms such as Maxent, Random Forest (RF), Support-Vector Machines (SVM), Boosted Regression Trees (BRT) and Generalized Linear Model (GLM) were compared using the criteria: area under the curve (AUC), sensitivity, specificity, Cohen's Kappa, deviance and True Skill Statistic (TSS). The future climate models available for Africa at horizon 2055 were used under the "Representative Concentration Pathways" scenario 4.5 and 8.5. Results suggested that pineapple suitable areas were governed by a combination of effects of climate (temperature and precipitation) and soils characteristics. Indeed, soil pH, temperature seasonality and precipitation of driest quarter were the main variables driving pineapple production in Benin. Results also indicated that RF was the most suitable technique to model the distribution of pineapples regardless of the variety. The current potential range of favorable areas for the two varieties was mainly found in the central and southern parts of the country. In the future, following the RCP4.5 scenario, there will be an increase in the area favorable for the cultivation of Smooth Cayenne variety by 5.28% compared to the current situation whereas, the area favorable for the cultivation of the Sugarloaf variety will be increased by 7.7%. However, suitable areas for cultivation of Smooth Cayenne and Sugarloaf following the RCP8.5 *scenario* will be increased, respectively by 21.82% and 31.64%. The low and medium suitability areas for the cultivation of smooth cayenne will decrease by 15.57% and 2.93%, respectively at the horizon 2055 with future conditions under RCP4.5, and 15.48% and 4.97%, respectively at the horizon 2055 with future conditions under RCP8.5. For sugarloaf, the low and medium suitable cultivation areas will decrease by 1.59% and 14.24, respectively at the horizon 2055 with future conditions under RCP4.5. According to RCP8.5, the low suitable areas will decrease by 5.08%. This study constitutes an initial step towards a sustainable scheme for planning exploration of the possibility of extending pineapple cultivation in Benin.

Key words: Climate change, modeling, algorithms, pineapple, potential area distribution

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RESUME

L'ananas est l'une des espèces fruitières tropicales les plus importantes, largement cultivée et économiquement importante au Bénin. L'étude visait l'identification des zones potentiellement favorables à la culture de l'ananas dans les conditions environnementales actuelles et futures au Bénin. Les variétés d'ananas cultivées au Bénin ont été considérées séparément: Pain de Sucre et Cayenne Lisse. Cinq algorithmes de modélisation: Maxent, Random Forest (RF), Support-Vector Machines (SVM), Boosted Regression Trees (BRT) et Generalized Linear Model (GLM) ont été comparés selon les critères: l'aire en dessous de la courbe (AUC), la vraie statistique de compétence (TSS), la statistique de Kappa, la sensitivité et la spécificité. Les modèles de climat futur disponibles pour l'Afrique à l'horizon 2055 ont été utilisés dans le cadre des scénarios RCP 4.5 et RCP 8.5. Les résultats ont suggéré que les zones propices à l'ananas sont régies par la combinaison des effets du climat et des caractéristiques des sols. Le pH du sol, la saisonnalité des températures et les précipitations du quart le plus sec sont les principales variables déterminant la production d'ananas au Bénin. Les résultats ont indiqué aussi que l'algorithme RF était la plus appropriée pour modéliser la distribution de l'ananas quelle que soit la variété. L'aire de répartition potentielle actuelle des deux variétés se trouve principalement dans le centre et le sud du pays. Dans le futur, suite au scénario RCP4.5, on observera une augmentation de la superficie favorable à la culture de la variété Cayenne Lisse de 5,28% par rapport à la situation actuelle alors que la superficie favorable à la culture de la variété Pain de sucre sera augmentée de 7,7%. Cependant les superficies propices à la culture de Cayenne Lisse et de Pain de Sucre suivant le scénario RCP8.5 augmenteront respectivement de 21,82% et 31,64%. Les zones d'aptitude faible et moyenne à la culture de la cayenne lisse diminueront respectivement de 15,57% et 2,93% à l'horizon 2055 avec des conditions futures sous RCP4.5 et de 15,48% et 4,97% respectivement à l'horizon 2055 avec des conditions futures sous RCP8.5. Pour le pain de sucre, les zones d'aptitude faible et moyenne diminueront respectivement de 1,59% et 14,24 à l'horizon 2055 avec les conditions futures sous RCP4.5. Selon le RCP8.5, les faibles surfaces convenables diminueront de 5,08%. Cette étude constitue une première étape vers une gestion durable en explorant les possibilités d'extension de la culture de l'ananas au Bénin.

Mots clés: Changement Climatique, modélisation, algorithmes, ananas, zones potentielles de distribution

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INTRODUCTION

World agricultural production has to be increased by 70% in the next 30 years to keep pace with the burgeoning population [1]. However, this production must be achieved in an environmentally-friendly condition which reduces the impacts of climate changes on agriculture. As such, there will be a need to minimize greenhouse gases emission, and pesticides and fertilizer use [2].

Climate changes refer to a long-term change in average weather conditions. Climate change occurs due to internal changes within the components of the climate system or in the interaction among those components, or because of changes in external forcing, either for natural reasons or human-induced activities [3]. Regional climate models project an increase in average temperatures, as well as change in precipitation patterns including the introduction of frequent and prolonged droughts [4]. This could have drastic consequences on sensitive crops like pineapple. It is therefore urgent to explore potential zones for probable cultivation of pineapple in order to diversify the present production areas of the crop.

Pineapple (*Ananas comosus* (L.) Merrill) is the second most important tropical fruit after banana in West Africa [1]. In that region, Benin constitutes the second-largest producer of pineapple after Nigeria and its production was 355 854 t in 2019 [5] contributing to 4.3% to agricultural GDP in 2017. In Benin, pineapple is grown in the southern part, mainly in the Atlantic Department and it is considered as a strategic crop since its selection in 2006 to be among potential crops to alleviate poverty [6]. Two pineapple varieties are grown in Benin: Sugarloaf and Smooth Cayenne. This intensive cultivation in a single area in the country increases the pressure and risk of soils degradation due to the heavy use of fertilizers. Pineapple consumes large amounts of nutrients and chemical fertilization that represent a large part of the total production costs [7]. This constitutes a limit for sustainable agricultural production in the long term.

Species distributions models (SDMs), also known as bioclimatic envelope models, ecological niche models, and habitat suitability models, explore the relationship between geographical occurrences of species and corresponding environmental variables [8, 9]. These models have been extensively applied to evaluate the cultivability of several tropical plant species [10, 11, 12,13]. Moreover, potential range (expansion or contraction) of suitable areas for plant species under current and future climates can be estimated using ecological niche modeling [14, 15]. Ecological niche modeling (ENM) approach was implemented to identify suitable areas for the production of Sugarloaf and Smooth Cayenne pineapples across Benin. The aim was to test whether certain areas other than the current production areas are effective for both varieties production, while depicting the relationships between the varieties and environmental dimensions.

MATERIALS AND METHODS

Study area and pineapple cultivars

This study was carried out in Benin (6–12°50'N and 1–3°40'E), sub-Saharan Africa. The country is divided into eight agro-ecological zones (Figure 1) from the north to the south following climate, soils, vegetation characteristics, and cultivation systems in each zone [16]. These agro-ecological zones are: the "extreme north Benin zone"; the "cotton farming zone of North Benin"; the "food-producing zone of South Borgou"; the "West Atacora zone"; the "cotton farming zone of the center"; the "Alluvial soils zone" located south of Benin; the "Zone of depression" and the "Zone of fishery" (Figure 1; [16]). The Atlantic department is currently the highest pineapple areas, and is located in the alluvial soils zone. Average temperatures ranging between 27 and 31°C are favorable for pineapple growth since it has been found that pineapple growth decreases rapidly at mean temperatures below 15°C and above 32°C [17] or below 10°C and above 35°C [18]. The mean annual rainfall of 1200 mm is favorable for pineapple growth and development because optimum rainfall for good commercial pineapple cultivation ranges from 1000 mm to 1500 mm [19]. The soil characteristics (good drainage and pH ranging from 5.5-6.0, are favorable because the best soils for pineapple culture have a neutral to acid pH with good drainage [20] in order to prevent water logging and root diseases.

In Benin, the two mostly cultivated pineapple cultivars are: smooth cayenne and sugarloaf. Smooth Cayenne accessions in Benin are characterized by smooth or partially spiny leaf, medium-sized fruits (1–2 kg) to large-sized fruits (up to 4 kg), cylindrical to oval shape, with large flat eyes and light-yellow flesh that was sweet and fibrous. The total soluble solids were high (12–16 °Brix). The fruit ripened steadily, turning yellow from the base [21]. Twenty accessions of 'Pérola' were also collected, commonly called 'Sugarloaf' or its French equivalent 'Pain de Sucre'; the plant was erect and medium-sized with spiny green leaves, and basal slips surrounding the medium-sized fruit. The latter, borne on a long peduncle, was dark green and turned to yellow when ripe, with an irregular conical or pyramidal shape; the flesh was white to pale yellow, firm, juicy and sweet, ranging from 10 to 16 °Brix. There were many slips, from four to more than twelve [21].

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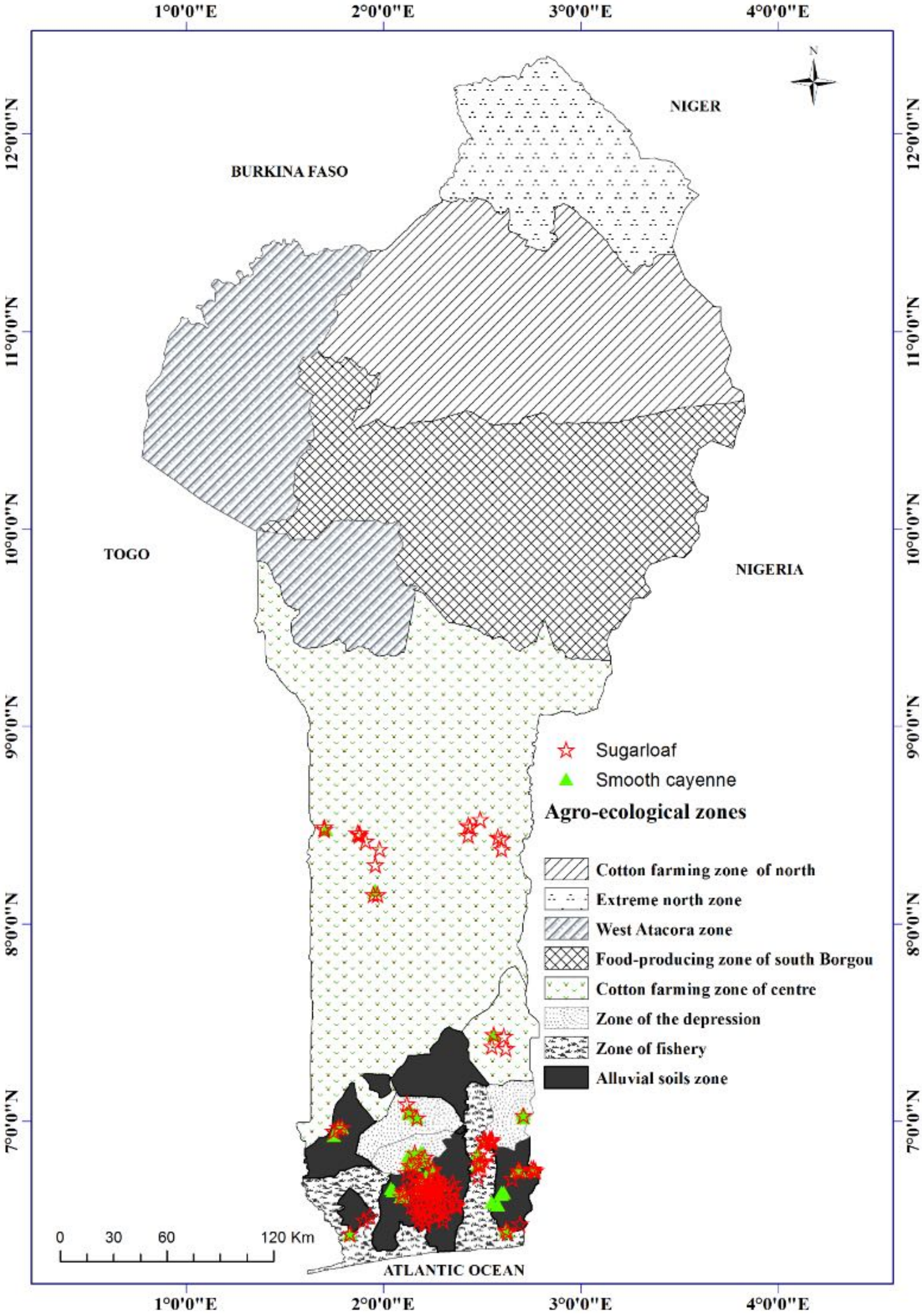


Figure 1: Benin agro-ecological zones and occurrence pattern of *Smooth cayenne* and *Sugarloaf*

Occurrence data

An extensive search was made across the country to gather records of the two varieties of pineapples (Sugarloaf and Smooth Cayenne) on the field in each agro-ecological region. On the field, mega-transects of 10 km length and 50 m width were used to collect data on both varieties. Occurrence data of the species were then collected in 22 (twenty-two) districts distributed across Benin. The districts located in the Sudanian zone were not investigated because of the climatic and soil conditions which could not favor the development of pineapple. Two (02) or three (03) mega-transects were done at each district for field surveys. The transects were chosen to cross the main agricultural areas and were crossed if possible. The main roads were used to reach districts and secondary roads to get access to the localities and areas holding the species. The choice of secondary roads for prospecting was made with the help of local people who have knowledge of the potential areas of the presence of the two varieties to maximize the number of occurrence records. Records of each variety were collected separately (Figure 1). Duplicate records were identified and removed with ENM tools (www.ENMTools.com). Overall, 127 and 63 records were obtained for Sugarloaf and Smooth Cayenne, respectively.

Environmental variables

Climatic data was downloaded from the Africlim database [22] at a spatial resolution of 30 arc sec (https://webfiles.york.ac.uk/KITE/AfriClim/). In addition, the soil characteristics were collected from global data on ISRIC Soil Database (www.isric.org [23, 24]) as follows: pH-H_2O, Cation Exchange Capacity (CEC), Sand, Silt, Organic carbon, Clay, and Bulk. The layers were used at different horizons (0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, and 60-100 cm). Both climate and soil layers were obtained at a fine spatial resolution of 30 arc sec (~ 1km).

Future climate layers were obtained for the RCP 8.5 (most drastic views of future conditions) and the RCP 4.5 (the most optimistic view). RCP implies collaboration between impacts, adaptation, and vulnerability research, climate, and integrated assessment modelling [25]. Due to uncertainty in observational baselines (future anomalies) in four different main bioclimatic variables; mean temperature of wettest quarter, mean temperature of driest quarter, precipitation of warmest quarter, precipitation of coldest quarter [22]. The 15 most steady remaining climatic variables (Table 1) were used to establish the relationships between the varieties and environmental dimensions.

Model development

The Jackknife test was used to provide alternate estimates of the most important variables in the model development and it also gives a qualitative idea of the independence of the variables considered. Five frequently used algorithms to develop models were compared: Maximum Entropy (Maxent, [26]), Random Forest (RF, [27]), Support-Vector Machines (SVM, [28]), Boosted Regression Tree (BRT, [14]), Generalized Linear Model (GLM, [29]). To select the insightful algorithm, the area under the curve (AUC, [30]), sensitivity [30], specificity [30], Cohen's Kappa [30], deviance and True Skill Statistic (TSS, [30]) were focused on. To estimate the suitable areas for pineapple (Smooth Cayenne and Sugarloaf) cultivation in the present-day and under future climates, the out-performing algorithm was used. Suitable areas for the cultivation of both varieties of pineapple yield in Benin under current and future climatic conditions were mapped using ArcGIS 10.1 software.

RESULTS AND DISCUSSION

Selection of environmental variables for Smooth Cayenne

A total of eight environmental variables mostly contributing to the model were selected (Table 2): precipitation from the wettest period (Bio13), precipitation of driest period (Bio14), seasonality of precipitation (Bio15), precipitation of driest quarter (Bio17), and four soil variables (pH_{H2O}, Clay, Bulk and Silt). In addition, the Jackknife test showed that the environmental variable with highest gain of information when used in isolation was precipitation of driest quarter, which, therefore appeared to have the most useful information by itself. The environmental variable that decreased the gain the most when it was omitted was pH_{H2O}, which, therefore appeared to have the most information that wasn't present in the other variables (Figure 2). Then, soil pH and precipitation of driest quarter remained the variables that hold more information not contained in the others which explained suitable areas distribution of cultivation of Smooth Cayenne.

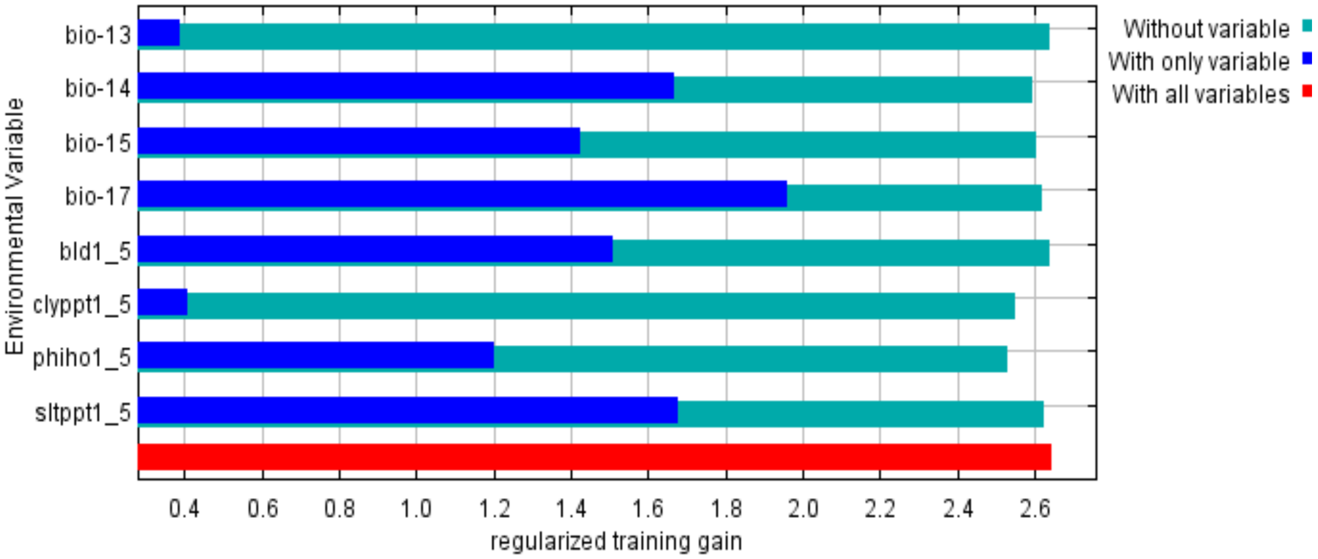


Figure 2: Jackknife test result on contribution of *Smooth Cayenne* models

Selection of environmental variables for the Sugarloaf

Model results showed that different combinations of environment variables ruled the distribution of each variety of pineapple cultivated in Benin. Distribution of the Sugarloaf variety was mainly driven by four climatic variables and four soil variables: Mean diurnal range (Bio2), Temperature seasonality (Bio4), Precipitation of the driest period (Bio14), Precipitation of the driest quarter (Bio17) as climatic variables and pH, Silt, Sand and Bulk as soil variables. Temperature seasonality and pH were variables that mostly contributed to the models (Table 3). The Jackknife test showed that the environmental variables that significantly decreased the gain the most when it was omitted was mean diurnal range among climate variables and pH among soil variables (Figure 3). Soil pH and average day time deviation (maximum temperature - minimum temperature, monthly average), therefore appeared to have the most information that was not present in the other variables. At the same time, the environmental variable with the highest gain when used in isolation was precipitation of the driest period, which, therefore, appeared to have the most useful information by itself.

These environmental variables selected as driving pineapple potential areas of distribution are consistent with the ecology of the species. It has been found that pineapple growth decreases rapidly at mean temperature below 10°C and above 35°C [18], optimum annual rainfall for good commercial pineapple cultivation ranges from 1000 mm to 1500 mm [19], and the soil characteristics, good drainage in order to prevent water logging and root diseases and a neutral to acid pH [31] are favorable for pineapple cultivation. These optimal conditions explain why the range of pineapple was higher below 7°50 latitude North of the study area. That zone has a mean annual rainfall of 1200 mm and it is covered by one major group of soils which is acrisol [32]. This type of soil is characterized by very deep soil and good drainage, that is, permeable soil and high water-holding capacity [33] and the pH ranges from 5.5 to 6.0 [34].

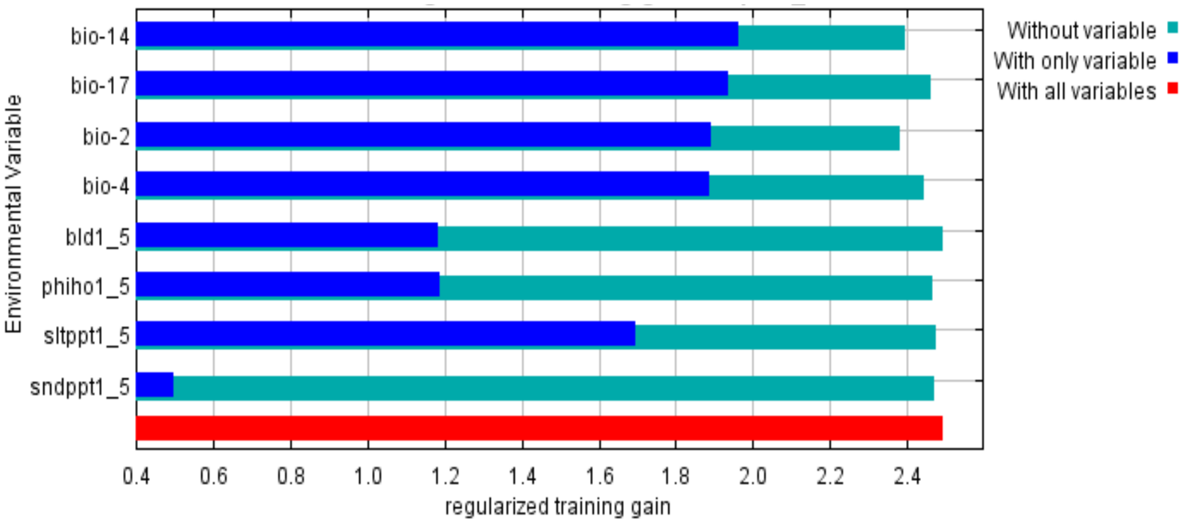


Figure 3: Jackknife test result on contribution of Sugarloaf models

Assessing the performance of the models

Statistical values used to evaluate the performance of the different models were presented in Figure 4 for the two varieties of pineapple. For the sugarloaf variety, the AUC values obtained were 0.98, 0.99, 0.93, 0.98, and 0.97 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. As regards to the sensitivity, values obtained were 0.94, 0.96, 0.90, 0.94, and 0.88 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. In the case of specificity, values obtained were 0.89, 0.95, 0.94, 0.89, and 0.94 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. When the TSS is considered, values obtained were 0.83, 0.90, 0.85, 0.83, and 0.81 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. As for the Cohen's Kappa coefficient, the values obtained were 0.62, 0.76, 0.76, 0.63, and 0.71 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. Regarding the deviance, values were 0.27, 0.18, 0.31, 0.38, and 0.29 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively.

For the smooth cayenne the AUC values obtained were 0.97, 1.00, 0.98, 0.98, and 0.96 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. Regarding the sensitivity, values were 0.95, 1.00, 1.00, 0.95, and 0.95 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. In the case of specificity values obtained were 0.96, 0.99, 0.96, 0.94, and 0.90 for

Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. When the TSS was considered, values obtained were 0.92, 0.99, 0.96, 0.90, and 0.85 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. As for the Cohen's Kappa coefficient the values obtained were 0.91, 0.73, 0.63, and 0.48 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively. As far as the deviance was of concern, values were 0.22, 0.11, 0.23, 0.21, and 0.22 for Maxent, Random Forest, Support-Vector Machines, Boosted Regression Tree and Generalized Linear Model, respectively.

Irrespective of cultivars, Random Forest algorithm yielded the highest performance and was deemed to be useful for the prediction. This result suggests the necessity of the evaluation of several models to select the most suitable in the modeling of the distribution of species. This result is consistent with the earlier findings which stated that the type of models depends on the rarity and spectrum of the species [35].

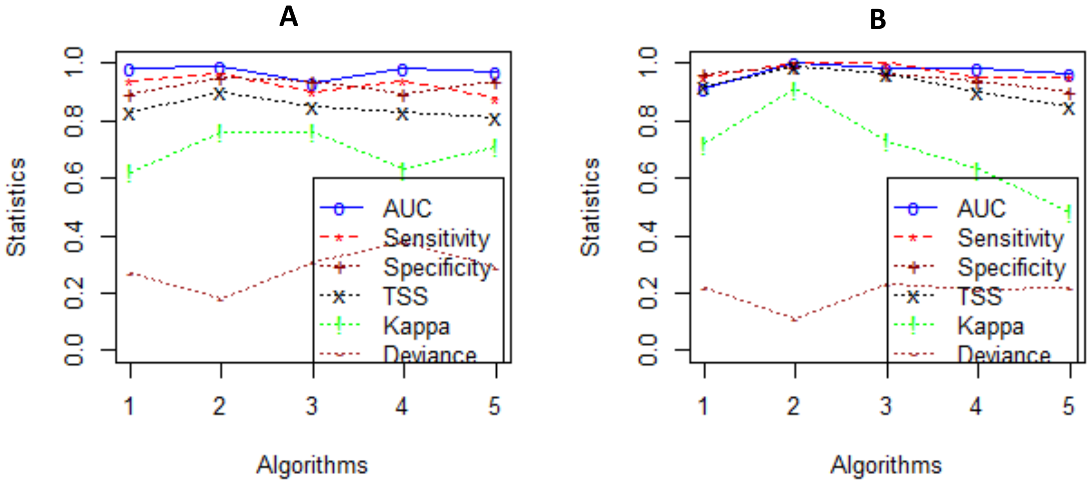


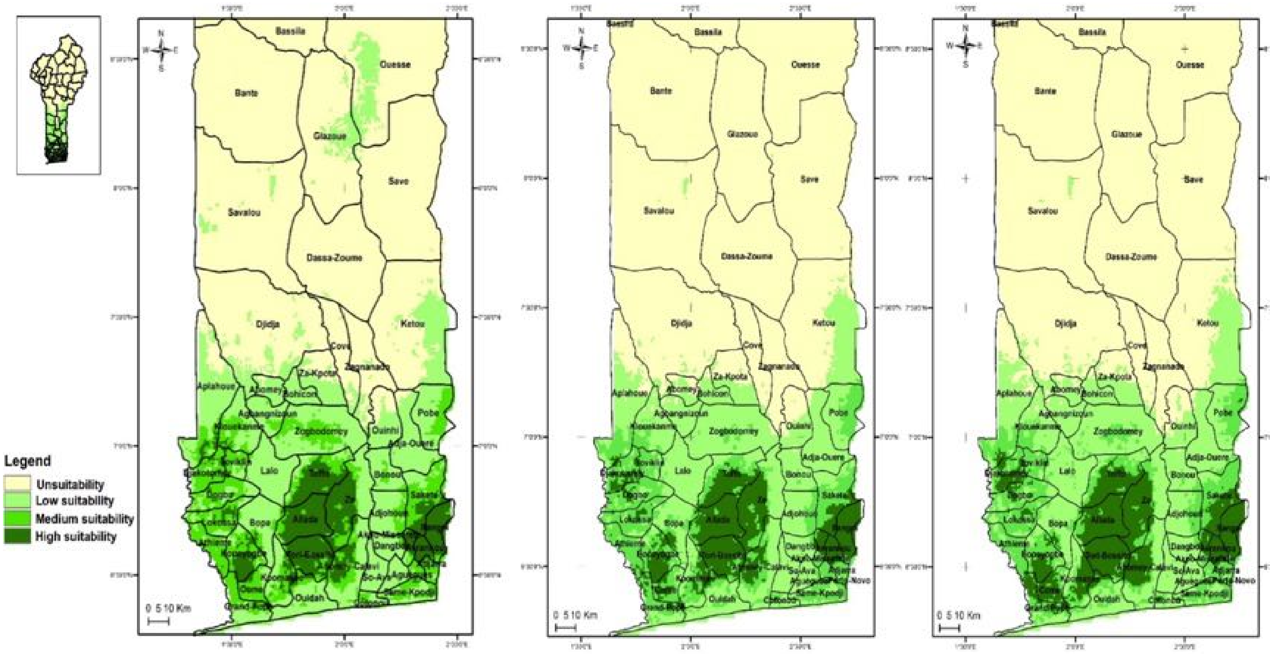
Figure 4: Performance assessment of the five selected algorithms for sugarloaf (A) and smooth cayenne (B). 1=Maxent, 2 = Random Forest, 3 = Support-Vector Machines, 4 = Boosted Regression Tree, 5 = Generalized Linear Model

Current and future suitable areas for cultivation of pineapple in Benin
Geographically, results of the current models suggested that suitable areas for the cultivation of pineapple overlap the south and central part of Benin, and were specifically located between 6°2 and 9° North. Nevertheless, the highly suitable

areas for the cultivation of the varieties of pineapple were confined to the southern part of the country between 6°2 and 7°5 North (Figures 5 and 6). The zone overlapped with the Agro-ecological Southern zone which is characterized by Guinean climate and acrisol type. Future models showed a variation in the suitable areas for the cultivation of pineapple for both varieties. The low and medium suitability areas for the cultivation of smooth cayenne will decrease by 15.57% and 2.93%, respectively at time horizon 2055 with future conditions under RCP4.5 and 15.48% and 4.97%, respectively at time horizon 2055 with future conditions under RCP8.5 whereas, the highly suitable areas increased by 5.28% with RCP4.5 and 21.82% with RCP8.5 (Table 4).

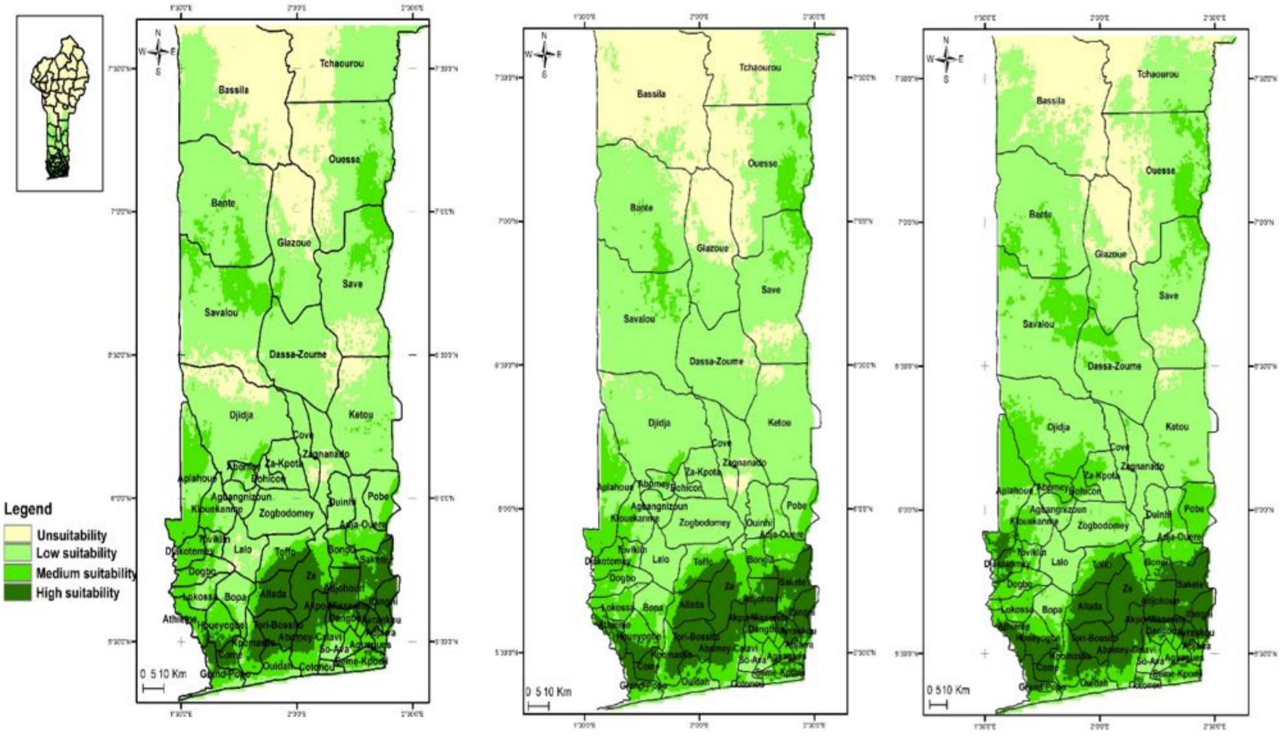
For sugarloaf, the low and medium suitable cultivation areas will decrease by 1.59% and 14.24%, respectively at time horizon 2055 with future conditions under RCP4.5 whereas the high suitable areas will increase by 7.7%. According to RCP8.5, the low suitable areas will decrease by 5.08% whereas the medium and high suitable areas will increase by 24.17% and 31.64%, respectively.

The model predicted that regions beyond 7°50 latitude North and 9°50 latitude North constituted medium and low suitable habitat, respectively for pineapple growth. These findings are supported by climatic conditions, as these regions have typically a more severe dry season and majority covered by acrisols. The results also revealed other zones which also appear to be very favorable for the cultivation of pineapple apart from the Atlantic department located in the alluvial soil zone where it is already intensively cultivated. These areas are mainly located in the Central and Southern part of Benin. The promotion of pineapple cultivation in the newly favorable areas allows the diversification of the cultivation environment for pineapple. This will lead in the long term to a reduction in the intensification of the cultivation of pineapples in the Atlantic Department and consequently contribute to better soil management. Using the most drastic future conditions projected, the RCP8.5 scenario model suggested that climate change conditions will positively affect both varieties by increasing the highly suitable area for cultivation. According to RCP4.5 future scenarios, climate change conditions will also positively affect Smooth Cayenne and Sugarloaf by increasing their highly suitable areas. These results suggest that the increase of pineapple cultivation in Benin will not be compromised by climate changes. To ensure improved pineapple yielding, there is a need for better soil [36, 37] and plant disease management.



(A) (B) (C)

Figure 5: Current suitable areas for Smooth Cayenne cultivation (A) and future suitable areas at horizon 2055 (B and C) with RCP4.5 (B) and RCP8.5 (C)



(A) (B) (C)

Figure 6: Current suitable areas for Sugarloaf cultivation (A) and future suitable areas at horizon 2055 (B and C) with RCP4.5 (B) and RCP8.5 (C)

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

Pineapple cultivation in Benin is more concentrated in the South. This study used Ecological Niche Modeling to bring out suitable zones for the cultivation of pineapple cultivars in Benin. This is of high importance as it will contribute to diversification of production areas, and reduce the intensive exploitation of the soil currently devoted to crop cultivation. The current potential range of favorable areas for the two varieties was mainly found in the central and southern parts of the country. In the future, following the RCP4.5 scenario, there will be an increase in the area favorable for the cultivation of Smooth Cayenne variety by 5.28% compared to the current situation whereas the area favorable for the cultivation of the Sugarloaf variety will be increased by 7.7%. Findings are helpful to promote this culture through the newly favorable areas. Appropriate strategies are needed for better contribution of pineapple to the local economy and food security and nutrition.

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Table 1: Summary of variables derived from downscaled monthly temperature and rainfall grids

		Baseline (1961–1990)		Mid-century (2041–2070)	
Codes description	**Units**	**Observed**	**Modelled**	**RCP4.5**	**RCP8.5**
Temperature variables					
BIO1 Mean annual temperature[1]	°C	24.3–24.4	22.0–24.1	26.0–26.9	26.6–27.8
BIO2 Mean diurnal range in temp[2]	°C	12.9–13.3	12.5–14.6	12.9–13.3	12.9–13.3
BIO3 Isothermality[3]	°C	63.6–64.9	59.3–62.4	62.1–64.5	61.5–64.5
BIO4 Temperature seasonality[4]	°C	2.3–2.4	2.3–2.8	2.3–2.6	2.3–2.5
BIO5 Max temp warmest month	°C	34.2–34.3	32.7–35.6	36.1–37.1	36.7–37.9
BIO6 Min temp coolest month	°C	13.0–13.2	10.8–13.1	14.6–15.6	15.2–16.5
BIO7 Annual temperature range[5]	°C	21.0–21.3	20.9–24.8	21.1–21.7	21.1–21.9
BIO10 Mean temp warmest quarter[6]	°C	26.9–27.1	24.7–27.2	28.6–29.9	29.2–30.7
BIO11 Mean temp coolest quarter[6]	°C	21.0–21.1	18.6–20.4	22.7–23.6	23.3–24.4
Moisture variables					
BIO12 Mean annual rainfall8	mm	678–882	692–973	678–951	683–974
BIO13 Rainfall wettest month	mm	145–176	156–189	149–198	151–203
BIO14 Rainfall driest month	mm	4–8	2–10	3–8	3–8
BIO15 Rainfall seasonality[4]	mm	49–59	55–67	50–65	50–67
BIO16 Rainfall wettest quarter[6]	mm	356–451	393–492	360–496	365–511
BIO17 Rainfall driest quarter[6]	mm	21–36	11–43	20–36	20–37

Table 2: Contribution of selected environmental variables for *Smooth Cayenne*

Code	Variables	Contribution (%)
bio-17	Precipitation of driest quarter	58.7
bio-14	Precipitation of driest period	16.8
phiho1_5	pH in H_2O	7.1
clyppt1_5	Clay	6.7
bld1_5	Bulk	5.5
sltppt1_5	Silt	2.1
bio-13	Precipitation from the wettest period	1.8
bio-15	Seasonality of precipitation	1.3

Table 3: Contribution of selected environmental variables for *Sugarloaf*

Code	Variables	Contribution (%)
bio-4	Temperature seasonality	38.2
bio-17	precipitation of driest quarter	20.1
bio-14	precipitation of driest period	16.6
bio-2	Mean diurnal range	9.1
phiho1_5	pH in H_2O	5.8
sltppt1_5	Silt	4.9
sndppt1_5	Sand	3
bld1_5	Bulk	2.1

Table 4: Dynamic of suitable areas for *Ananascomosus* under current and future climate conditions in Benin

Species		**Low suitability**		**Medium suitability**		**High suitability**	
Ananascomosus	**Characteristic**	**Area (Km^2)**	**Trends %**	**Area (Km^2)**	**Trends %**	**Area (Km^2)**	**Trends %**
Smooth Cayenne	**Current**	9644	---	3620	---	2557	---
	RCP4.5_55	8142	-15.57	3514	-2.93	2692	+5.28
	RCP8.5_55	8151	-15.48	3440	-4.97	3115	+21.82
Sugarloaf	**Current**	26022	---	7008	---	3726	---
	RCP4.5_55	25608	-1.59	6010	-14.24	4013	+7.7
	RCP8.5_55	24700	-5.08	8702	+24.17	4905	+31.64

Legend: (+): Positive percentage indicates gain; (-): Negative percentage indicates loss. Low suitability stands for probability < 0.10, medium suitability stands for probability between 0.15 and 0.5; high suitability stands for probability is >0.5

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