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Identification of Potential Future Areas for Sustainable Cashew *(Anacardium occidentale* L.) Nut Production in Togo Using the Maxent Model

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Understanding present and potential habitats is critical for developing climate-resilient cashew-growing techniques and sustainable management strategies. This study aims to identify the existing distribution of *Anacardium occidentale* L. in Togo and anticipates the possible impact of climate

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change on its habitat distribution by 2050 using two global circulation models (HadGEM3-GC3.1-L and MIROC6) and two shared socioeconomic paths (SSP245 and SSP585). The maximum entropy algorithm, 2538 species occurrence records, and a set of seventeen (17) climatic and soil variables were used. The findings revealed that soil, followed by annual precipitation (bio12) and temperature seasonality (bio4), are the most important environmental variables influencing cashew distribution in Togo. According to the present model, 78.92% of Togo's topography is very favourable to sustainable cashew-growing practices. According to the MOROC6 Model, very favourable cashew nut production areas will be decreased to 5.24% in the SSP 245 scenario and altogether disappear with the SSP585 scenario by 2050. However, for the HadGEM3-GC3.1-L model by 2050, the areas of sustainable cashew nut production in Togo will be reduced to 3.71% and 0.26% respectively for the SSP245 and 585 scenarios. In short, the results of this study, which was carried out for the first time in Togo, point out the need to put in place a strategy for the conservation and sustainable cultivation of cashew trees in Togo.

Keywords: Anacardium occidentale L.; climate change; ecological niche modelling; sustainable agriculture.

1. INTRODUCTION

"Plant species have been used for a number of purposes throughout human history. They have existed for a long time and are still used in scientific research today. The cashew tree (*Anarcardium occidentale* L.) belongs to the Anacardiaceae plant family. Cashew trees are endemic to Brazil and the Lower Amazon" [1]. "The genus Anacardium has eight native species from tropical America, the most commercially significant is A. *occidentale*" [2]. "This imported tree species in Africa has become an important source of revenue for rural communities" [3,4]. "It is primarily grown for its nuts, which are valuable industrial and export raw materials" (Akinhanmi, 2008). "The crop is thriving in Africa, with raw nut output increasing from 1 million tons to 1.8 million tons between 2011 and 2018, representing a 5.8% annual growth rate. Cashews are a popular appetizer. They are also utilized in the culinary industry and as an ingredient in a range of confectionery products. People gain from the nutritious content of cashew nut kernels. They are rich in vitamins (A, D, and E), lipids, and proteins" [1,5]. "Cashew plants help to combat climate change through carbon sequestration" [6]. "It lowers atmospheric carbon levels and fosters a safe atmosphere for human growth. Cashew cultivation has increased because of its great hardness and minimal soil and climatic needs" [7]. It is best suited to locations with a warm tropical environment with alternating wet and dry seasons. Climate change is now widely acknowledged and considered as one of the world's most serious environmental issues. Bogner et al. [8] remark that "global climate change, which is primarily caused by increases in atmospheric concentrations of anthropogenic greenhouse gases, has important implications for human health, socioeconomic activity, and ecosystems". Species may move their ranges in response to climate change [9]. Given the socioeconomic and environmental importance of A. *occidentale*, it is critical to understand how climate change may affect its area of distribution. As a result, Atakpama et al. [7] decided to conduct a research study to "assess the current distribution and predict the potential impact of climate change on the distribution of *Anacardium occidentale's* habitat in Togo under two Representative Concentration Pathways (RCP4.5 and RCP8.5)". We decided to conduct this study using the Shared Socioeconomic Pathways (SSP) scenarios, which are new scenarios for predicting the impact of climate change on biodiversity. This study aims to assess the current distribution and predict the potential effect of climate change on the distribution of the habitat of *Anacardium occidentale* L. in Togo. Specifically, this study aims:

- To identify potential areas for sustainable cashew production in Togo;
- To determine the environmental factors affecting the success of cashew plantations in Togo;
- To predict the impact of climate change on potential cashew-growing areas in Togo.

2. METHODOLOGY

2.1 Description of the Study Area

A country in West Africa, Togo, covers an area of 56,600 km² and is bordered by the Atlantic

Ocean, Benin, Ghana, and Burkina-Faso to the South, East, West and North respectively. It is located between 6º06'N and 11º08'N latitudes and 0°09 W and 1º49 W longitudes on the coast of the Guinean Gulf. The climate is intertropical, with considerable variance from south to north. The rainy season is shorter from south to north. From 8°30 north in the west and 9° north in the east to the Burkina Faso border, a subtropical Sudanian dual season pattern and its variations exist, with three to six dry months. The southern half of the nation has a sub-Equatorial Guinean climate with four seasons and two variants: the Guinean lowland type, which is less wet with 1,000 to 1,300 mm/year, and the Guinean mountain type, which is rainier with around 1,600 mm/year (Fig. 1).

2.2 Study Species

Anacardium occidentale L. is a woody plant with a flaring canopy that may reach a height of up to 15 meters, and occasionally more. It has a highly branching trunk with thick, evergreen, dark-green leaves (red or light green in juveniles) and a regular, hemispherical canopy of 12 to 14 metres in diameter. The branches are spherical and hang downward. The stem bark is rough and brown, with a pinkish border. Alternate phyllotaxis leaves are simple, entire, oval or oblong, rounded at the top, and leathery with a dark green color. The blooms, which are supported by a very short pedicel, are tiny, pentamerous, zygomorphic, and white or pale yellow with pink streaks at the time of bloom, turning pink somewhat later. They are clothed with large, somewhat pubescent bracts. The calyx is composed of free, green, oblong, upright sepals, with quincunx pre-flowering and forming a tube the length of the pedicel" [7]. The petals are white or yellow, occasionally tinged with pink, free, linear to lance-shaped, alternated, and imbricate before blossoming. As Lefèbvre noted in 1969, the stamens, usually in groups of ten, are fused by the base of the netting in a tube of 2 mm length. Generally, each cyma's terminal bloom is hermaphroditic, whereas the laterals are unisexual.

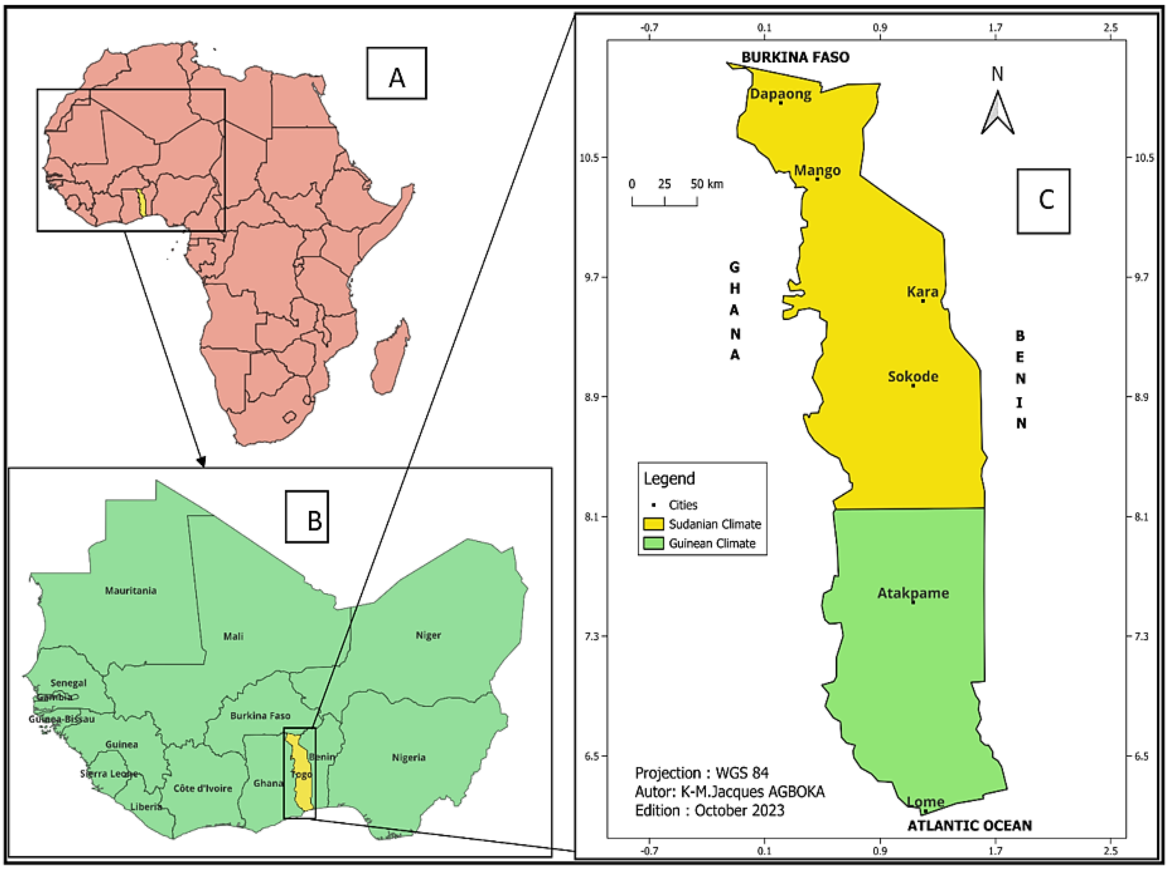

Fig. 1. Location of the study area A : Togo in Africa B: Togo in West Africa C: Climatic zones of Togo

2.3 Occurrence Data Collection

Between August and December 2023, occurrence data for cashew trees in Togo were gathered using a GPS (Global Positioning System). The research conducted by Atakpama et al*.* [7] allowed us to collect occurrence points from Benin and Ghana. These cashew occurrence sites were recorded using GPS. To increase the model's accuracy, it was suggested that occurrence data include as much of the area as feasible where the species is influenced by similar climatic conditions. As a result, new cashew occurrence data in West Africa from the Global Biodiversity Information Facility platform (https://www.gbif.org/) were acquired using the "gbif" plugin in the QGIS 3.24 software1 (Fig. 2). These are the updated data from 1950 to 2021. After crosschecking and suppressing incorrect and duplicated occurrences, a total of 2,538 points of occurrence were included in the modeling. Table 1 shows information on the places of occurrence and their sources.

Table 1. Sources and number of occurrence points used for modelling

Source of occurrence points	Number of occurrence points
Atakpama et al. [7]	705
Fieldwork	833
GBIF	1000

2.4 Environmental Data

Table 2 shows environmental data including climate, elevation and soil. The soil data was collected from the Harmonized Soil database of FAO https://www.fao.org/soils-portal/data-hub/soil-maps-anddatabases/harmonized-world-soil-database-v12/en/ (accessed on 12 December 2023). The climate and elevation data were obtained from the WorldClim version 2.1 database (http://www.worldclim.org, accessed on 15 December 2023) and included the 19 bioclimatic variables. Data on the bioclimatic variables were downloaded for both the current (1970–2000) and future (2050; 2041–2060) climate at the resolution of 30 arc-seconds (~1 km^2). Previous studies reported some discontinuities in the bioclimatic variables, namely the mean temperature of the wettest quarter (Bio 8), mean temperature of the driest quarter (Bio 9), precipitation of the warmest quarter (Bio 18), and precipitation of the coldest quarter (Bio 19) in sub-Saharan Africa (Booth, 2022), which were attributed to sudden changes in the quarterly periods used to calculate these variables (Booth, 2022). Therefore, we omitted the four variables in further analysis.

Table 2. Environmental variables used for modelling

Environmental variables	Description of the variable
Soil	Soil
Elevation	Altitude
Temperature Variables	
bio1	Annual Mean Temperature
bio2	Mean Diurnal Range
bio3	Isothermality (BIO2/BIO7) (* 100)
bio4	Temperature Seasonality (standard deviation *100)
bio5	Max. Temperature of Warmest Month
bio6	Min. Temperature of Coldest Month
bio7	Temperature Annual Range (BIO5-BIO6)
bio10	Mean Temperature of Warmest Quarter
bio11	Mean Temperature of Coldest Quarter
Pluviometry variable	
bio12	Annual Precipitation
bio13	Precipitation of Wettest Month
bio14	Precipitation of Driest Month
bio15	Precipitation Seasonality (Coefficient of Variation)
bio16	Precipitation of Wettest Quarter
bio17	Precipitation of Driest Quarter

“These variable layers were cropped along the West African boundaries and then converted to ASCII files compatible with the MaxEnt algorithm (version 3.4). The models were performed using all environmental variables” [10,11] instead of correlative analysis and choice of variables as done in several previous studies by Dimobe et al*.* [12] and Atakpama et al*.* [7]. The potential future distributions of *Anacardium occidentale* under climate change were predicted using two Global Circulation Models (GCMs): “HadGEM3-GC3.1-LL” (Third Hadley Centre Global Environment Model in the Global Coupled Configuration 3.1) developed by the Hadley Center, United Kingdom (Andrews et al., 2020); and MIROC6 (Model for Interdisciplinary Research on Climate) developed by the Japanese modelling community, Tatebe et al*.* [13]. The future climate conditions were projected at the 2050 horizon (average for 2041–2060) under two IPCC-CMIP6 Shared Socioeconomic Pathways (ssp) scenarios, ssp245 and ssp585 were used to

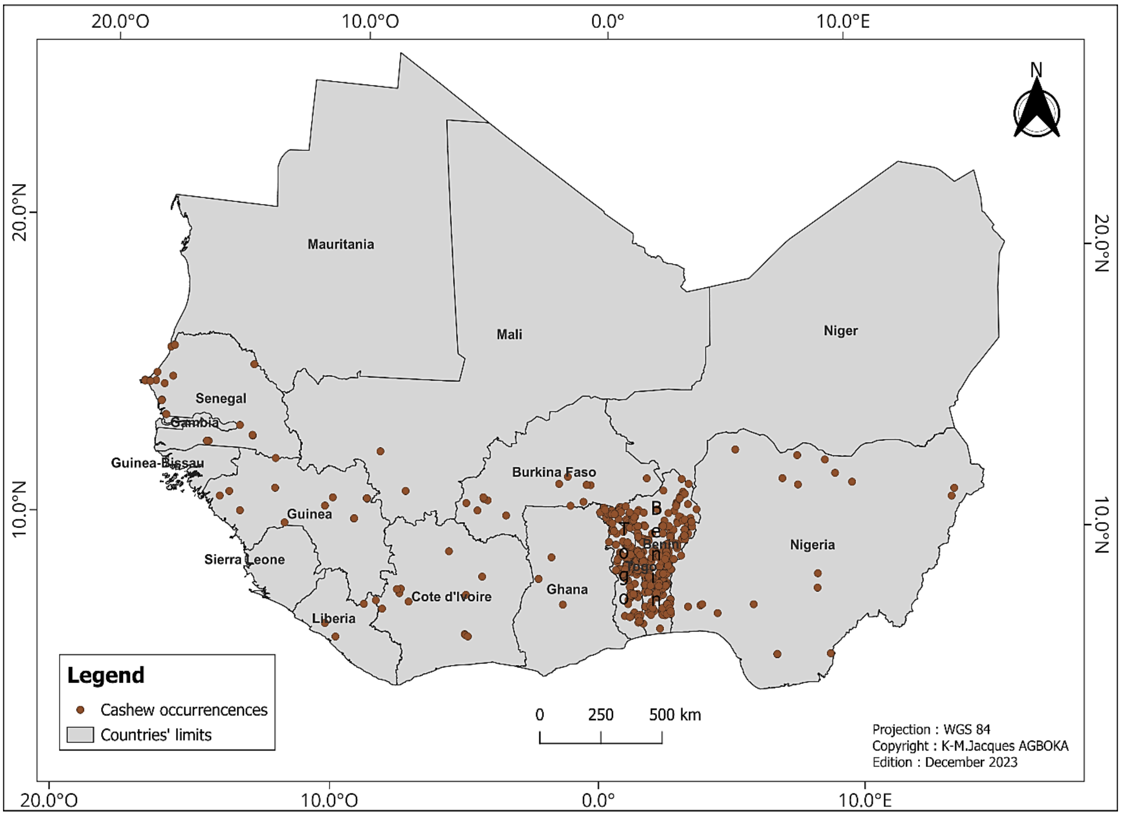

Fig. 2. Spatial distribution of cashew tree in West Africa

reduce the climate uncertainty, Koo et al. [14]. Of these, "the ssp245 is the medium forcing scenario with intermediate climate change challenges and the ssp585 would be the most chaotic scenario if we assume no measures are taken to avoid the climate effects" [15].

2.5 Modelling and Validation of the Model

The Excel file of cashew tree occurrence points has been converted into a CSV file, for compatibility with the MaxEnt model. To make the model more accurate, it has been run ten times. A total of 25% of the points of presence were used to test the model and the remaining 75% of the data were used to train the model, Nneji et al. [16].

"To analyze model accuracy, the area under the receiver operating curve (AUC) was calculated using receiver operating characteristics (ROC) analysis. Swets [17] classified the AUC values into three categories: 0.5–0.7, 0.7–0.9, and AUC values >0.9, which indicate poor, moderate, and high model performance, respectively. The AUC value close to 0.5 indicates that the model is no better than a randomly generated model, while the AUC values >0.9, indicate the SDM strength of the model" [18]. "Jackknife analysis was used to determine which climatic variables were important for the distribution of *Anacardium occidentale"* [19]. The True Skill Statistics (TSS) is the capacity of the model to accurately detect true presences (sensitivity) and true absences (specificity). TSS ≤ 0 indicates a random prediction, while values close to 1 (TSS > 0.5) characterize a model with good predictive power [20]. the calculation of the TSS was as follows Allouche et al. [20]:

True skill statistic (TSS) = Sensitivity + Specificity-1

The QGIS 3.24 software 1 was used to map the cashew potential current and future growing areas. Two habitats were first defined based on the 10-percentile threshold: unfavourable habitat (habitats with a probability below the threshold) and favourable habitat (habitats with a probability above the threshold) as noted by Atakpama et al. [7]. Then the favourable habitat was subdivided into less favourable, moderately favourable, and highly favourable. The area of each habitat and its dynamics under each scenario were calculated.

3. RESULTS

3.1 Contribution of Variables and Model Performance

The average AUC and the True skill statistic (TSS) values were respectively 0.949 (Fig. 4) and 0.88, showing a good prediction of habitat. The variable that contributed mostly to the models was the soil variable (hwsd), followed respectively by the annual precipitation (bio12), and the temperature seasonality (bio4). The least contributing variable was the altitude (elev) as indicated on Fig. 3.

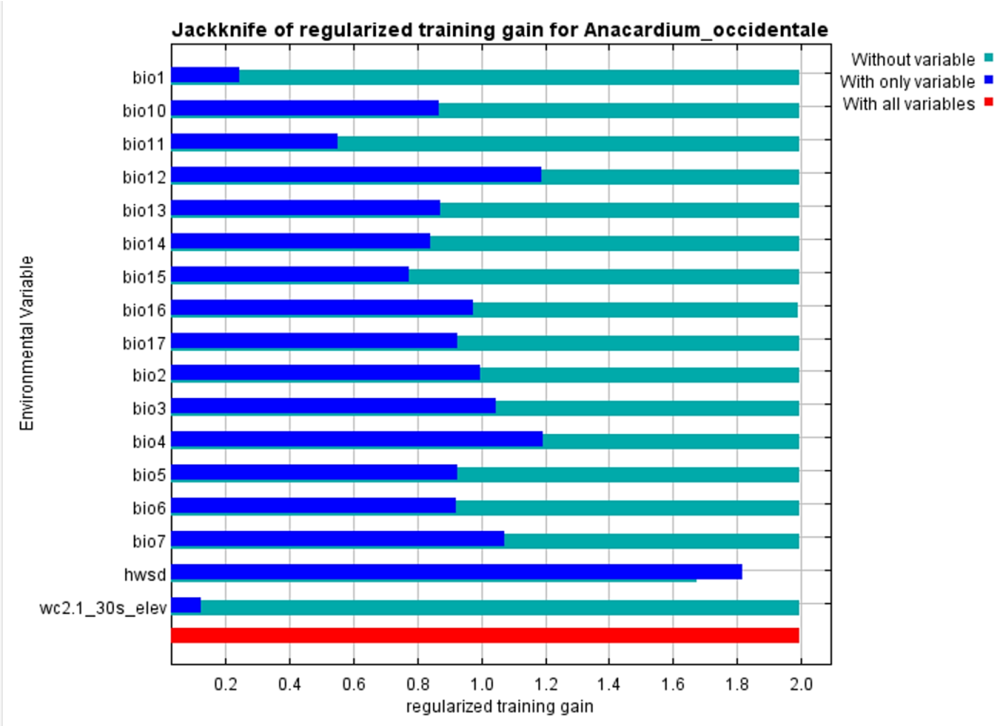

Fig. 3. Contribution of variables in the modelling according to the Jackknife test

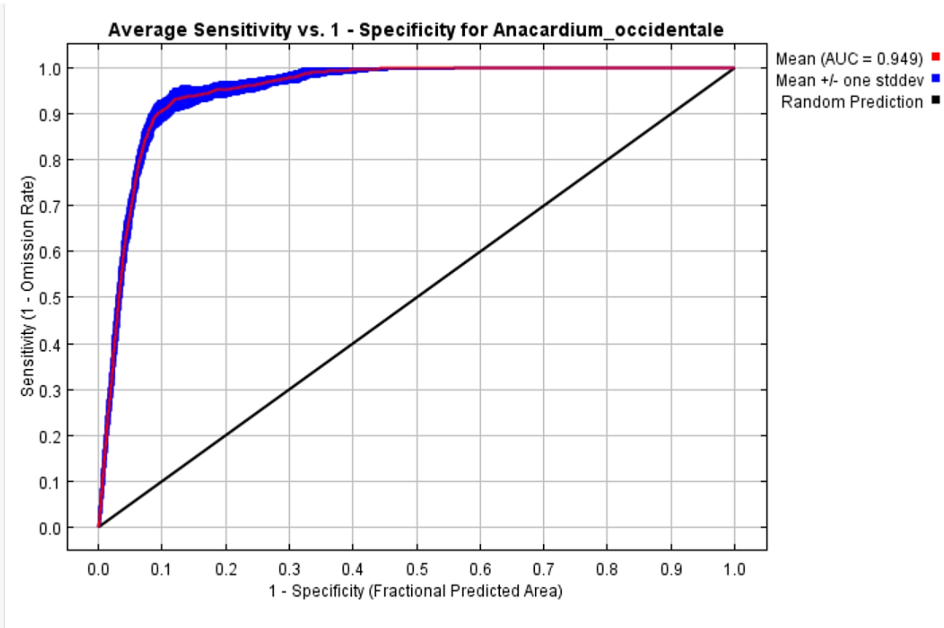

Fig. 4. The Cross-validated areas under the receiver operating characteristic curve (AUC)

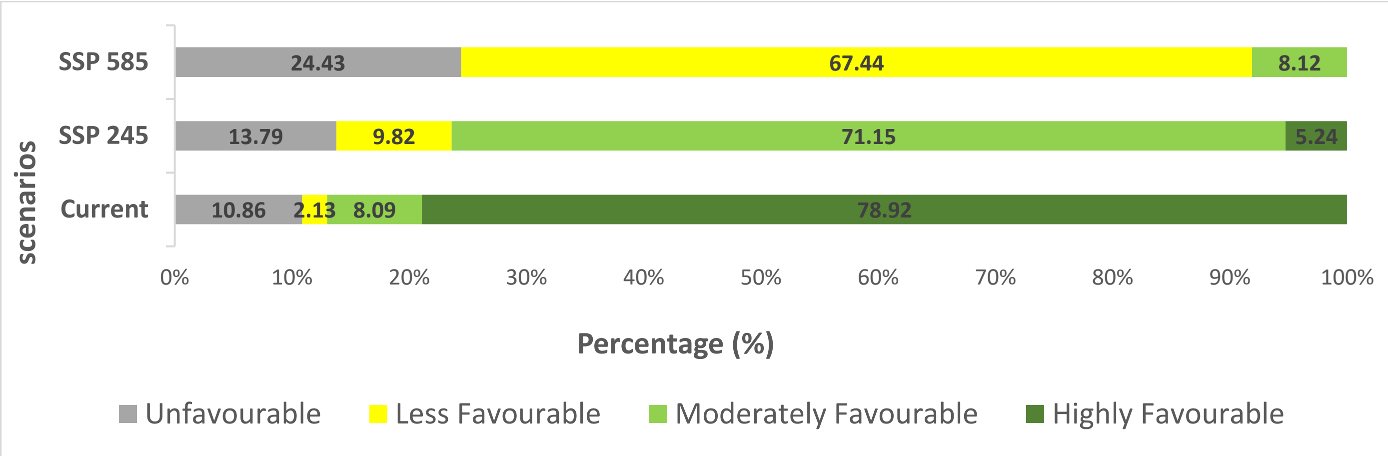

Fig. 5. Proportion of current and potential future habitats according to MIROC6 under ssp245 and ssp585 scenarios of the cashew tree in Togo

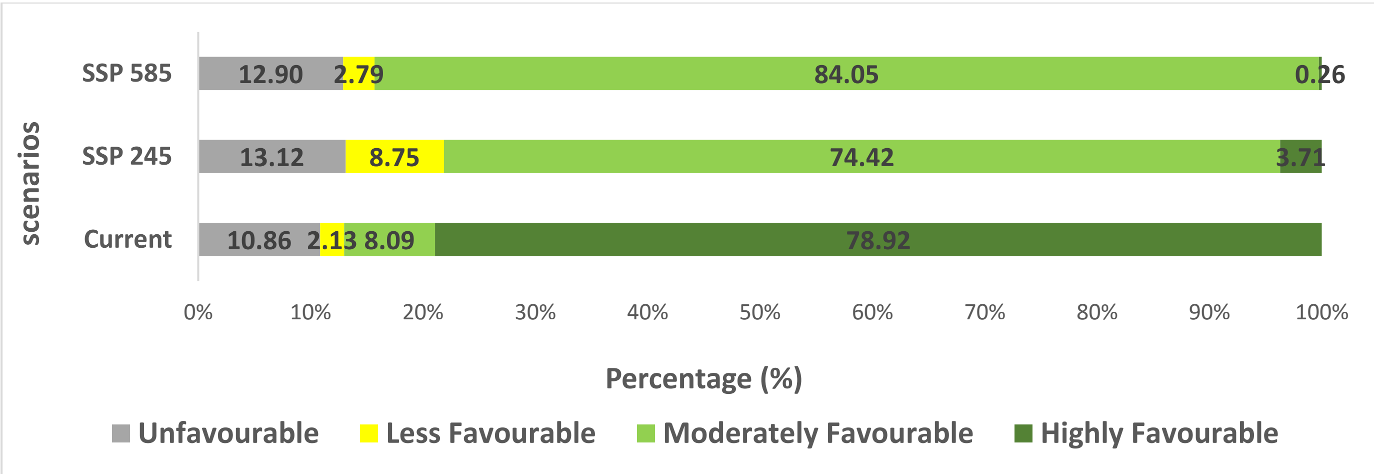

Fig. 6. Proportion of current and potential future habitats according to HadGEM under ssp245 and ssp585 scenarios of the cashew tree in Togo

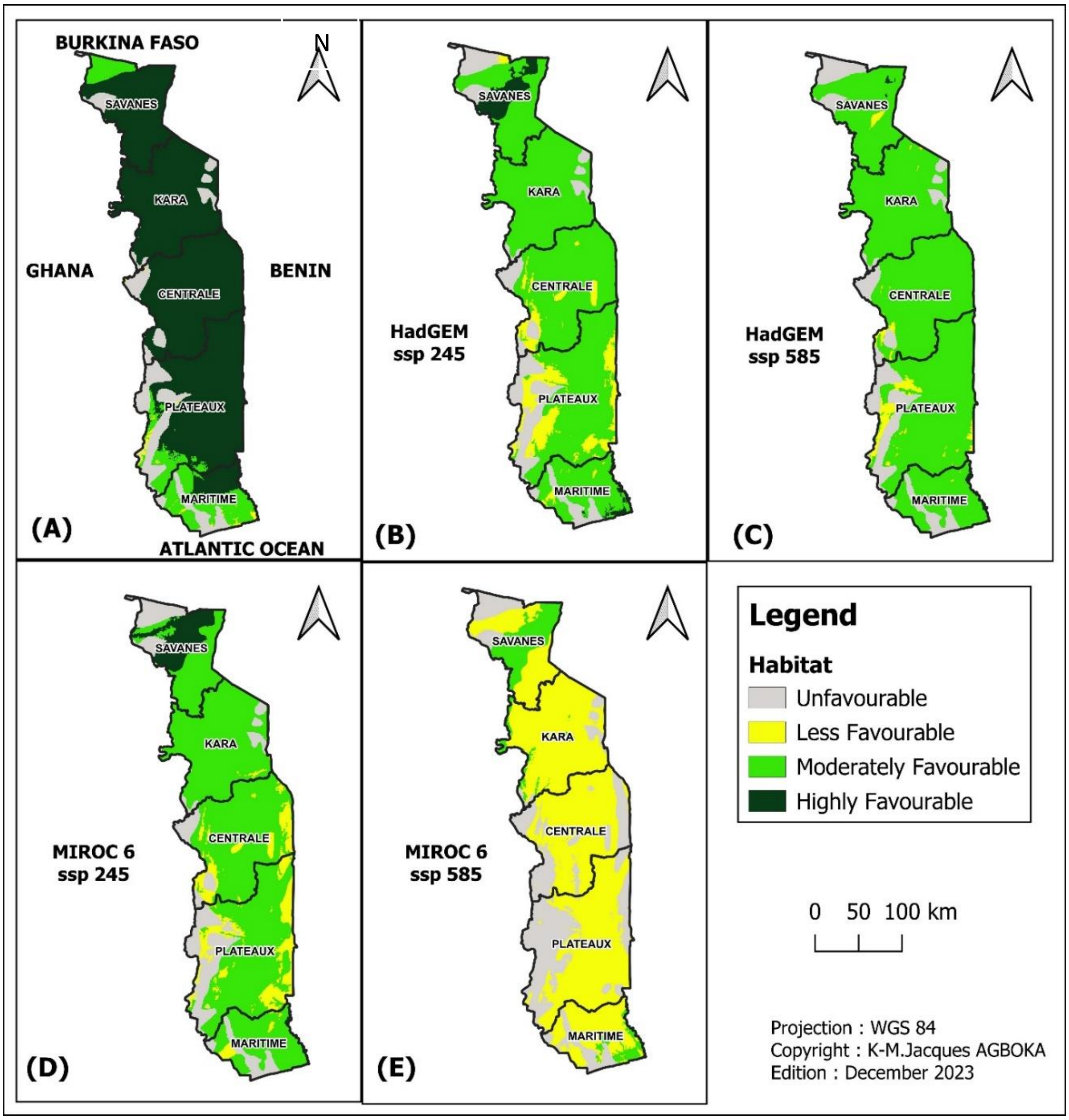

Fig. 7. Current habitat suitability according to economic regions; and future potential distribution in 2050 for *Anacardium occidentale* in Togo, according to GCM-HadGEM
A, scenarios; B, ssp 245; C, ssp585 GCM-MIROC6, scenarios; D, ssp 245; E, ssp 585.

Current and future potential cropping area of *A. occidentale* in 2050: The current predictions for potential suitability (less favourable, moderately favourable and highly favourable) regions identified 89.14% of Togo's national territory, while the potentially unfavourable areas account for 10.86% of the territory (Figs. 5 and 6). The current scenario shows that *A. occidentale* is potentially distributed in the Eastern part of the Plateaux region, most of the part of the Central region, the whole of the Kara region and most of the areas of the Savanes region (Fig. 7).

The future climate change impacts on the potential distribution of *A. occidentale* in Togo using the HadGEM3-GC3.1-LL and MIROC6 models under ssp245 and ssp585 scenarios are shown in Fig. 7. Based on the AUC and TSS values for the 2050 period, models using ssp245 and ssp585 data had high predictive performance (AUC> 0.90; TSS = 0.88). These Global Circulation Models indicated that there was a significant spatial extension of the suitable ((less favourable, moderately favourable and unfavourable) regions when compared with the current values, while the highly favourable suitable regions were decreased (Fig. 7). With the HadGEM model using ssp245 and ssp585 scenarios, the regions defined as having high suitability will decrease (Fig. 6). The results from the MIROC6 model using the ssp245 and ssp585 scenarios are shown in Fig. 5. The MIROC6 model has predicted that the high potential areas of cashew cultivation will be reduced to 5.24% for the scenario ssp245 but the ssp585 scenario predicted the complete disappearance of areas with high potential cashew nut production. The HadGEM model predicted that potential areas of high cashew cultivation will be 3.71% and 0.26% of Togolese territory, under the ssp245 and ssp585 scenarios respectively. The HadGEM model predicted a large expansion (from the Maritime region to the Savanes region) of potentially moderately favourable areas for *A. occidentale* under both scenarios (Fig. 7). But for the MIROC6 model the potential moderately favourable area for *A. occidentale* under ssp245 has changed to less favourable under ssp585, these changes are observable from the Maritime region to the Savanes region (Fig. 7).

4. DISCUSSION

4.1 Model Reliability and Variables Contribution

The strength and validity of species distribution models are dependent on the input data. This work employed the maximum entropy (MaxEnt) technique, which has been used by various authors in species distribution [21,22], to map probable cashew-producing sites in Togo. This approach's strength is its capacity to incorporate occurrence data and environmental factors across the research region [23]. It also has the ability to run both quantitative and qualitative data [7]. The value of the Area Under the Curve accurately predicted the geographic distribution of cashew trees in Togo. Currently, the less favourable environment for cashew cultivation is located in locations with significant rainfall, notably in the southern hilly highlands and Togo's coastline zone. The Kara and Central areas are quite favourable. This finding is consistent with the species' present cultivation regions as well as the cashew tree's rainfall needs [24]. Future forecasts from both models and scenarios indicate a decline in the appropriate habitat (very favourable) relative to the present area (current> 2050). Edaphic variables are among the environmental factors that can predict and influence species distribution, particularly plant species [25,26]. The findings of this study revealed that soil is a key determinant in the regional distribution of cashews, followed by annual precipitation (bio12) and temperature seasonality (bio4). Soil influences plant physiological status, hence its impact on the model is significant, as Gnahoua and Louppe [27] discussed the implications of the cashew's edaphic needs.The plant does not survive on clayey, waterlogged lowland soils like those found in Togo's Maritime area. This scenario might be connected to soil pH, which has been demonstrated to have a significant impact on plant species distribution [28]. The pH of the soil can alter the availability of resources and plant nutrient absorption.In addition, FAO [29] indicates that the optimum pH for cashew growth is between 4.5 and 6.5, with the lower limit as low as 3.8. Seasonal temperature and precipitation determine soil moisture content [26]. The influence of seasonality, temperature, and annual precipitation confirms Lyam et al. [22] findings. These scientists demonstrated that temperature and precipitation have important roles in plant species and vegetation distribution. Both of these factors added to soil have a direct impact on the geographical distribution of cashews and might be the key environmental characteristics in the species' ecology [7].

4.2 Implications of Future Climate Conditions

Predicting how species will adapt to climate change is a critical component in developing biodiversity conservation and management strategies, as well as making cashew nut production climate resilient [30-32]. Climate forecasts show that the extent of habitat now suitable for cashew farming in Togo would alter under both HadGEM and MIROC6 scenarios (ssp245 and ssp585). This might be because the cashew tree lacks the ability to adjust to climate change. Furthermore, climate change is expected to limit the geographical range of cashew plants. These findings contradict those of Atakpama et al. [7], who discovered that climate change will not diminish the geographical spread of cashew trees in Togo. This distinction stems from the fact that our study employed the Shared Socioeconomic Pathways (SSPs) scenarios, whereas Atakpama et al. [7] used the Representative Concentration Pathways (RCPs) scenarios. The forecast models employed for the 2050 horizon revealed that ecosystems conducive to cashew development will decline. Given the development of habitats using HadGEM, MIROC6, and both scenarios ssp245 and ssp585, it is obvious that climate change will pose a danger to cashew farming in Togo. It is thus a crop that is not resistant to climate change. Mod [26] also suggests that biotic and human disturbances might influence the distribution of species niches. Natural disturbances such as herbivory, human settlements, and density in SDMs should be effective predictors of climate change's effects on species niches [7]. This can help us understand how temperature and rainfall patterns may impact vegetation dispersal. According to HadGEM's predictions under ssp245 and ssp585 scenarios, and MIROC6's projection under ssp245, more than 50% of cashew trees will be conserved/cultivated sustainably by 2050 [33-35]. According to the MIROC6 model, under the ssp585 scenario, Togo's habitats that are now highly beneficial to species would be increasingly influenced by climate change as they become less suitable.

5. CONCLUSION

This study examined how climate change affects the spatial distribution of possible production areas for cashew trees in Togo by 2050. The findings indicate that soil is the most important predictor of the geographical distribution of cashew trees in Togo. Current climatic conditions suggest that 78.92% of the country's land area is ideal for cashew nut farming. The fraction of highly favourable habitats would drop considerably by 2050 in both models (HadGEM and MIROC6) under two climatic scenarios (ssp245 and ssp585). These findings will assist cashew plantation growers and the Ministry of Agriculture, Livestock, and Rural Development in developing effective policies to strengthen the population's resistance to future climate circumstances. Designing locations as possible sustainable growth zones for cashews. Designating areas as potential sustainable growing areas for the cashew will also help improve the conservation status of A. *occidentale.*

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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