Identification of potential future areas for sustainable cashew *(Anacardium occidentale* L.) nut production in Togo using the Maxent model.

Abstract

Understanding current and future potential habitats is crucial for designing sustainable management policies and cashew-growing practices that are more resilient to climate change. This study assessed the current distribution and predicted the potential effect of climate change on the habitat distribution of *Anacardium occidentale* L. in Togo under two global circulation models (HadGEM3-GC3.1-L and MIROC6) and two shared socio-economic pathways (SSP245 and SSP585) by 2050. The maximum entropy algorithm, 2538 species occurrence records and a combination of seventeen (17) climate and soil variables were used. The results showed that soil, followed respectively bythe annual precipitation (bio12),and the temperature seasonality (bio4), are the most significant environmental factors affecting cashew distribution in Togo. Based on the current model, 78.92% of the Togolese landscape is highly favourable to sustainable cashew-growing practices. In 2050, according to the MOROC6 Model, the areas of sustainable cashew nut production will be reduced to 5.24% under the SSP 245 scenario and will completely disappear under the SSP585 scenario. However, for the HadGEM3-GC3.1-L model in 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

Plantspecies have been employed for a variety of reasons throughout human history. They have been around for a long time and are still employed in scientific studies today. *Anarcardium occidentale* L.,the cashew tree is a member of the Anacardiaceae plant family. The cashew tree is a Brazilian and Lower Amazonian nativespecies(Kunjumon and Ashoka, 2022). The genus *Anacardium* contains eight native species from tropical America, among which A. *occidentale* is the most economically important (Some, 2014).This introduced tree species in Africa has become an essential source of income for rural populations (Ndiaye, 2021andBoyerra, 2007). It is mainly cultivated for its nut which is an important industrial and export raw material

(Akinhanmi, 2008). Within Africa, the crop is booming and raw nut production has increased from 1 million tons to 1.8 million tons, with an annual growth of 5.8% between 2011 and 2018 (Hien, 2019). Cashew nuts are popular appetizers. They are also used in the food sector and as a component in a variety of confectionary items. Humans benefit from the nutritional value of cashew nut kernels. They are high in vitamins (A, D, and E), as well as lipids and proteins(Kunjumon and Ashoka, 2022). The cashew plantations contribute to the efforts to address climate change through carbon sequestration(Ndiaye, 2019). It reduces atmospheric carbon levels and promotes a healthy environment for human development. The increase in the cultivated area of the cashew is due to its high hardness and low soil and climate requirements Atakpama *et al*. (2023). It is especially suitable for areas with a warm tropical climate with alternating wet and dry seasons.Climate change is now broadly recognized and accepted as evident and one of the world's most pressing environmental challenges. Global climate change, mostly driven by increases in atmospheric concentrations of anthropogenic greenhouse gases, has significant impacts on human health, socio-economic activities, and ecosystems as notedby Bogner *et al*. (2008). Under climate change, species may shift their ranges to cope with climate change(Walther *et al.*, 2002).Given the socio-economic and environmental importance of A. *occidentale*, it is necessary to know the impact that climate change will have on the spatial distribution of A. *occidentale*. For this reason, Atakpama *et al.* (2023) have decided to conduct a research study to assess the present-day distribution and predict the potential effect 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 significant variations from the south to the 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 border of Burkina Faso, there is a subtropical Sudanian dual season pattern and its variants with three to six dry months. The southern part of the country experiences a sub-Equatorial Guinean climate with four seasons and two variants: the Guinean lowland type, which is less rainy with 1,000 to 1,300 mm/year, and the Guinean mountain type, which is rainier with about 1,600 mm/year (Figure 1)

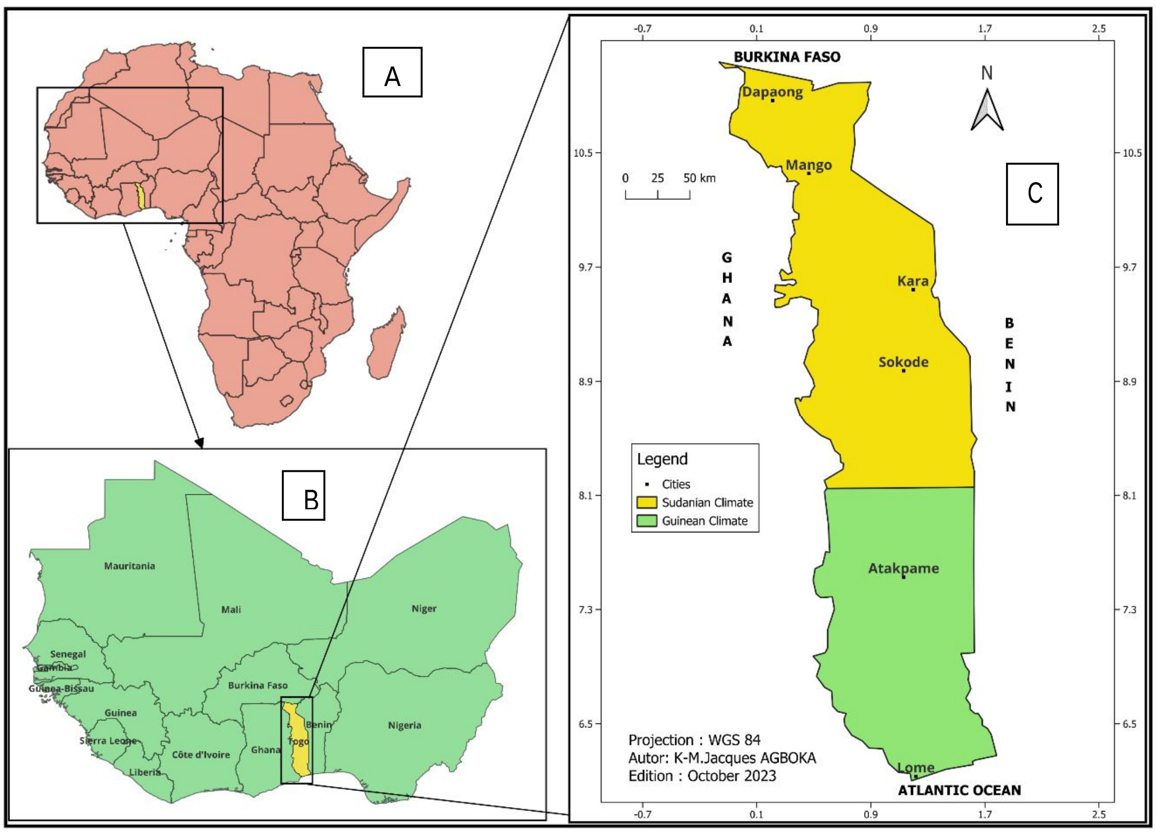

Figure 1: Location of the study areaA :Togo in Africa B: Togo in West Africa C:Climatic zones of Togo

2.2. Study species

Anacardium occidentale L. is a woody species with a flared canopy of up to 15 m in height, sometimes more than 15 m. It has a highly branched trunk with dense, evergreen, anddark-green foliage (red or pale green in the juvenile state) with a regular, hemispherical canopy measuring 12 to 14 m in diameter. The branches have a globular and drooping habit. The stem bark is rough grey with a pinkish edge. The leaves of alternate phyllotaxis are simple, whole, oval or oblong, rounded at the top, and leathery of dark-green colour.The flowers, supported by a very short pedicel,are small, pentamerous, zygomorphic, white or pale yellow streaked of pink at the time of the bloom, becoming pink a little afterwards. They are covered with broad bractsthat are slightly pubescent. The calyx is made up of free, green, oblong, erect sepals, with quincunx pre-flowering and forming a kind of tube of a length equal to that of the pedicelAtakpama *et al.* (2023).The petals are white or yellow,sometimes streaked of pink, free, linear to lance-shaped, alternated, and with imbricate pre-flowering. As Lefèbvre mentioned in 1969, the stamens, generally to the number of 10, are welded by the base of the nets in a tube of 2 mm length. Generally, the terminal flower of each cyma is hermaphroditic and thelaterals are unisexual.

2.3. Occurrence data collection

Occurrence data of the cashew trees across Togo were collected using a GPS (Global Positioning System) between August and December 2023. The study carried out by Atakpama*et al.* (2023) enabled us to collect occurrence points from Benin and Ghana. These cashew occurrence points were taken using GPS.To improve the accuracy of the model, it was recommended to use occurrence data that cover as much as possible the area where the species is driven by the same climatic factors. Therefore, additional occurrence data of the cashews in West Africa provided by the Global Biodiversity Information Facility platform (https://www.gbif.org/) were collected using the "gbif" extension in the QGIS 3.24 software1 (Figure 2). These data are the updated data from 1950 to 2021. A total of 2,538 points of occurrence were used for the modelling after crosschecking and suppression of wrong and duplicated occurrences.Table 1 below shows details of the points 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.* (2023)705	
Fieldwork833	
GBIF	1000

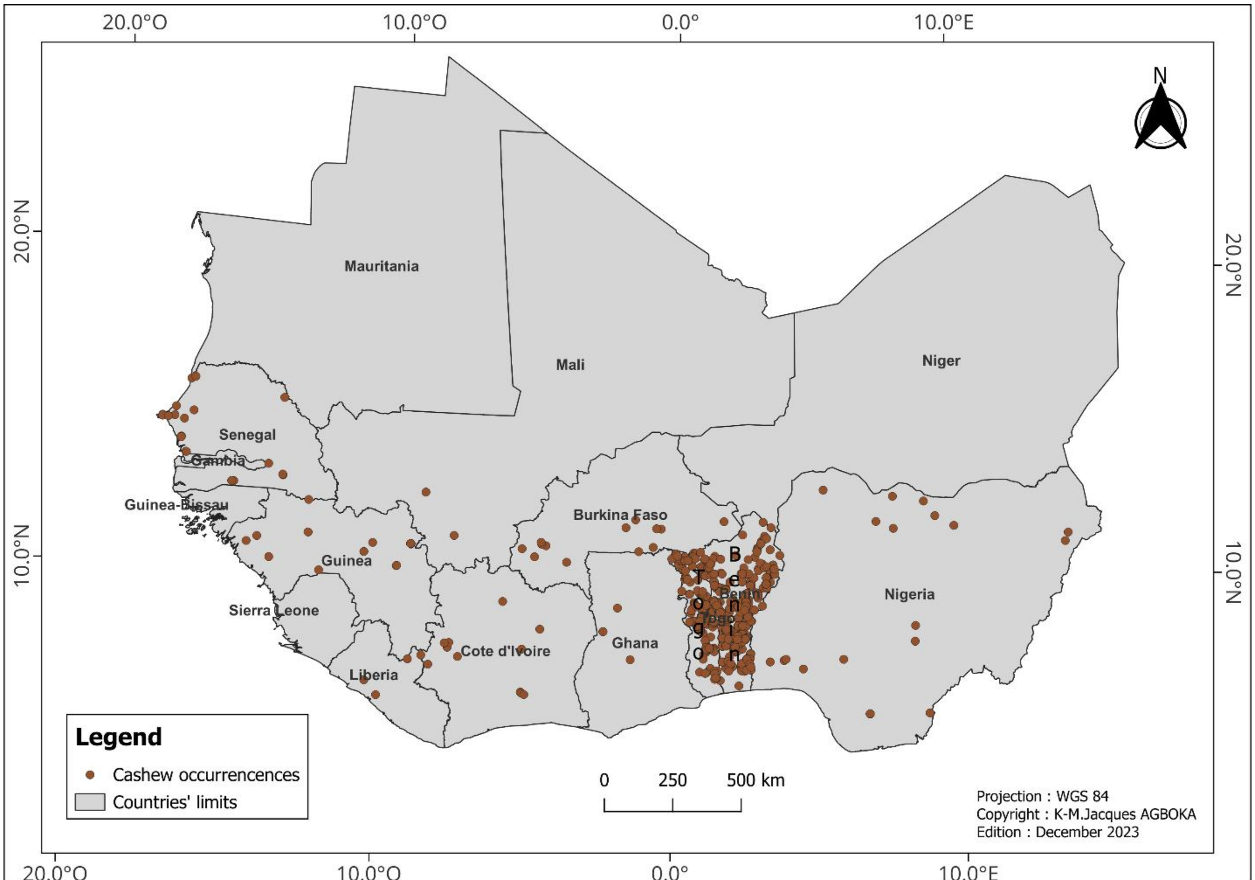

Figure 2: Spatial distribution of cashew tree in West Africa.

2.4. Environmental data

Table 2 below shows environmental data including climate, elevation and soil.The soil data was collected from the HarmonizedSoildatabase of FAO https://www.fao.org/soils-portal/data-hub/soil-maps-anddatabases/harmonized-world-soil-database-v12/en/ (accessedon 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(Moukrim *et al.*,2020;Feng *et al.*, 2019) instead of correlative analysis and choice of variables as done in several previousstudies by Dimobe *et al.* (2020) and Atakpama *et al.* (2023).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.*(2019). 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 reduce the climate uncertainty, Koo *et al.* (2017). 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 (Ames-Martínez *et al.*, 2022).

2.5. Modelling and validation of the model

The occurrence data were entered into an Excel file and then converted to a "CSV" format, compatible with the MaxEnt algorithm. The model was repeated ten times to increase accuracy. We randomly selected 25% of the presence records to build the testing model, and the rest of the data was used for training as observed by Nneji *et al.*(2020).

To analyze model accuracy, the area under the receiver operating curve (AUC) was calculated using receiver operating characteristics (ROC) analysis. Swets (1988) classified the AUC values into three categories: 0.5–0.7, 0.7–0.9, andAUC 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(Wei *et al.*, 2018). Jackknife analysis was used to determine which climatic variables were important for the distribution of *Anacardium occidentale*(Saha *et al.,* 2021).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 (Allouche *et al*., 2006).the calculation of the TSS was as follows Alloucheet al. (2006):

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 habitatswere 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.* (2023). 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 (Figure 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 bythe annual precipitation (bio12),and the temperature seasonality (bio4).The least contributing variable was the altitude (elev)as indicated onFigure 3.

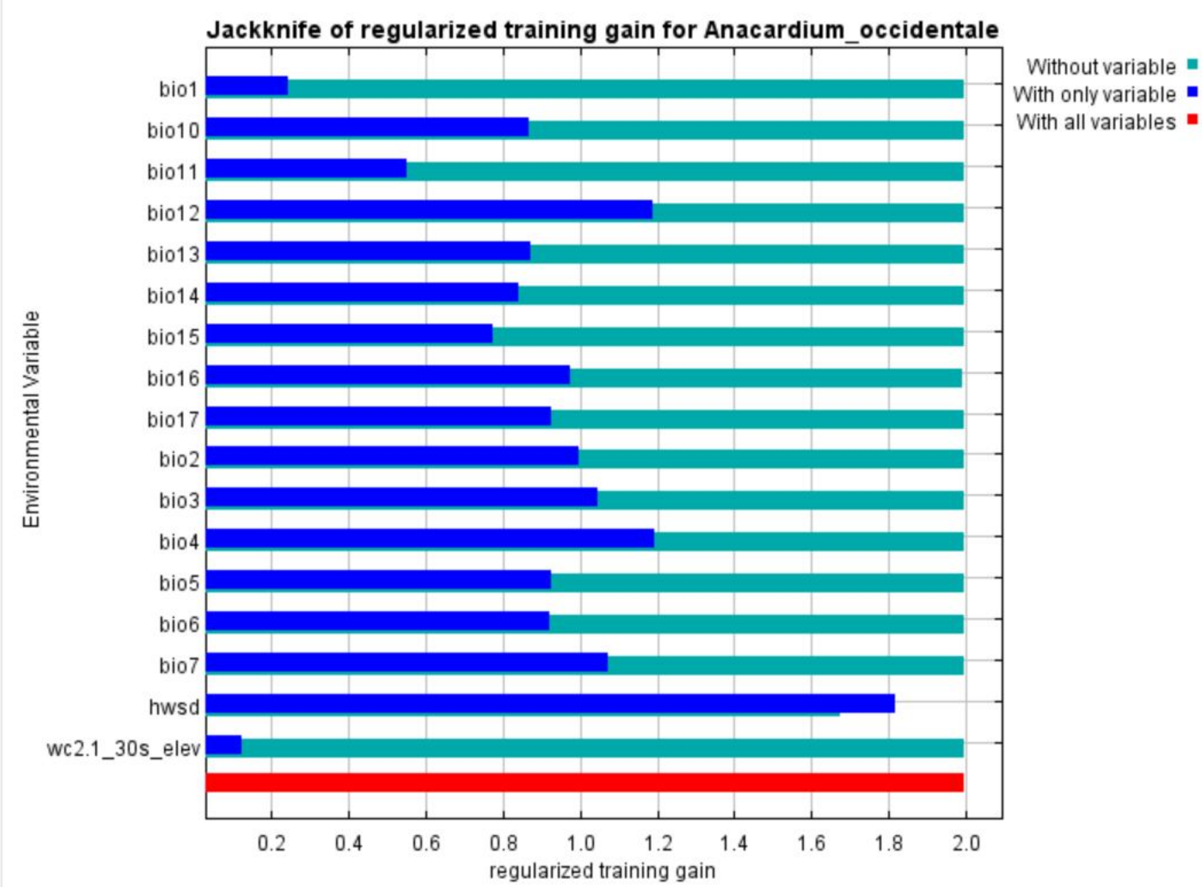

Figure 3: Contribution of variables in the modelling according to the Jackknife test

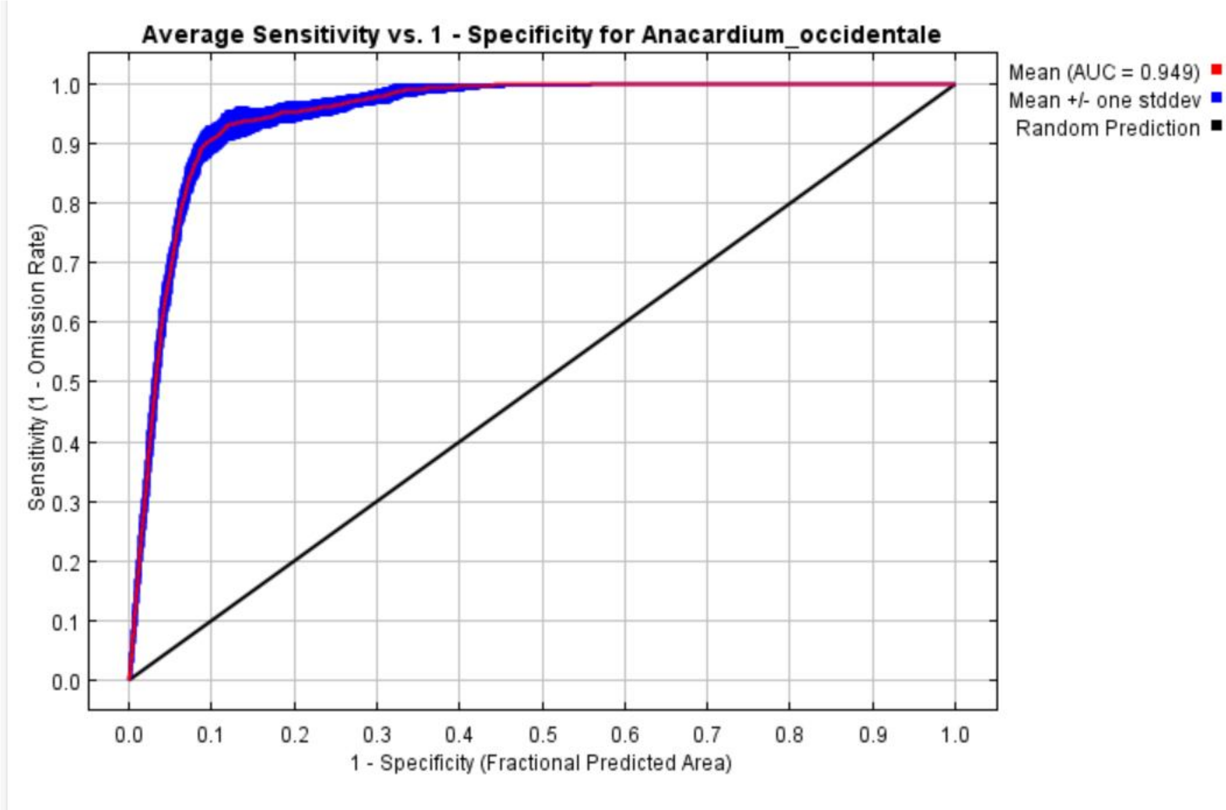

Figure 4: The Cross-validated areas under the receiver operating characteristic curve (AUC)

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 unfavourableareas account for 10.86% of the territory (Figures 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. (Figure 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 Figure 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 (Figure 7). With the HadGEM model using ssp245 and ssp585 scenarios, the regions defined as having high suitability will decrease (Figure 6). The results from the MIROC6 model using the ssp245 and ssp585 scenarios are shown in Figure 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) ofpotentially moderately favourable areas for *A. occidentale* under both scenarios (Figure 7).But for the MIROC6 modelthe 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 (Figure 7).

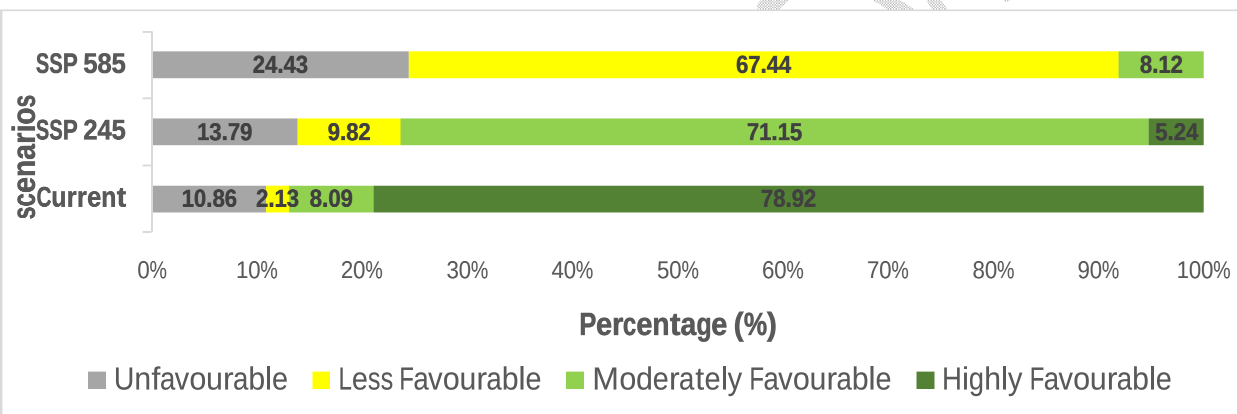

Figure 5: Proportion of current and potential future habitats according to MIROC6under ssp245 and ssp585 scenarios of the cashew tree in Togo.

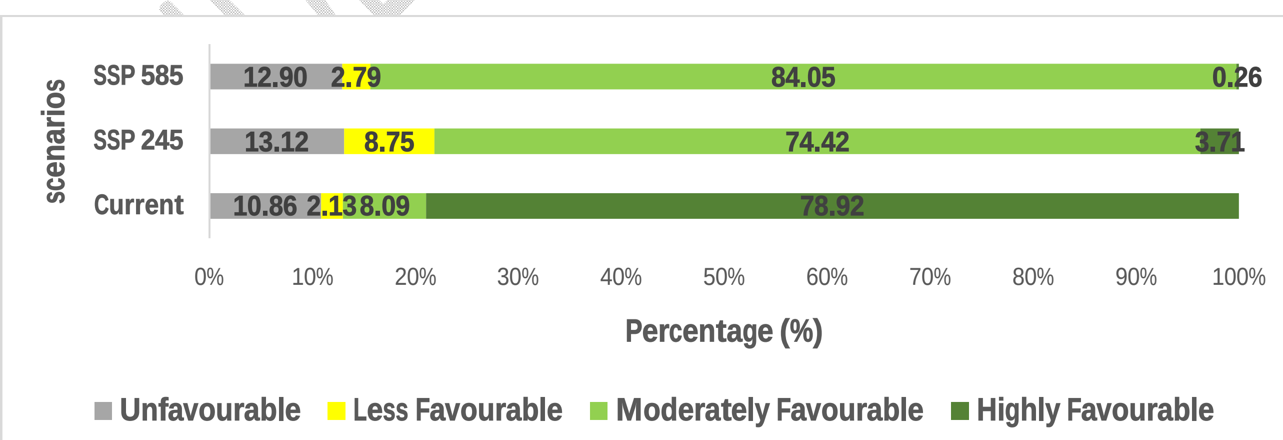

Figure 6: Proportion of current and potential future habitats according to HadGEM under ssp245 and ssp585 scenarios of the cashew tree in Togo.

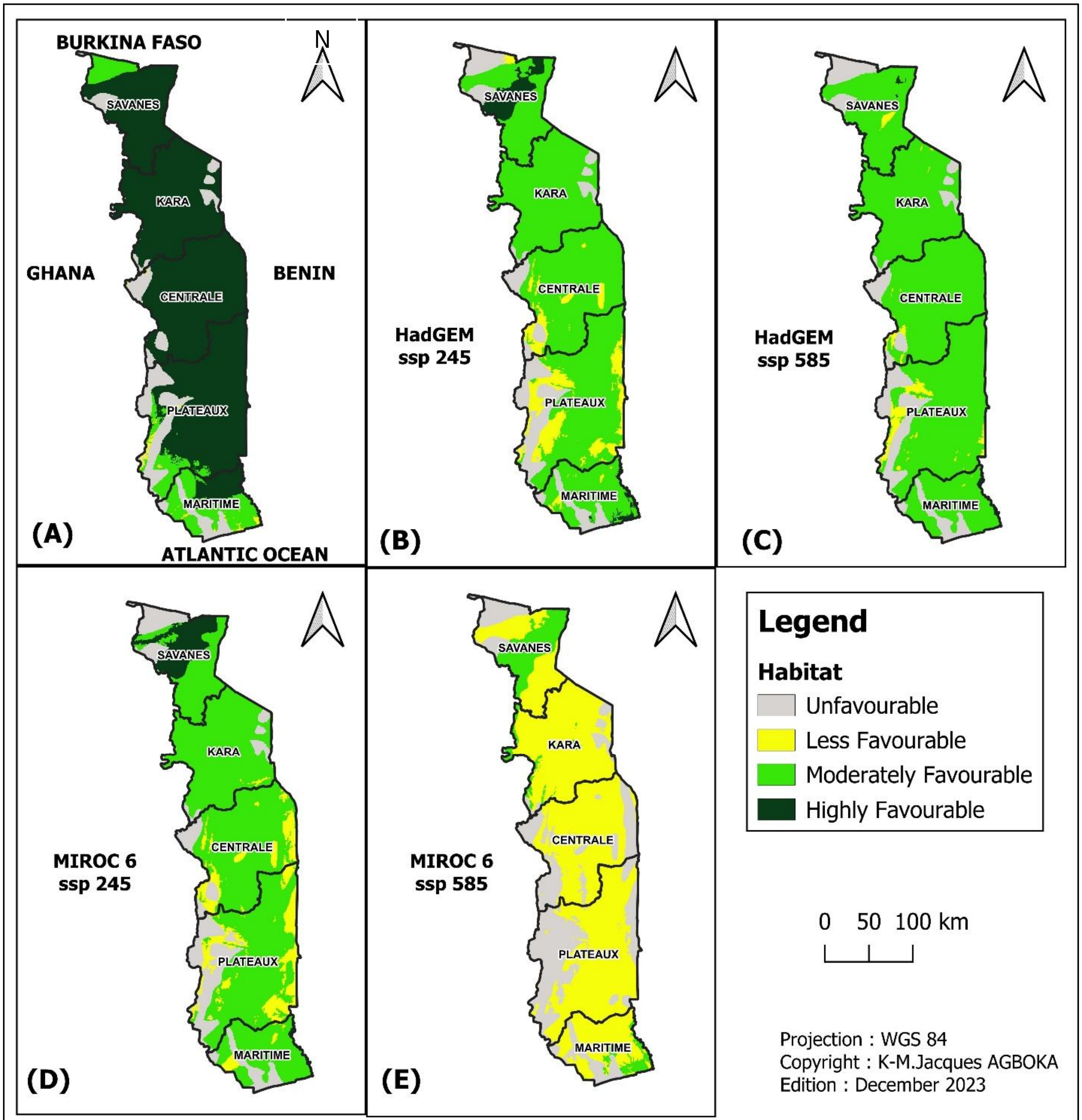

Figure 7: Current habitat suitability according to economic regions; and future potential distribution in 2050 for *Anacardium occidentale* in Togo, according to GCM-HadGEM

A, scenarios;B, ssp 245; C, ssp585 GCM-MIROC6, scenarios; D, ssp 245; E, ssp 585.

4. Discussion

4.1. Model reliability and variables contribution

The strength and validity of species distribution models depend on the input data. This study used themaximum entropy (MaxEnt) approach used by several authors in species distribution (Abdou *et al.,* 2016; Lyam *et al.*, 2012) for mapping potential growing areas of the cashew in Togo. This approach's strength is its ability to combine occurrence data and environmental variables across the study area(Lahoz-Monfort *et al.,* 2014). It also has the facility to run with quantitative and qualitative data simultaneously (Atakpama *et al.*, 2023). The value of the Area Under the Curve showed a good prediction of the cashew trees' geographic distribution in Togo. Currently, the less favourable habitat for cashew cropping is found in areas of high rainfall, particularly in the mountainous areas of the south and the coastal zone of Togo. The Kara and Central regions are highly favourable. This result is in line with the current cultivation areas of the species and is also consistent with the rainfall requirements of the cashew tree (Ricau, 2013).The future predictions according to both models and in all scenarios showed adecreasein the suitable habitat (highly favourable) when compared to the current suitable area (current > 2050).Edaphic factors are one of the environmental factors that can predict and affect species distribution, specifically plant species (Austin and Van Niel, 2011)and Mod (2016). The results of this study have shown that soil is a major factor in the spatial distribution of the cashew,followed respectively by the annual precipitation (bio12), and the temperature seasonality (bio4). Soil affects plants' physiological state, so its effect on the model is considerable. The implication of edaphic requirements of the cashew was stated by Gnahoua and Louppe (2003). The species does not thrive in clayey and flooded soils of lowlands such as those in the Maritime region of Togo. This situation could be linked to soil pH which was shown to affect considerable plant species distribution (Chytry*et al.*, 2003). The pH can affect soil resource availability and nutrientuptake by plants (Hossner, 2008). Seasonal temperature and precipitation define the soil moisture content (Mod, 2016). The contribution of the seasonality, the temperature, and the annual precipitation supports the findings of Lyam *et al.*(2012). These authors showed that temperature and precipitation are major factors in plant species and vegetation distribution. Both of these variables added to soil act directly in the spatial distribution of the cashew and could be the primary environmental parameters in the ecology of the species (Atakpama *et al.*, 2023).

4.2. Implications of future climate conditions

Predicting how the species might respond to climate change is a fundamental component in designing biodiversity conservation and management policies and also in making cashew nut production climate-resilient. Climate projections indicate that the area of habitat currently favourable for cashew cropping in Togo is expected to change according to HadGEM and MIROC6 and under both scenarios (ssp245 and ssp585). This could be becausethe cashew tree is unable to develop the capacity to adapt to climate change. In addition, we can also say that climate change will reduce the geographical distribution of cashew trees.These results are contrary to those of Atakpama *et al.* (2023), who found that climate change would not reduce the geographical distribution of cashew trees in TogoThis difference is due to the fact that in our study we used the Shared Socio-economic Pathways (SSPs) scenarios, whereas Atakpama *et al.*(2023) used the Representative Concentration Pathways (RCPs) scenarios.The predictive models used for the 2050 horizon showed that habitats highly favourable to cashew development will decrease. Considering the evolution of habitats with HadGEM, MIROC6and both scenarios ssp245 and ssp585, it is clear that climate change will be a threat to cashew cultivation in Togo. It is therefore a crop which is not resilient to climate change. In addition, biotic factors and anthropogenic disturbances can affect the species' niche distribution as indicated byMod (2016). Including natural disturbances such as herbivory, human settlements and density in the SDMs should be an excellent predictor of understanding the impact of climate change on the species niche (Atakpama *et al*., 2023). This can lead toan understanding of how temperature and rainfall change patterns could affect vegetation distribution. According to the prediction of HadGEM under ssp245 and ssp585 scenarios; and MIROC6 under ssp245 more than 50% will be adequate for the conservation/sustainable cultivation of cashew trees in 2050. The model MIROC6 has predicted that under the ssp585 scenario, the habitats currentlyhighly favourable to the species in Togo will be more affected by climate change because they will become less favourable.

Conclusion

This study assessed the effects of climate change in predicting the spatial distribution of potential cultivation area for cashew trees in Togo by 2050. The results show that soil is the most important predictor of the spatial distribution of cashew trees in Togo. Current climate conditions indicate that 78.92% of the country's land area is extremely suitable for cashew nut cultivation. For both models (HadGEM and MIROC6), the proportion of highlyfavourable habitats will decrease significantly by 2050 under two climate scenarios (ssp245 and ssp585). These findings will help cashew plantation farmers and the Ministry of Agriculture, Livestock and Rural Development to develop strong policies to increase the population's resilience to future climate conditions. Designating areas as potential sustainable growing areas for the cashew will also help improve the conservation status of A. *occidentale*.

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