Artigo

IMPACT OF CLIMATE CHANGE ON THE SUITABILITY OF \textit{Coffea arabica} CULTIVATION IN BRAZIL IN THE PERIOD 2040-2080

IMPACTO DAS MUDANÇAS CLIMÁTICAS NO PERÍODO 2040-2080 SOBRE A APTIDÃO DO CULTIVO DE \textit{Coffea arabica} NO BRASIL

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ABSTRACT: The objective of this work was to evaluate the impact of climate change on areas suitable for Arabica coffee cultivation under different climate change scenarios. The work was carried out for all of Brazil, using data from 1960-2020. The BCC - CSM 1 climate model was used to obtain future climate data for all RCP 2.6, 4.5, 6.0, 8.5 scenarios. All future scenarios of climate change showed a reduction in the total areas suitable for coffee cultivation in Brazil, with an average reduction of 50%. Furthermore, areas restricted by excessive heat and water deficiency were the most common throughout the country in the future scenarios, with an average of 63% of the entire territory.

KEYWORDS: CMIP5, Climate, Coffee.

RESUMO: O objetivo desse trabalho foi avaliar o impacto das mudanças climáticas sobre as áreas aptas para o cultivo do Coffea arabica nos diferentes cenários de mudanças climáticas. O trabalho foi realizado para todo o Brasil, sendo utilizado dados no período de 1960-2020. Ainda, para obtenção dos dados climáticos futuros foi utilizado o modelo climático o BCC – CSM 1, de todos os cenários RCP 2.6, 4.5, 6.0, 8.5. Todos os cenários futuros de mudanças climáticas demonstraram redução no total de áreas aptas ao cultivo do cafeeiro no Brasil, com redução média de 50%. Ainda, as áreas com restrição por excesso térmico e deficiência hídrica foram as mais comuns por todo o país nos cenários futuros, com média de 63% de todo território.

PALAVRAS-CHAVE: CMIP5, Clima, Café.
1. Introduction

The cultivation of coffee is pivotal in the global agricultural landscape, particularly in tropical and subtropical regions. It not only serves as a significant source of employment but also substantially contributes to the income of numerous communities, especially those engaged in family farming (MUÑOZ-RIOS; VARGAS-VILLEGAS; SUAREZ, 2020).

Coffee is regarded as one of the most widely traded commodities on a global scale, exerting a critical influence on international trade. Brazil, in particular, stands out as the world's foremost producer and exporter of coffee (DURMAZ; ZHENG, 2023). Brazilian coffee farming constitutes a major driving force behind the nation's economy, providing both direct and indirect employment opportunities across the entire production chain, from harvesting to exportation (DURMAZ; ZHENG, 2023).

In addition to its economic significance, coffee also holds cultural and social importance in many regions (TRIOLO et al., 2023). It is a beloved beverage enjoyed by people worldwide, often served as a symbol of hospitality and a means to gather friends and family. Numerous coffee-producing regions boast deeply rooted traditions related to cultivation, harvesting, and coffee preparation, passed down through generations (WOLDE et al., 2017).

Nevertheless, the coffee sector faces substantial challenges, including price fluctuations in the global market, climate-related issues, plant diseases, and environmental concerns. Consequently, coffee producers often seek ways to enhance sustainability and resilience in production (GIRMA, 2023).

Climate change has become an unprecedented global challenge in the 21st century (BATTISTI; NAYLOR, 2009). The scientific evidence is overwhelming: human activities are contributing to a significant increase in the Earth's average temperature (COOK et al., 2016). This phenomenon is causing cascading effects worldwide, and one of the most affected sectors is
food production (FRANZKE et al., 2022).

The rise in global average temperatures is an undeniable reality. In the last century, the global average temperature increased by approximately 1 degree Celsius, with a margin of error of about 0.2 degrees Celsius (FLETCHER, 2018). This change has already had considerable impacts on ecosystems, extreme weather events, and species distribution patterns (WALTHER et al., 2002).

The Intergovernmental Panel on Climate Change (IPCC) warned in its 2018 report that, if significant measures are not taken to reduce greenhouse gas emissions, we could face temperature increases between 1.5 degrees Celsius and a staggering 6 degrees Celsius by the end of the century (RHODES, 2019). These numbers represent an imminent threat to our ability to produce food sustainably.

The cultivation of Arabica coffee, one of the most cherished and economically important crops in many tropical regions of the world, is particularly susceptible to climate change (PHAM et al., 2019). Increased evaporation, prolonged periods of drought, and reduced soil water availability for plants are critical factors negatively impacting coffee production (DAMATTA; RAMALHO, 2006).

Therefore, the main objective of this study is to comprehensively assess the impact of climate change on suitable Arabica coffee cultivation areas in different climate change scenarios. This will involve a detailed analysis of temperature, precipitation, humidity patterns, and other relevant factors in various coffee-producing regions. Additionally, it will seek to identify adaptation and mitigation strategies that can be implemented to ensure the long-term sustainability of the coffee industry.
2. Materials and Methods

The climatic elements Air Temperature (°C) and Precipitation (mm) were collected from 4,947 meteorological stations of the Meteorological Database for Teaching and Research (BDMEP) of the National Institute of Meteorology of Brazil - INMET (Brazil, 1992), for the period 1960-2020 (Figure 1). The data from IPCC are the results of simulations from global models of some research centers contributing to the IPCC-AR5 report, forced by observed concentrations of greenhouse gases during the 20th century and forced by an estimated concentration for the 21st century (IPCC, 2013). The global climate model used was the BCC – CSM 1.1 developed at the Beijing Climate Center (BCC), with a resolution of 125 x 125 km, 26 vertical levels, and components including atmosphere, land surface, ocean, sea ice, terrestrial carbon cycle, and ocean biogeochemical cycles (Flato et al., 2014). Climate data for the RCP scenarios were collected through the WorldClim 2 platform.

Figure 1 – Explanatory Flowchart of Data Acquisition Steps.

Source: Own author.
To identify areas suitable, restricted, or unsuitable for coffee cultivation, ideal climatic suitability ranges for air temperature (°C), air temperature in November (°C), air temperature in the coldest month of the year (°C), and water deficit for C.arabica were used, following the works of the following authors: Camargo (1977), Matiello (1991), and Camargo and Pereira (1994). An explanatory flowchart of the work’s steps can be seen in the figure 2.

Figure 2 – Explanatory Flowchart of the Work’s Development Stages.

The software used in the study included Quantum GIS (QGIS) 3.16.4 for data interpolation and map creation, Python 3.10.0 for scripting and data processing, and Excel Version 2109 for statistical analysis.
3. Results and Discussion

The comprehensive study on the agroclimatic zoning of Coffea arabica, considering different scenarios of climate change, provides a crucial insight into the future of coffee production in Brazil. One of the most notable conclusions is the significant increase in areas considered unsuitable for coffee cultivation, while there is a considerable reduction in areas classified as suitable, as highlighted in Figure 1.

These changes directly affect important coffee-producing regions such as the states of Minas Gerais and São Paulo, where suitable cultivation areas are decreasing in all scenarios. However, it is interesting to note that parts of the southern region of the country are undergoing a transformation, shifting from unsuitable due to thermal insufficiency to becoming suitable for coffee cultivation, as clearly demonstrated in Figure 3.

The impact of these climate changes on coffee production is a growing concern. Regions with high altitudes, which were historically favorable for cultivation, may now face climate challenges that harm productivity. Furthermore, many of the new areas becoming suitable for cultivation do not possess the ideal altitude characteristics to stimulate the best development of coffee plants, as highlighted in a previous study by Carvalho et al. in 2019.

A significant portion of the Brazilian territory has shown changes in climate class in relation to current conditions, both in the scenarios for 2041-2060 and those for 2061-2080 (as illustrated in Figure 3). Regions such as western Mato Grosso and the state of Mato Grosso do Sul have shifted from classes characterized by restrictions due to excessive heat to those facing both thermal and water restrictions. This suggests that a potential increase in water deficit will have significant impacts on coffee plantations, given the coffee's high susceptibility to water stress.

In this context, the implementation of supplementary irrigation systems for coffee plantations emerges as a viable alternative to mitigate
the adverse effects of potential climate change scenarios. This strategy can significantly help reduce losses in coffee production in the country, as discussed by Moreira et al. in their 2021 study.

Figure 3 – Climatic Zoning for Coffea arabica in Brazil under Different Climate Change Scenarios.

![Figure 3](image-url)
3. Conclusions

The future climate changes may negatively impact coffee culture in all the studied RCP scenarios. All scenarios of the BCC - CSM 1.1 model show a decrease in the total suitable coffee cultivation areas in Brazil, with an average reduction of 50%. Furthermore, areas with restrictions due to excessive heat and water deficiency are the most common throughout the country in future scenarios, with an average of 62.95% of the entire territory.

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