Climate Change Scenarios and the Dragon Fruit Climatic Zoning in Brazil

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Abstract

BACKGROUND:

The presente paper aims to compute climatological zones apt for the cultivation of pitaya based on trends in the occurrence of climate change events from the IPCC in Brazil. We used temperature and precipitation data from 4,942 cities collected on the NASA / POWER platform from 1990 to 2020 to elaborate on the current scenario. The climate change scenarios were obtained using the CHELSA platform (Climatologies at high resolution for the earth's land surface areas) and corresponded to the periods 2041-2060 and 2061-2080 associated with four IPCC climate change scenarios. The spatialization and interpolation of data occurred according to the aptitude classes designed to meet the thermal and water needs of the crop.

RESULTS:

Forecasts of increase in temperature indices and reduction in accumulated rainfall were found in all Brazil, but with greater impact in the North and Northeast regions, which had the greatest reduction in areas at low risk for the cultivation of pitaya. In the South and Southeast regions, a large part of the areas remained suitable for the production of this fruit until 2080.

CONCLUSION:

The results suggest that climate change does not benefit the cultivation of pitaya in some regions of Brazil because the dimensions of the areas apt for economic production be restricted.

Introduction

The pitaya or dragon fruit is an exotic fruit culture attractive to the consumer due to its eccentric appearance and its nutritional, antioxidant and anti-inflammatory benefits (Tsai et al., 2019; Trivellini et al., 2020). Its agricultural and economic potential has promoted the expansion of cultivation to different regions of Brazil with varied climatic conditions. In addition, the rusticity of the pitaya combined with its ability to tolerate high temperatures has allowed the cultivation in different environments, especially under stress conditions, as found in semi-arid regions where conditions of high temperatures and long periods of water limitation in the soil are frequent (Sosa et al., 2020).

The production of this fruitful is conditioned to the climatic characteristics of the cultivation environments, which, when they present extreme conditions of temperature and precipitation, exert adverse consequences on the metabolism of the plants, thus affecting their growth and productive performance. In addition, the evident changes in the climate, promoted by the increase in the global average surface air temperature, have resulted in greater emission of greenhouse gases that influence the development of crops (Adefisan, 2018), as it contributes to reducing the availability of water to plants due to increased evaporation of water from the soil (Chen and Gong, 2020). In this context, variations in the climate scenario can reflect on the pitaya cultivation environment, which, associated with the genetic component, alters the phenology and harms production (Jamieson et al., 2012; Melo et al., 2020; Venancio et al., 2020). Therefore, the phenological stages of this crop (Figure 1) can change with variations in climates conditions, especially in the reproductive stage, which can vary from early to late, which directly influences the production and harvest time of the fruit.

To predict possible climate changes, the Intergovernmental Panels on Climate Change (IPCC) periodically prepare reports that allow estimating possible changes in the climate based on scenarios based on emissions and changes in the concentration of greenhouse gases, precipitation levels and variable thermal indexes (Taylor, Stouffer, Meehl, 2012). These IPCC scenarios indicate climate changes that impact crop development and plant adaptability to growing environments. Thus, a better understanding of these impacts can contribute to the development of strategies that minimize the effects of climate change on crops. For this, an important tool is climate zoning, which provides information on risk management and agricultural planning, in addition to helping to delimit the suitability of crops at macro-climatic and regional scales (Wollmann and Galvani, 2013).

Considering the accentuated macroclimatic variations that occur in Brazil and the high potential for cultivation of pitaya, Hylocereus and Selenicereus species, more elaborate studies are needed to obtain the climatic zoning associated with climate change scenarios, helping to identify and direct potential areas for the cultivation of this fruit in the Brazilian territory. Thus, this paper aimed to compute climatological zones apt for the cultivation of pitaya species Hylocereus and Selenicereus based on IPCC climate change scenarios.

Materials And Methods

This study was developed in Brazil, which has a territorial area of 8,510,345.5 km^2 (IBGE, 2020) and has different climate classes or life zones according to Holdridge, with the predominant basal tropical moist forest life zone (60.57%) in the country, occupying the largest part of the territory of the North, Midwest and Northeast regions (Figure 2).

Climatic data of average air temperature (°C) and rainfall (mm) from 4,942 cities, distributed throughout the Brazilian territory (Figure 2) and collected in the period 1990-2020, were used to elaborate the scenario of current conditions of temperature and rainfall in Brazil. These data were obtained from the platform National Aeronautics and Space Administration / Prediction of Worldwide Energy Resources – NASA / POWER, providing meteorological data with spatial resolution of 1° latitude-longitude (Stackhouse et al., 2015). The climate variables collected were spatialized using the geographic information system (GIS) and interpolated by ordinary kriging in the spherical model, one neighbor and a spatial resolution of 0.25° (Krige, 1951).

Climate change scenarios were obtained using temperature and precipitation projection data extracted from the BCC-CSM1-1 model (Xiao-ge et al., 2013) available on the CHELSA V1.2 platform (Climatologies at high resolution for the earth's land surface areas - https://chelsa-climate.org) (Karger et al., 2017). The model was executed at the National Center for Atmospheric Research (NCAR) (Xiao-ge et al., 2013) and corresponded to the intervals to 2041-2060 and 2061-2080 associated with four representative concentration pathways (RCPs) scenarios that predict policy actions on greenhouse gas emissions. The RCPs scenarios are part of phase 5 of the coupled model intercomparisons project (CMIP5) (Taylor et al., 2012) and participate in the assessment in the fifth report issued by the IPCC AR5 (IPCC, 2013).

RCPs represent a range of radiative forcing values ranging from 2.6 to 8.5 W m^{-2} for the year 2100 (Van Vuuren et al., 2011). Thus, this work evaluated four scenarios corresponding to a low greenhouse gas emission scenario (RCP 2.6), two intermediate scenarios (RCP 4.5 and RCP 6.0), and a scenario with high emissions (RCP 8.5) (IPCC, 2014).

Global climate model (GCM), were used because they are the most suitable tools to generate climate projections in studies of climate change in hydrology and water resources (Zamani and Berndtsson, 2019). The Beijing Climate Center (BCC) Climate System Model version 1.1 (BCC-CSM1.1) has a resolution of 280 km (Xin et al., 2018; Wei et al., 2019) and is characterized as a climate system model coupled which includes atmosphere, ocean, land surface, and sea ice (Wu et al., 2013).

Classes of annual thermal and water requirements for the cultivation of pitaya species Hylocereus and Selenicereus were elaborated to obtain and represent the ranges of high, medium, and low aptitude for the development of pitaya plants (Figure 3). Temperature indices between 18 and 26°C were considered adequate to promote greater production and optimal fruit development (Donadio, 2009; Mizrahi, 2014; Vázquez et al., 2020). On the other hand, temperatures below 18 ºC cause fruit drop and increase the time for fruit development (Nerd and Mizrahi, 1998; Nerd et al., 2002). While high temperatures, above 26 ºC, promote a reduction in productivity and abortion of flower buds (Nerd and Mizrahi, 1998; Nerd et al., 2002; Zee et al., 2004; Mizrahi, 2014; Trivellini et al., 2020).

Annual rainfall between 600 and 2000 mm was considered adequate for the development and greater production of plants (Donadio, 2009; Zee et al., 2004, Paulli and Duarte, 2013). Rainfall smaller than 600 mm was considered to cause low yield due to water stress, as well as rainfall above adequate that causes damage to the root system, flowers and fruits, and consequently, low fruit yield (Merten, 2003). The development of all the analyzes used in the work followed the steps informed in the flowchart in Figure 4.

Results And Discussion

Brazil has an average annual rainfall of 1.987 (±725) mm (Figure 5A). However, the accumulated rainfall between the Brazilian regions is very different, with a variation of 409 to 3.625 mm in the Northeast and North regions, respectively. These results indicate the existence of different climatic classes between and within regions of Brazil, which configures in different climatic conditions as observed by Alvares et al. (2013). Among the Brazilian states, the highest annual precipitation index (2,999.79 ± 305.32 mm) was observed in the state of Amapá (AP), while the lowest indexes (800.86 ± 213.18 mm) were registered in the state of Rio Grande do Norte (RN), results similar to those observed by Moraes et al. (2020) and Oliveira et al. (2017).

In the last three decades, the annual average temperature was 22.20 (±3.20) ºC with index varying from 13.11 to 28.01 ºC among Brazilian states, with the lowest values registreds in the South region, and the highest in the North and Northeast regions (Figure 5B). In addition, the states of Amapá (27.10 ± 0.46 ºC) and Santa Catarina (18.02 ± 1.51 ºC) corresponded to the localities with the highest and lowest average air temperature, respectively. These results were similar to those found by Casaroli et al. (2018).

In the climate change scenarios for the period 2041-2060, decreasing trends in the volume of rainfall distributed in Brazil were observed (Figure 6) when compared to the current scenario (Figure 5A). Among the RCPs scenarios, the highest mean annual precipitation (1,827 ± 677 mm) was found in RCP 2.6 (Figure 6A). However, the RCP 4.6, RCP 6.0, and RCP 8.5 scenarios presented mean annual precipitation of 1,772 (±637), 1,731 (±603), and 1,808 (±657) mm, respectively (Figures 6B, C and D). In the period 2061-2080, the spatial distribution of precipitation did not differ from the variation that occurred in the period 2041-2060, with similar precipitation volumes (Figure 7). The RCP 2.6 scenario showed greater rainfall accumulation (1,835 ± 638 mm) (Figure 7A), while lower rainfall volumes (1,741 ± 644 mm) were recorded in the most intense climate change scenario - RCP 8.5 (Figure 7D). Precipitation accumulations of 1,790 (±659) and 1,750 (±635) mm were observed in scenarios RCP 4.5 and RCP 6.0, respectively (Figures 7B and C).

Weather events in all RCPs scenarios showed variations in rainfall volumes in all regions of Brazil, with greater impact in the Northeast region, which had an increase in areas characterized with precipitation < 750 mm, and in the North region, which presented higher rainfall volumes. These conditions are adverse for the cultivation of pitaya and can make economic production unfeasible because they do not meet the proper requirement for plant development (Donadio, 2009; Paulli and Duarte, 2013). Although from the Cactaceae family, the pitaya does not adapt to environments with annual rainfall below 600 mm due to water stress, as well as environments with high rainfall above 2,000 mm annually, where damage to the root system and low fruit production can occur (Merten, 2003).

Climate change projections for the period 2041-2060 indicated an increase in mean air temperature indices compared to the current scenario, especially in the North and Northeast regions (Figure 8). The RCPs scenarios presented mean temperature increases of up to 4.34 ºC, establishing greater increments in RCP 8.5, which had mean temperature indices of 26.54 (±2.40) °C (Figure 8D). In addition, the average temperature gradually increased with the variation in the intensity of the RCPs scenarios, with territorial expansion of the temperature indices between 27-30 ºC in the North and Northeast regions (Figure 8). Although with an increase in temperature, the RCP 2.6 scenario had less impact on temperature changes (25.54 ± 2.28 ºC) compared to the other scenarios (Figure 8A). For scenarios RCP 4.5 and RCP 6.0, the mean temperatures found were 26.06 (±2.30) °C and 26.10 (±2.31) °C, respectively (Figure 8B and C).

In period 2061-2080, the RCP scenarios showed increasing trends in the average air temperature similar to those observed in the period 2041-2060. The occurrence of temperatures between 27-30 ºC was spatially higher in climate change scenarios, especially in RCP 8.5, which promoted high temperatures in the North, Northeast, and Midwest regions of the country (Figure 9D). In this scenario, the highest temperatures were found with mean values around 27.62 (±2.42) ºC. On the other hand, smaller increments in the mean temperature were registered in the scenario RCP 2.6 which had indices of 25.36 (±2.29) °C (Figure 9A).

These thermal changes do not benefit pitaya production because they inhibit the formation of flower buds, directly promoting a reduction in production (Nerd and Mizrahi, 1998; Nerd et al., 2002; Mizrahi, 2014). Temperature indexes above 38 ºC shorten the duration of flower bud development, which results in low fruiting and fruits with reduced weight (Chun and Chang, 2020), and promotes a 15 to 20% reduction in flower production (Nerd et al., 2002). In this context, pitaya crops in the North and Northeast regions would have productive and economic damages due to the predicted thermal changes until 2080.

Brazil has an aptitude for the cultivation of pitaya (*Hylocereus* spp and *Selenicereus* spp) in 37.07% of its territory, where the Midwest, Southeast, and Northeast regions, and the Paraná state are classified as having a high aptitude for the cultivation of this fruit (Figure 10). In these regions, the areas located in the states of Mato Grosso do Sul (MS), Goiás (GO), and Espirito Santo (ES) represented a low risk for cultivation of pitaya in 100%, 98.82%, and 98.05% of their territories, respectively (Figure 11).

The regions with medium aptitude represented 36.31% of the Brazilian territory, located in the northwestern portion of the North region, the northern portion of the Northeastern region, southern Minas Gerais state, and in the southern states (Figure 10). The average aptitude of the South region is represented by environments with low temperatures, while in the areas of the North region it is influenced by the occurrence of high rainfall. The states with the largest territory with the medium aptitude class were Acre (AC), Rondônia (RO), Roraima (RR), Maranhão (MA) and Santa Catarina (SC) (Figure 11).

In addition, the development of regional research within the field of evaluating the performance of different species of Pitaya, can help identify the most productive cultivars adapted to local conditions edafoclimátológicas.

The unfavorable environments for the cultivation of pitaya were classified as having low aptitude or high cultivation risk, being located in a large part of the North region of Brazil. Conform figure 5, the North region is characterized by the occurrence of high temperatures and a large volume of rainfall, climatic conditions that are inadequate for the cultivation of pitaya because excessive soil moisture impairs root development and high temperatures make the formation unfeasible. of flower buds (Merten, 2003; Nerd et al., 2002; Mizrahi, 2014; Chun and Chang, 2020). Thus, the states that showed low potential for cultivation of pitaya were Amapá (AP) and Pará (PA), with 100% and 93.53% of the territory classified as high risk for cultivation, respectively (Figure 11).

The estimate of climate change for 2041-2060 showed a reduction in areas apt for the cultivation of pitaya, mainly in the Northeast and Midwest regions (Figure 12). This reduction varied according to the intensity of climate change scenarios, where low risk areas (high aptitude) reduced by 25.25%, 24.94%, 28.17%, and 21.37% with scenarios RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, respectively. In the RCP 2.6, RCP 4.5, and RCP 6.0 scenarios, environments with high aptitude were predominant in the states of São Paulo (SP), Rio de Janeiro (RJ), Minas Gerais (MG), Espirito Santo (ES), Paraná (PR), and Rio Grande do Sul (RS) (Figures 13A, B and C).

The RCPs scenarios promoted the greater spatial distribution of the medium aptitude class that occupied over 40% of the Brazilian territory. Among the scenarios, RCP 2.6 indicated the largest spatial distribution (44.50%) of the medium aptitude class (Figure 12A), showing the states of Piauí (PI), Maranhão (MA), and Ceará (CE) with the greatest predominance of the class because it occupied 94.55%, 94.01%, and 91.97% of the territory, respectively (Figure 13). In RCP 6.0 scenario, areas of medium aptitude occupied 42.05% of the Brazilian territory and predominated in the North and Northeast regions (Figure 12C).

Regardless of the CPR scenario, areas of low aptitude or high risk were predominant in the North region. However, this class had greater expansion in RCP 6.0 and RCP 8.5, representing 29.77% and 32.34% of the country's territory (Figures 12C and D) and more frequently in the states of Amapá (AP) and Amazonas (AM) (Figures 13C and D).

The results of pitaya climate zoning under changing climatic for the range 2061-2080 were similar to those observed in the period 2041-2060 (Figure 14). Low aptitude environments were more frequent in the North and Northeast regions, being expanded with climate change scenarios. In the Northeast region, high risk areas for cultivation increased in the RCP scenarios, especially in Pernambuco state, which had 35.73%, 45.24%, 39.35%, and 59.48% of its territory classified as unsuitable for cultivation of pitaya in the RCP 2.6, RCP scenarios 4.5, RCP 6.0, and RCP 8.5, respectively (Figure 15).

Areas apt or at low risk for cultivation had a higher occurrence in the South, Southeast, and Midwest regions (Figure 14). However, this class was reduced under the conditions of climate change scenarios, occupying 32.92%, 24.19%, 23.03%, and 14.46% of the areas of the Brazilian territory with scenarios RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, respectively.

These results indicate that the increase in temperature reduced the size of potential areas for pitaya production in the 2041-2060 and 2061-2080 periods, except in the Southeast region. However, the increase in temperature has transformed areas in the South region currently with medium aptitude in highly favorable areas in the future for the cultivation of pitaya. In this case, the climatic dynamics can cause the migration of this crop. Therefore, it can be established that thermal and precipitation changes negatively affect the expansion of pitaya cultivation in Brazil and that there is a risk of production losses in established orchards. Thus, climate modeling associated with future climate scenarios can contribute to filling knowledge gaps that help to establish resilience strategies for the production of pitaya against the effects of climate change.

Conclusion

The IPCC forecast scenarios showed increases in temperature indices and a reduction in the volume of rainfall in all Brazil, but with greater change in climate indices in the RCP 8.5 scenario in both periods, 2041-2060 and 2061-2080. These changes had a greater impact in the North and Northeast regions, causing an intense reduction in areas considered apt or of low risk for the production of pitaya. The intensity of climate change favored the increase in climate risk in the areas of the Center-West region, while the South and Southeast regions remained apt for the production of pitaya until 2080. Thus, it is suggested that the climate changes predicted by the IPCC will not be beneficial for the cultivation of pitaya in Brazil, especially in the North and Northeast regions because the dimensions of the areas apt for economic production may be restricted.

Declarations

Conflict of Interest: The authors declare that they have no conflict of interest.

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Authors' contributions:

Rafael F. Lima: Formal analysis, Conceptualization, Methodology, Investigation;

Alexson F. Dutra: Data Curation, Original draft, Writing - Review & Editing; Lucas E. O. Aparecido: Project administration, Term, Conceptualization, Methodology, Investigation, Writing - Original draft, Writing – Review & Editing; Francisco de Alcântara Neto: Writing - Review & Editing; Guilherme Botega Torsoni: Term, Funding acquisition, Conceptualization, Writing - Review & Editing; Marcos Renan Lima Leite: Visualization, Writing Original draft, Writing - Review & Editing.

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Code availability: The software used was python and scripts are available

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Consent to participate: All authors approved

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Figures

Figure 1

Pitaya phenological stages.

Figure 2

Location map of the study area and virtual stations.

Figure 3

Key to the climate zoning of the pitaya.

Figure 4

Flowchart of the methodology used in this study.

Figure 5

Precipitation annual A) and average annual temperature B) for the current scenario in Brazil.

Figure 6

Average annual precipitation for the period 2041-2060 under different climate change scenarios (RCP).

Figure 7

Average annual precipitation for the period 2061-2080 under different climate change scenarios (RCP).

Figure 8

Annual average temperature for the period 2041-2060 in different climate change scenarios (RCP).

Figure 9

Annual average temperature for the period 2061-2080 in different climate change scenarios (RCP).

Figure 10

Aptitude zoning or climatic risk for the cultivation of pitaya in Brazil under current climatic conditions.

Figure 11

Distribution of aptitude classes for pitaya cultivation in Brazilian states under current climatic conditions.

Figure 12

Aptitude zoning or climate risk for pitaya cultivation in the period 2041-2060 under different climate change scenarios (RCP).

Figure 13

Distribution of aptitude classes for pitaya cultivation in Brazilian states for the period 2041-2060 under different climate change scenarios (RCP).

Figure 14

Aptitude zoning or climate risk for pitaya cultivation in the period 2061-2080 under different climate change scenarios (RCP).

Figure 15

Distribution of suitability classes for pitaya cultivation in Brazilian states for the period 2061-2080 under different climate change scenarios (RCP).