Preliminary analysis for agroclimatic zoning proposal for peach tree cultivation in Mozambique

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10.1590/0034-737X202370040003

ABSTRACT

Mozambique is a country located in the southwest of the African continent. The country has great climatic diversity. The tropical monsoon (Am), tropical savanna (Aw), hot semiarid (BSh), and humid subtropical (Cwa and Cfa) and subtropical highland (Cwb) climates stand out. The regions classified a subtropical have climatic potential for the rational exploitation low and medium chill requirement of peach trees. There are already technologies for the cultivation of peach trees in subtropical regions in Brazil. The objective of this study was to identify the zoning of suitable areas and provide bases for the establishment and expansion of peach cultivation in Mozambique. Meteorological data from 108 stations and the geotechnological tool ArcGIS 10.1 were used to spatialize temperature, rainfall, and humidity data and then reclassify them for the generation of maps using the Geostatistical Analyst extension. In parallel, maps of mean annual temperatures and climate classification were used. Regions in the subtropical areas of Mozambique with suitable temperature and rainfall are viable for peach plantations. The results showed the Northwest, Central and South regions is more suitable for the economic exploitation of peaches trees.

Keywords: climate classification; peach; *Prunus persica* L.

INTRODUCTION

The peach tree (*Prunus persica* L. Bastsch) is a fruit tree belonging to the family *Rosaceae* of Asian origin. Because it is a temperate fruit tree, it has a dormancy mechanism (Pio *et al.*, 2018).

Temperate fruit trees to regions with defined climatic seasons. In these regions, temperatures are appropriate for growth during spring and summer. In fall and winter, to survive low temperatures, temperate fruit trees have developed an adaptation mechanism that involves the acquisition of chilling resistance and growth control, known as dormancy (Erez, 2000).

Dormancy is the mechanism by which temperate fruit trees protect plant tissue, which is sensitive to unfavorable climatic conditions, especially below freezing temperatures (Campoy *et al.*, 2011). In turn, the lack of a sufficiently chilling period or a long winter and, consequently, the nonbreaking of dormancy alter the flowering and leafing of temperate fruit trees. This promotes leafing and erratic flowering, with a reduction in the number of buds sprouted and plant growth, the shortening of internodes, the growth of vertical branches, low fruiting, deformed fruits and, in more severe conditions, plant death. (Campoy *et al.*, 2011).

The main obstacle in the production of temperate fruits in the tropics is to break the dormancy period (Erez, 2000). However, through genetic improvements, there are culti-

Submitted on January 18th, 2022 and accepted on November 02nd, 2022.
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vars with fewer chilling requirements that can be grown in subtropical zones (Souza *et al.*, 2019). Some low chilling peach cultivars do not enter into deep endodormancy and are, therefore, able to respond to external cues of growth and development (Citadin *et al.*, 2022).

The exploitation of peach trees in subtropical regions has expanded, especially in Brazil. In this sense, there has been an intensification of studies related to genetic improvements, and dozens of cultivars can be grown in regions with mild or practically nonexistent winter (Scariotto *et al.*, 2013 and Citadin *et al.*, 2014; Tadeu *et al.*, 2019). A series of studies was conducted to adapt culture management techniques for peach cultivation in the tropics (Pio *et al.*, 2018).

The adoption of peach cultivars that require less chilling in mild winter regions makes it possible to harvest fruits in periods with lower supply (Barbosa *et al.*, 2010) because the harvest of early peaches in subtropical regions occurs earlier in the season compared to that in traditional temperate regions (Araújo *et al.*, 2008).

Mozambique is a country located in the better south or southeast, but not southwest of the African continent. The country has great climatic diversity. In subtropical zones, the exploitation of the peach tree, may be possible.

In the tropics, compared to the dry season, in which droughts of variable duration are frequent, the rainy season is characterized by greater rainfall intensity and frequency (Moraes *et al.*, 2005; Uele *et al.*, 2017). In this regard, agricultural zoning, based on the climate and soil potential of a region, and adversities are of high relevance.

The rainy season is characterized by remarkable spatial fluctuation; therefore, the use of different agricultural calendars for each state or region of a country is advised (Moraes *et al.*, 2005). The mapping of climatically homogeneous microregions can establish compatible indicators for the rational exploitation of crops. The use of geographic information systems (GIS), remote sensing, and spatial analysis are useful for developing strategies to select potential species for cultivation. GIS has played a key role in zoning studies and zone identification, adding knowledge and providing information (Sá Júnior *et al.*, 2012).

Zoning for peach cultivation may inform producers regarding appropriate regions for peach production in Moçambique. The main objective of this study is to Preliminary analysis for agroclimatic zoning proposal for peach cultivation in Mozambique.

MATERIAL AND METHODS

Characterization of the área

The study region is located on the eastern coast of Southern Africa and is bordered by Tanzania (north); Malawi and Zambia (northwest); Zimbabwe, South Africa and Swaziland (west); South Africa (south); and the section of the Indian Ocean known as the Mozambique Channel (east). The region is approximately located between 10° S and 27° S latitude and between 30° E and 41° E longitude (Figure 1) and it has a total area of 801,590 km² (Anuário Estatístico 2019). Only a small portion of its territory, where its capital is located, is south of the Tropic of Capricorn in the South Temperate Zone.

Spatialization of meteorological data

The agroecological zoning for peach tree cultivation in Mozambique consisted of following the cultivation standards in terms of the number of hours of chill required for plant development, related to plant budbreak (Lang *et al.*, 1987), in addition to the mean, maximum, and minimum annual rainfall, humidity, and temperatures.

Rainfall frequency at the existing stations was determined based on statistical calculations of the data observed between 01/1989 and 12/2019, accounting for 30 years of monthly data obtained using a conventional rain gauge. The historical series of frequencies over the years during the study period was analyzed, totaling 108 record points, and rainfall, air temperature, and humidity were analyzed were collected from the Food and Agriculture Organization (FAO) website, climwat 2.0 for cropwat 8.0 (FAO, 2021).

The total rainfall of each year from 01/1989 to 12/2019 was compared to the rainfall index for the period, which was obtained from the mean annual rainfall in the study.

Minimum, mean, and maximum temperatures were also used for the meteorological data. A multiple linear regression was calculated in which the mean temperature was adopted as the dependent variable and longitude and altitude were adopted as the independent variables. Latitude was not considered because it has collinearity with longitude. Map algebra was used after acquiring the multiple linear regression coefficients (Table 1), based on equation 1, and a matrix image of the mean temperatures of the states of Mozambique was obtained (Gasparini *et al.*, 2015).

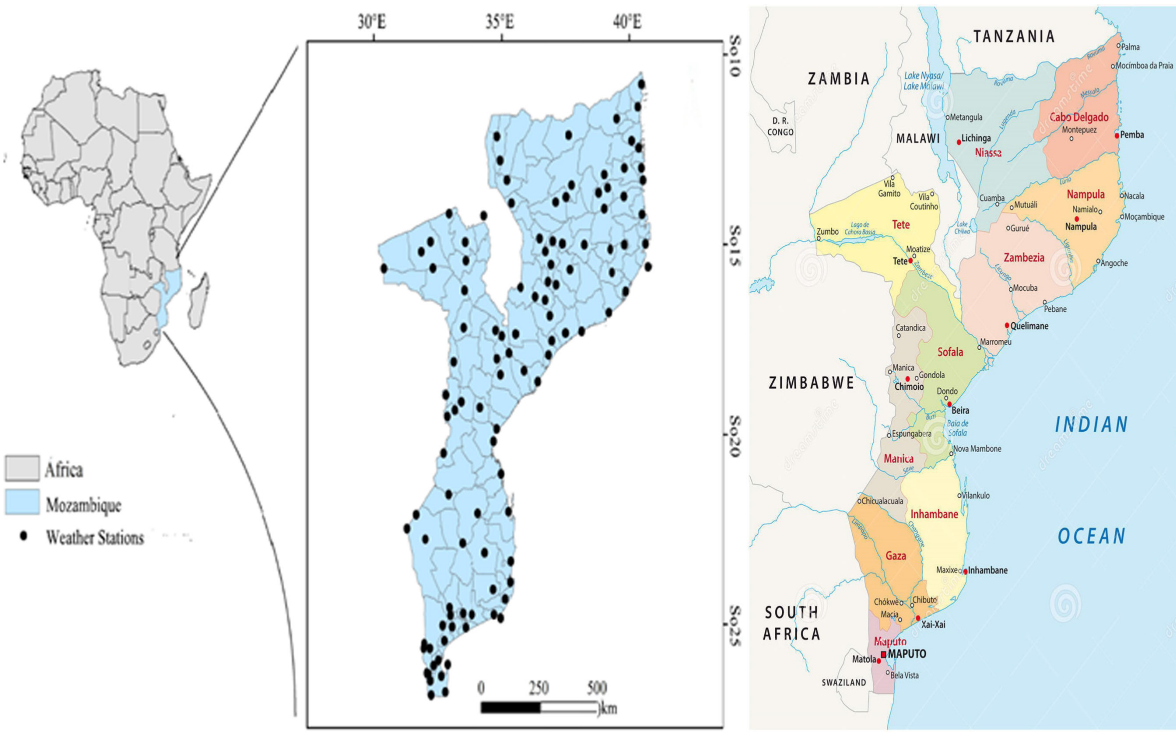

Figure 1: Map showing Mozambique with its administrative divisions and spatial distribution of weather stations - Africa. Source: https://www.worldatlas.com/maps/mozambique.

Table 1: Multiple linear regression statistics were used to estimate the mean temperatures of Mozambican states and to produce maps

Variables	Coefficients	Statistics-t	P-value
Intercept	24.63701	141.6269	1.2E-122 *
Altitude	-0.00317	-8.70249	4.61E-14 *
Longitude	-1.19512	-37.0967	0.0654

*significant p-value ($p < 0.05$).

$$\text{Temp}: \beta_o + \beta 1\chi + \lambda + \beta 2\chi Z$$

where: *Temp*: mean temperature (ºC); β_o: Intercept; β: Coefficient; λ: Longitude (decimal degrees); $\beta 2$: Coefficient; and Z: Altitude (m).

Sum of chilling the hours of below 7.2 °C were calculated for the period between May and September using a model adjusted for Mozambique based on the model reported by Damario *et al.* (1999), who estimate the hours of chilling from minimum air temperature data. The Köppen climate classification for Mozambique was used to aid in the determination of regions for peach cultivation (Köppen, 1931).

The mean rainfall, mean temperature and mean humidity for the previous 30 years were input, and spatial interpolation using the ordinary kriging method was applied through the ArcGIS Geostatistical Analyst extension, with statistical adjustment of the exponential semivariogram according to Cecílio *et al.* (2012) to generate the matrix image of the mean annual rainfall, mean annual temperature, and mean annual humidity, which were obtained from the 108 weather stations; the stations were located based on altitude and coordinates of the parallels, latitude, longitude to generate maps in ArcGIS version 10.1. Adjacent data for the creation of maps were collected from the Food and Agriculture Organization (FAO) website, climwat 2.0 for cropwat 8.0 (FAO, 2021). The maps were generated at the Department of Water Resources of the Federal University of Lavras (UFLA), Lavras, MG, Brazil.

RESULTS

The Figure 2A showed that the coastal region of Mozambique has the highest rainfall. This is believed to be due to the boundary zone between the ocean and mountains. In the west, annual rainfall exceeds 500 mm, with fluctuations depending on latitude. In the western region, chilling fronts enter the country, normally providing hot and humid summers and lower mean temperatures and rainfall in winter (Figure 2B).

Regarding rainfall, the country does not have areas with rainfall scarcity, and the highest indices occur in the Center, North, and Southern Coastal regions (Figure 2A).

Based on the distribution of mean annual rainfall and temperature, the areas that are potentially suitable for peach tree cultivation are located in the Northwest regions of the provinces of Niassa, the central regions of the provinces of Tete and Manica, the South regions of the provinces of Maputo already produce peach and are the provinces where the exploitation is most significant, as they are at higher altitudes. In these areas, the climate is characterized by mild temperatures with a mean annual temperature of not more than 24 °C (Figure 2B) and rainfall ranging between 800 and 1000 mm (Figure 2A).

In some regions, the mean annual rainfall in the areas at lower altitudes, such as the provinces of Zambezia, Nampula and Cabo Delgado, varies between 200 and 1,000 mm. The southern zone comprises the entire coastal strip of Gaza and approximately the entire province of Inhambane to the Save River. In this zone, the rainfall varies from 600 to 800 mm, and rainfall irregularity can cause periods of drought during traditional rainy seasons (Figure 2A).

Based on high air humidity displayed in Figure 2C, the regions of Niassa, with humidity ranging from 78 to 84% (green color), Nampula and Zambezia, with humidity ranging from 84 to 90% (light blue color), and the regions of Zambezia and Gaza, with humidity ranging from 90 to 96% (dark blue color), are zones in which fungal diseases are more likely to occur.

The temperatures shown in Figure 3 are those that occur, on average, every year in several regions, meaning that in some regions, the temperatures are high and may hinder the minimum amount of chill necessary for the development of peach cultivars recommended for subtropical and tropical regions.

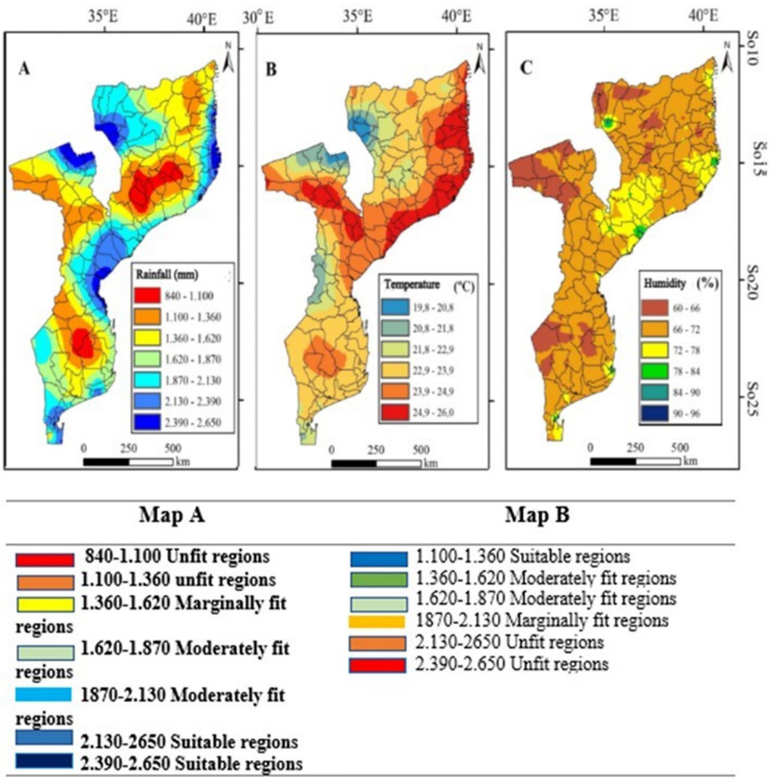

Figure 2: Climatic zoning to determine areas suitable and unfit for peach cultivation, based on rainfall (A), temperature (B), and humidity (C) in Mozambique averages recorded from 1989 to 2019. Data extracted from the FAO website (FAO, 2021).

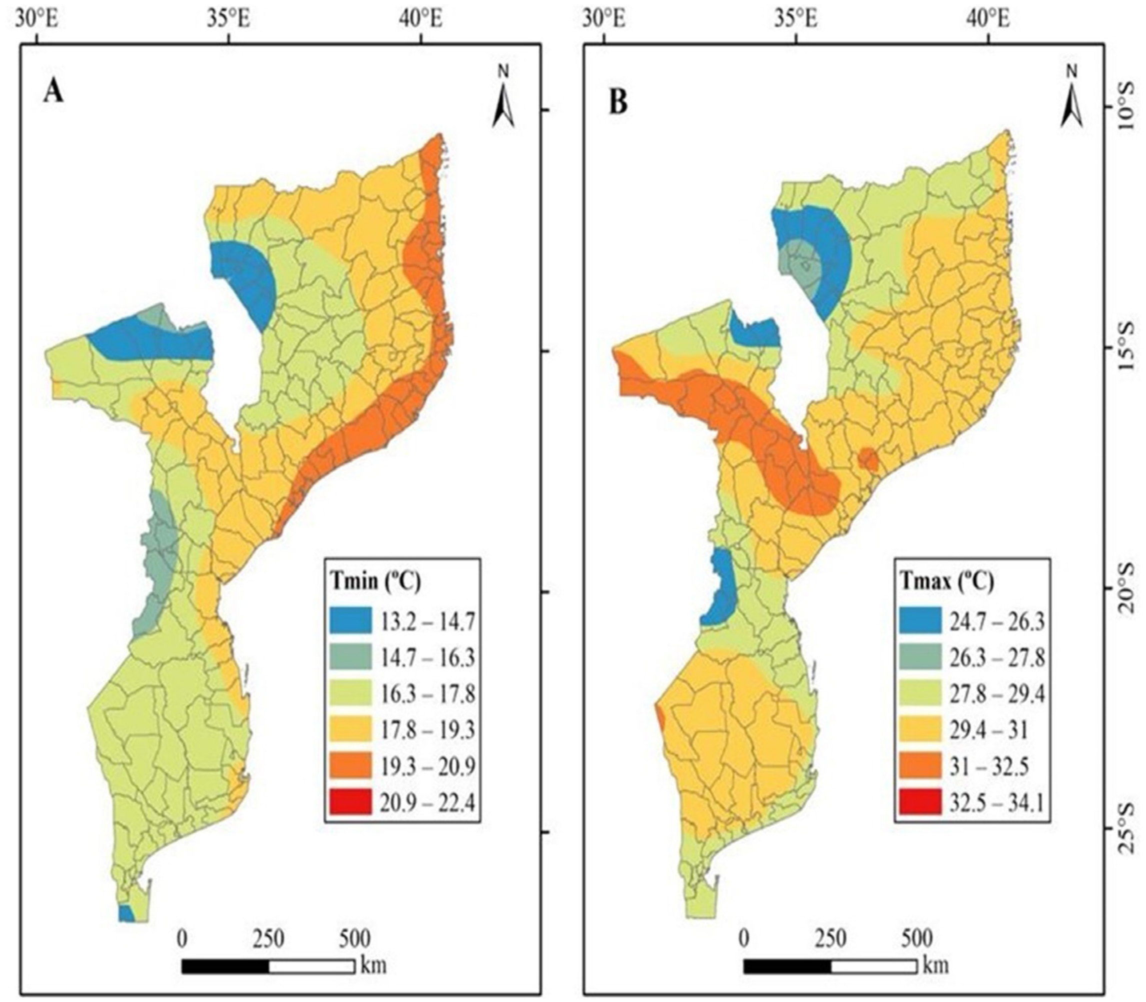

Figure 3: Climatic zoning of areas suitable and unfit for peach cultivation, based on the minimum temperature (A) and maximum temperature (B) in Mozambique (1989 to 2019). Data extracted from the FAO website (FAO, 2021).

As showed in Figures 3 and 1, the cultivation of peach trees is recommended in some regions with favorable microclimates, such as States (provinces): Niassa (Northwest – districts of Lichinga and Ulongue), Tete (district of Angónia) and Manica (Central - districts of Sussundenga, Manica and Chimoio) and Maputo (South - district of Namaacha).

The climatic issues related to rainfall and number of chill hours for peach tree cultivation are considered key factors in the choice of regions with the greatest suitability for peach cultivation in regions of the states of Mozambique. In this sense, agroclimatic zoning is of paramount importance for establishing policies for potential peach cultivation zones.

As seen in Figure 4, the regions that have a climate characterized as humid subtropical (Cwa and Cfa) and subtropical highland (Cwb), according to the Köppen climate classification, are suitable for the rational exploitation of temperate fruit trees with lower chill hour requirements (Kottek *et al.*, 2006).

Notably, in recent years, the cultivation of temperate fruit tree species has crossed the agricultural frontier as a result of genetic improvements, such as the development of peach tree cultivars that require less cumulative chill hours.

DISCUSSION

In Mozambique, annual rainfall is abundant and occurs in the summer months (December to February), varying from 850 to 1000 mm annually on the coast and to approximately 550 mm annually in the west (Schouwenaars, 1988). Rainfall is well distributed, with no separation between rainy and dry seasons (Reason, 2007).

According to Uele *et al.* (2017), the displacement of the Intertropical Convergence Zone favors a longer rainy

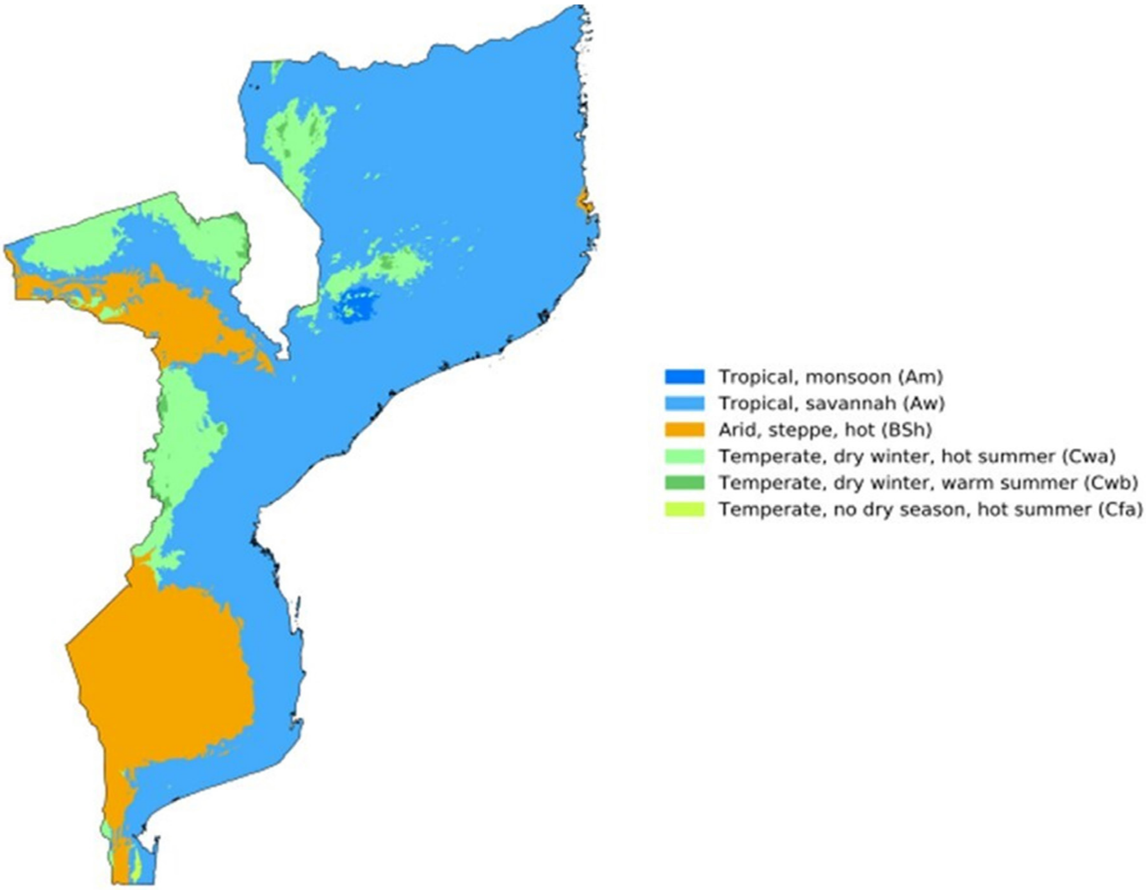

Figure 4: Köppen climate classification of Mozambique. Source: Köppen (1931). Note: in printed version of paper, please do not use color printing. Data extracted from the FAO website (FAO, 2021).

season in the Central and Northern regions of Mozambique (approximately eight to nine months) and a shorter rainy season in the Southern region of Mozambique (approximately four to six months).

For peach cultivation, one of the challenges is leaf diseases, such as shot hole and rust diseases, which thrive in high relative humidity. Peach trees need adequate conditions that do not favor the development of fungal diseases, i.e., high humidity. Where humidity is high, peach tree cultivation may not be economically viable given phytosanitary problems (Figure 2C). High air humidity, voluminous rainfall and high temperatures combined favor the development of fungal diseases, thus impairing the productivity and quality of peaches. According to Bleicher & Tanaka (1982), epidemics of fungal diseases in peach trees can be widespread during hot and humid periods; they are frequent in subtropical areas, which are the most favorable areas for infection; and they can occur in rainy years with high temperatures.

According to Pio *et al.* (2018), if conditions do not favor a chilling environment that meets at least 50% of what is required, the problem can be solved by breaking dormancy.

States (provinces): Niassa (Northwest – Massangulo – Missão districts of Lichinga and Ulongue), Tete (district of Angónia, Vila-Vasco-de-Gama, Furancungo district Macanga) and Manica (Central – Espungabera, districts of Sussundenga; Manica, Chimoio,) and Maputo (South - Goba-Fronteira and Vila-Gamito, district of Namaacha) have low mean annual temperatures, varying from 19 to 21 °C. According to Souza *et al.* (2019), temperature is essential for the cultivation of peach trees in subtropical regions, i.e., mild temperatures in the fall and winter and high temperatures in the summer.

Even with favorable climatic conditions, because agroclimatic zoning was performed considering the macroscale, the existence of local variations in soil suitability was not evaluated, and this complementary evaluation is recommended (Caramori *et al.*, 2008).

Rainfall and temperature are important factors that directly affect peach cultivation and favorable yields, as illustrated in Figures 5 and 6, the monthly average temperature throughout the year 2019 as one of the factors that influence peach cultivation. While precipitation illustrates which months there is a lot of rain. According to Cecílio *et al.* (2012), temperature and rainfall are the most important meteorological variables to be considered in studies of production processes for temperate fruit trees.

Therefore, agroclimatic zoning is a very useful and highly successful tool for the planning of temperate fruit tree orchards, as it allows minimization of the negative impact of the climate and, at the same time, exploration of the potential of orchards in different regions (Pio *et al.*, 2018). Numerous studies have been developed with the aim of stimulating the production of temperate fruit trees in atypical regions through evaluations of climatic parameters, as performed by Caramori *et al.* (2008), Bardin-Camparotto *et al.* (2014), Pommer *et al.* (2009) and Sarmento *et al.* (2008).

The main regions producing temperate fruit trees in subtropical regions are located in the Cfa (humid subtropical, hot summer), Cfb (humid subtropical, mild summer), Cwa (humid subtropical, dry winter and hot summer) and Cwb (humid subtropical, dry winter and mild summer) climates (Pio *et al.*, 2018).

A series of each cultivars that require from 50 or 150 hours of chilling, such as 'Aurora', 'Kampai', 'Rubimel', 'Maciel', 'Libra', 'Ouromel 2', 'Bolão', 'Tropical', 'Diamante', 'Eldorado' and 'Biuti', was released by Agronomical Institute of Campinas - IAC and Embrapa Temperate Agriculture in Brazil, enabling production in subtropical and tropical regions with mild winters and summers with high temperatures (Souza *et al.*, 2013; Scariotto *et al.*, 2013; Citadin *et al.*, 2014; Raseira *et al.*, 2014; Tadeu *et al.*, 2019).

The ideal technologies should stem from an understanding of the bioclimate-altitude interaction because research objectives and crop development processes are affected by these factors. By accounting for these factors, the best balance can be achieved between the climate and agricultural technologies or techniques related to temperate fruit trees regarding the amount of chill hours. Importantly, higher altitude directly affects temperature. To improve production methods for temperate fruit trees in specific states, it is essential to observe the relationship between a cultivar and climatic and edaphic factors, including the altitude of each region (Souza *et al.*, 2013).

Currently, there is abundant new information on the introduction of new cultivars or species adapted to the conditions of particular regions as well as data on the growth and quality of fruit trees in commercial plantations. This has increased knowledge regarding the characterization of soils and climate, allowing a more precise indication of the genetic material to be used for cultivation in each region. The intent is to improve the quality of agronomic and meteorological information and to characterize the microregions suitable and unfit for agricultural exploitation.

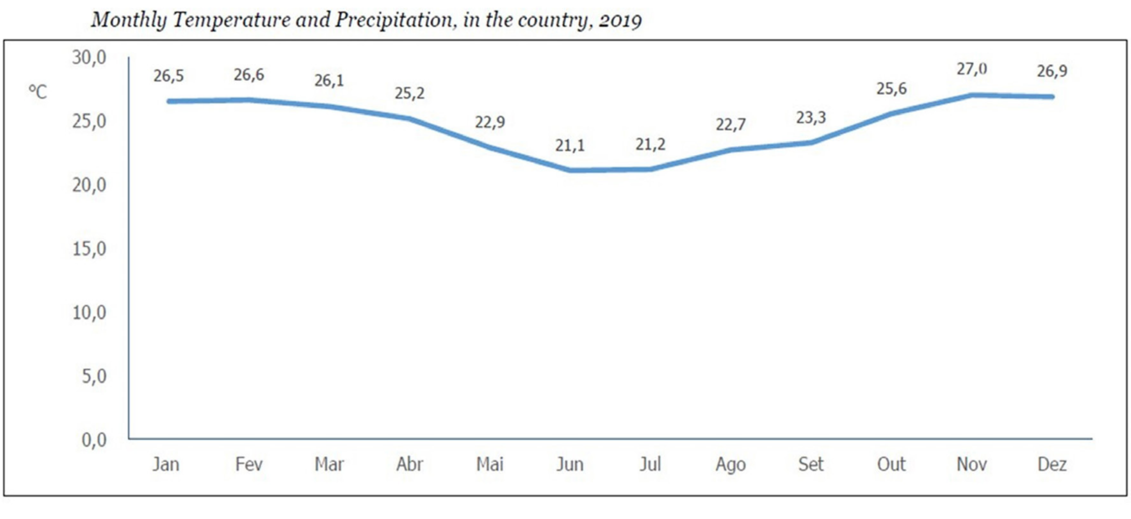

Figure 5: Meteorological factors that influence peach cultivation: temperature (°C). Source: Statiscal yearbook, 2019. Note: in printed version of paper, please do not use color printing.

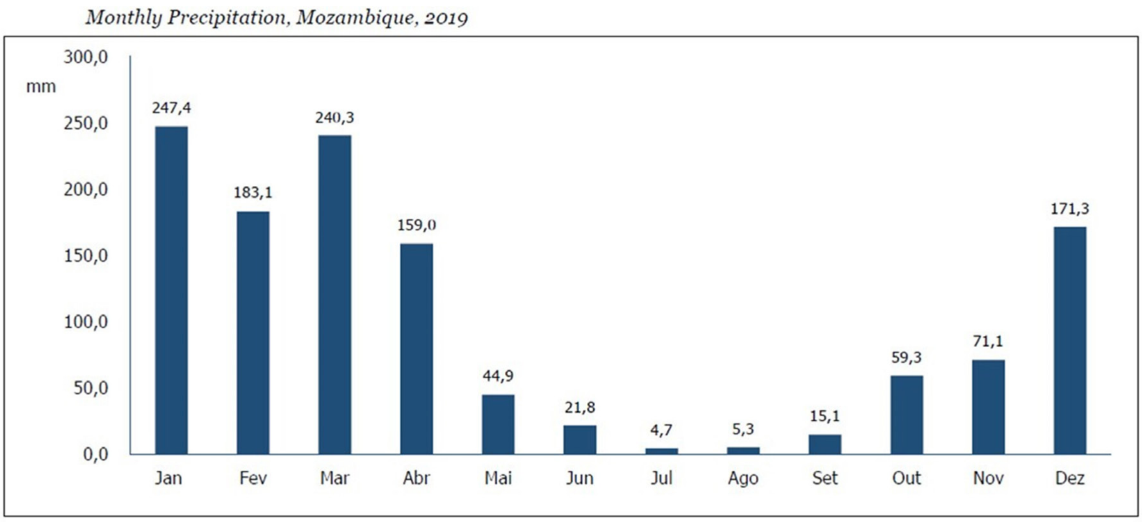

Figure 6: Meteorological factors that influence peach cultivation: accumulated rainfall (mm). Source: Statiscal yearbook, 2019. Note: in printed version of paper, please do not use color printing.

CONCLUSION

Regions in the subtropical areas of Mozambique with suitable temperature and rainfall are viable for peach plantations.

The results showed the Northwest, Central and South regions is more suitable for the economic exploitation of peach trees.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest carrying the research and publishing the manuscript.

ACKNOWLEDGMENTS

The authors thank the Minas Gerais Research Foundation (FAPEMIG), the National Council for Scientific and Technological Development (CNPq), and the Brazilian Federal Agency for the Support and Evaluation of Graduate Education (CAPES) for financial support. We also thank the Federal University of Lavras (UFLA) for technological and infrastructural support.

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