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AGROMETEOROLOGY - Article

Agroclimatic zoning for urucum crops in the state of Minas Gerais, Brazil

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ABSTRACT: Hardier crops are needed in the arid regions of the Brazilian state of Minas Gerais, and annatto (*Bixa orellana* L.) is a good candidate. Producers, however, do not know if their areas are suitable for its cultivation and so are not investing in its implementation. Agroclimatic zoning would provide guidance to the producers. Identifying potential areas for the production of this crop would thus contribute to the agroclimatic zoning of *B. orellana* in Minas Gerais. We collected data for air temperature and precipitation from 852 meteorological stations in the state to classify regions as suitable, marginally suitable, or unsuitable for the crop. Suitable regions had an air temperature between 22 and 27 °C and precipitation between 800 and 1600 mm·y^{-1}. Marginally suitable regions had an air temperature between 22 and 27 °C and precipitation less than 800 mm·y^{-1}. Unsuitable regions had air temperature less than 22 °C or greater than 27 °C. A geographic information system was used for the spatial interpolation of air temperature and precipitation for all meteorological stations using kriging. The agroclimatic zoning of annatto crops for Minas Gerais was obtained by interpolating the two maps, air temperature and precipitation. Minas Gerais has great potential for urucum production, and agroclimatic zoning enabled the classification of regions by climatic suitability. The northern, western, northwestern, and part of the eastern regions of Minas Gerais have favourable climates suitable for the cultivation of *B. orellana*.

Key words: climatic risk, climatic modeling, agrometeorology, *Bixa orellana* L.

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INTRODUCTION

Urucum (annatto) (*Bixa orellana* L.) is a shrubby species endemic to the tropical climates of the Americas that is becoming an important crop worldwide (Valério et al. 2015). It is planted in countries such as Peru, Mexico, Ecuador, Indonesia, and Kenya and in other areas of eastern Africa (Elias et al. 2002; Costa et al. 2013). The plant is native to the Amazon region of Brazil (Brito et al. 2015), but 37% of the national crop production is concentrated in the southeast, in the states of São Paulo and Minas Gerais, with annual yields of 2869 and 1449 tonne, respectively (Lopes et al. 2008).

B. orellana is a rapidly growing perennial species of the Bixaceae family (Barbieri et al. 2011), reaching 2-4 m in height, with ovoid fruit capsules that contain 30-40 seeds. The seeds are rich in carotenoids, which produce the characteristic red colour of the fruit (Costa et al. 2013; Mantovani et al. 2013). Urucum has a regional and national importance in the production of pigments used as natural dyes in the food, pharmaceutical, and cosmetic industries (Vilar et al. 2014), with high commercial value (Costa et al. 2008; Valério et al. 2015).

Harder et al. (2008) reported that annatto is used in Brazil for various purposes, 70% of the production was used in the processing of the pigments, 20% in the extraction of the pigments, and 10% was exported as seeds. Urucum dyes are used for colouring remedies and other pharmaceutical products and in food, sunscreen, and insect repellent. Restrictions on the use of artificial colours in food by the Food and Agriculture Organization and the World Health Organization (WHO) have increased the interest in natural dyes, such as those from the urucum plant. Bastos et al. (1999) reported that the pigments extracted from annatto were among the few allowed by the WHO that were non-toxic and did not alter the taste of food but still added value to the products.

The plants are hardy and typically tropical and are highly adaptable, able to grow in a variety of climates (Brito et al. 2015), but both energetic and hydric conditions outside the ideal range limit the development of crops with satisfactory yields (Sá Júnior et al. 2012). Lopes et al. (2008) reported that little information was available about the influence of climatic conditions on the annatto. Urucum develops well where the air temperature (T_{AIR}) is between 22 and 27 °C and can tolerate low rainfall. The plant grows, flowers, and produces fruit throughout most of the year, and conditions are considered ideal if the annual rainfall (P_{ANNUAL}) is well distributed and > 1200 mm, with a monthly supply of 100-150 mm.

Regional climatic conditions are an essential factor for the selection of species for cultivation. Knowledge of the climatic variability of a region is thus important, because the climate directly affects the development of the crop (Sá Júnior et al. 2012). Climatic adversities negatively affect a country's agricultural production and economy, so zoning techniques are needed to identify, with greater security, the locations and most appropriate dates for sowing crops (Falasca et al. 2012). Zoning consists of agricultural-aptitude, agroclimatic, agricultural, and climatic-risk zoning.

Agroclimatic zoning is the combination of meteorological information with crop requirements for identifying regions suitable, unsuitable, or marginally suitable for a crop (Wrege et al. 2015). Agroclimatic zoning is also the investigation of the dynamics of the consequences of natural systems on surfaces using a man-made vegetable production system (Wollmann and Galvani 2013).

Geographic information systems (GISs) can be used to obtain information for the spatial distribution of climates suitable to crops in preparation for agroclimatic zoning (Zaro et al. 2014; Pena et al. 2016). Agroclimatic zoning has been applied for various crops, e.g. *Chenopodium quinoa* in Bolivia (Geerts et al. 2006), *Macadamia integrifólia* in Brazil (Schneider et al. 2012), *Ricinus communis* in Argentina (Falasca et al. 2012), and *Jatropha curcas* in Brazil (Yamada and Sentelhas 2014). Urucum production has not yet been zoned in Minas Gerais.

The annatto is a good candidate as a hardy crop for production in the arid regions of Minas Gerais. Producers, however, do not know which areas are most suitable for cultivation and thus do not invest in its implementation. Considering that agroclimatic zoning will provide a guide for the producers, the purpose of this study was thus to identify the regions in Minas Gerais with the potential for urucum cultivation by agroclimatically zoning *B. orellana*.

MATERIALS AND METHODS

Minas Gerais (lat 13°94-22'50"S, long 41°73-52'87"W) occupies 586,528 km^2 in southeastern Brazil and contains five climatic classes (Koppen 1948): Am, Aw, BSh, Cwa, and Cwb. The Aw climatic class, however, dominates most of the state (Sá Júnior et al. 2012).

We collected data about air temperature and precipitation from 852 meteorological stations of the National Institute of Meteorology network (INMET) in Minas Gerais (Figure 1) from 1961 to2015.

We used the technique of zoning the agroclimatic types to evaluate the potential of urucum cultivation. Climatic variables were defined by the needs of the *B. orellana* plants: average annual T_{AIR} and total P_{ANNUAL}. The classes of climatic suitability for cultivation were established by combining the two climatic variables (Lopes et al. 2008; Ramalho et al. 1988). Regions were considered climatically suitable for cultivation when T_{AIR} remained between 22 and 2 °C and P_{ANNUAL} was between 800 and 1600 mm·y^{-1}. Marginally suitable areas needed constant irrigation, with T_{AIR} between 22 and 27 °C and P_{ANNUAL} always <800 mm·y^{-1}. T_{AIR} in unsuitable areas was < 21 °C or > 27 °C (Figure 2).

With agroclimatic zoning defined in function of T_{AIR} and P_{ANNUAL}, we characterized the areas by their water balances. This characterization is important for cultivation, because little information is available concerning the influence of climate on annatto culture. This analysis is also important for zoning other areas in the future.

Monthly rainfall and average air temperature were used for calculating the potential evapotranspiration (PET), as proposed by Camargo (1971):

$$PET = 0{,}01 \times (Qo/2{,}45) \times T \times ND \quad (1)$$

where Q_o is daily solar atmospheric irradiance (M·m^{-2}·d^{-1}), *T* means air temperature (°C), and *ND* is number of days.

The parameters of water balance [actual evapotranspiration, soil water storage, water deficiency, and water surplus] were entered into a spreadsheet based on the methodology proposed by Rolim et al. (1998), who used the method developed by Thornthwaite and Mather (1955)

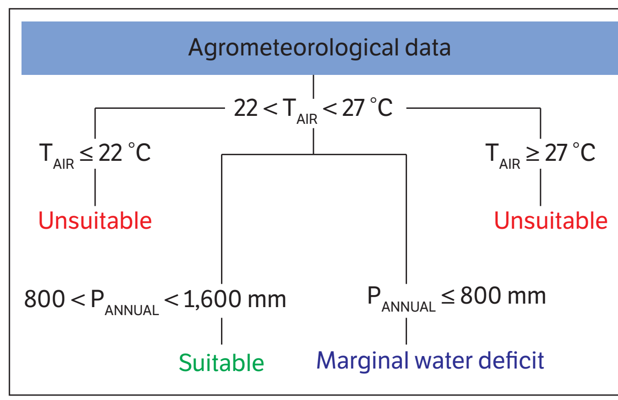

Figure 2. Criteria for classifying the suitability of *Bixa orellana* L. according to the agroclimatic attributes: T_{AIR} = annual average temperature (°C) and P_{ANNUAL} = annual rainfall (mm·y^{-1}).

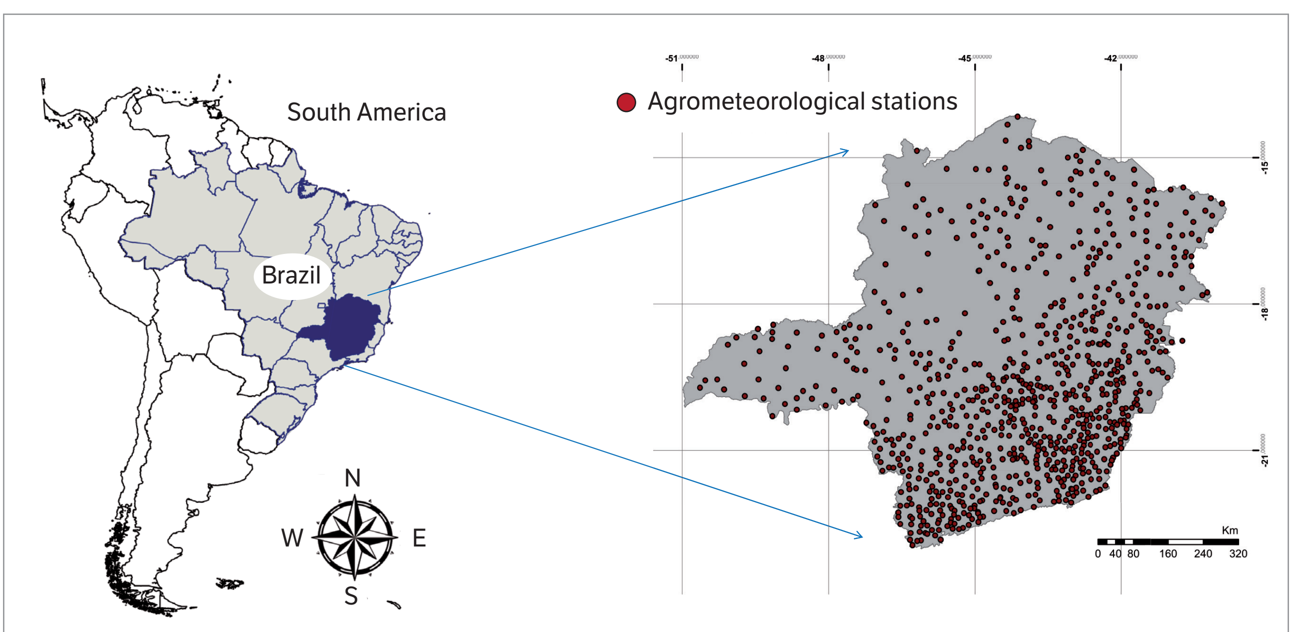

Figure 1. Meteorological stations used in agroclimatic zoning of the *Bixa orellana* L. in Minas Gerais, Brazil.

(Equations 2 to 7), with an available water-storage capacity (*WS*) of 100 mm. This *WS* was used due the root system of the urucum attain up to 100 cm (Barbieri et al. 2011; Mahendranath et al. 2011).

$$if\ \ (P - PET)_i < 0 = \begin{cases} NAC_i = NAC_{i-1} + (P + PET)_i \\ STO_i = WCe^{\frac{(NAC_i)}{WC}} \end{cases} \quad (2)$$

$$if\ \ (P - PET)_i \geq 0 = \begin{cases} STO_i = (P - PET)_i + STO_{i-1} \\ NAC_i = WCln^{\frac{(STO_i)}{WC}} \end{cases} \quad (3)$$

$$ALT_i = STO_i - STO_{i-1} \quad (4)$$

$$AET_i = \begin{cases} P + |ALT_i| & ,if\ ALT < 0 \\ PET_i & ,if\ ALT \geq 0 \end{cases} \quad (5)$$

$$DEF = PET - AET \quad (6)$$

$$SUR_i = \begin{cases} 0 & ,if\ WC < 0 \\ (P - PET)_i - ALT_i & ,if\ WC = 0 \end{cases} \quad (7)$$

where *PET* is potential evapotranspiration (mm); *P* is rainfall (mm); *DEF* is water deficiency at the soil-plant-atmosphere system (mm); *WC* is available water capacity (mm); *STO* is soil water storage (mm); *NAC* = Sum rainfall – potential evapotranspiration; *AET* is actual evapotranspiration (mm); *SUR* is water surplus at the soil-plant-atmosphere system (mm); *ALT* is soil water storage of the current month – soil water storage of the preceding month (mm) and *i* is the monthly period.

A GIS (ArcGIS 9.0©, ESRI) was used for the spatial interpolation of T_{AIR} and P_{ANNUAL} for all meteorological stations using kriging (Krige 1951) and a spherical model with one neighbour and a resolution of 0.25°. Kriging is a univariate geostatistical method widely utilized for its efficiency in data interpolation (Viola et al. 2010; Carvalho et al. 2012), and largely used in zoning (Schneider et al. 2012; Possas et al. 2012).

The agroclimatic zoning of the annatto crop for Minas Gerais was obtained by the interpolation of the two maps (T_{AIR} and P_{ANNUAL}).

RESULTS AND DISCUSSION

T_{AIR} in Minas Gerais ranged from 14.2 to 23.8 °C and was highest and lowest in the north and in the south, respectively (Figure 3). P_{ANNUAL} ranged from 780 to 1796 mm·y^{-1}, similar to the range reported by Alvares et al. (2014). P_{ANNUAL} was > 1600 mm in the southwest and was < 1000 mm only in the northwest, the driest part of the state (Rodrigues et al. 2015), encompassing the region known as the Vale of Jequitinhonha and part of the Rio Doce (Figure 4). Climatic variability was similar to the mapping of climatological norms presented by the National Weather Service of the Brazil (INMET 2015).

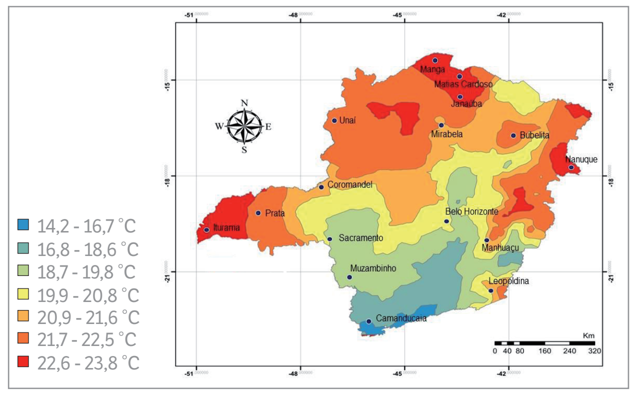

Figure 3. Annual mean air temperature map for State of Minas Gerais, Brazil.

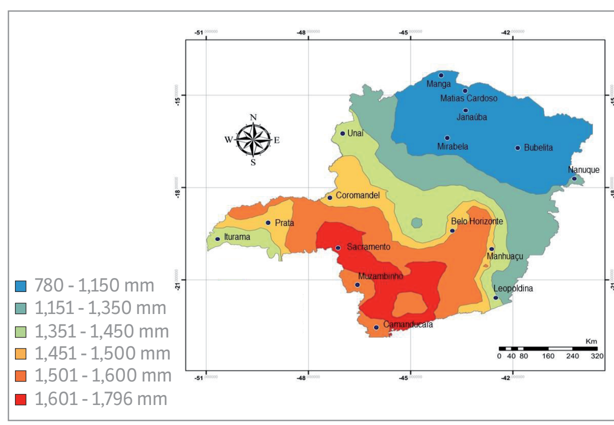

Figure 4. Total annual rainfall in State of Minas Gerais, Brazil.

Meteorological conditions were highly variable throughout Minas Gerais. For example, *PET* ranged from 750 to 1200 mm·y^{-1} (Figure 5c) and *SUR* ranged from 0 to 900 mm·y^{-1} (Figure 5f). *DEF*, a highly important meteorological parameter for crops (Khamssi et al. 2011; Sakai et al. 2015), ranged from 1 to 400 mm·y^{-1}, with an average of 107 mm·y^{-1}. DEF was highest (400 mm·y^{-1}) in Manga and Matias Cardozo, both in the northern region. Overall, 126 locations (15% of the total) in Minas Gerais had *DEFs* > 200 mm·y^{-1} (Figure 5e).

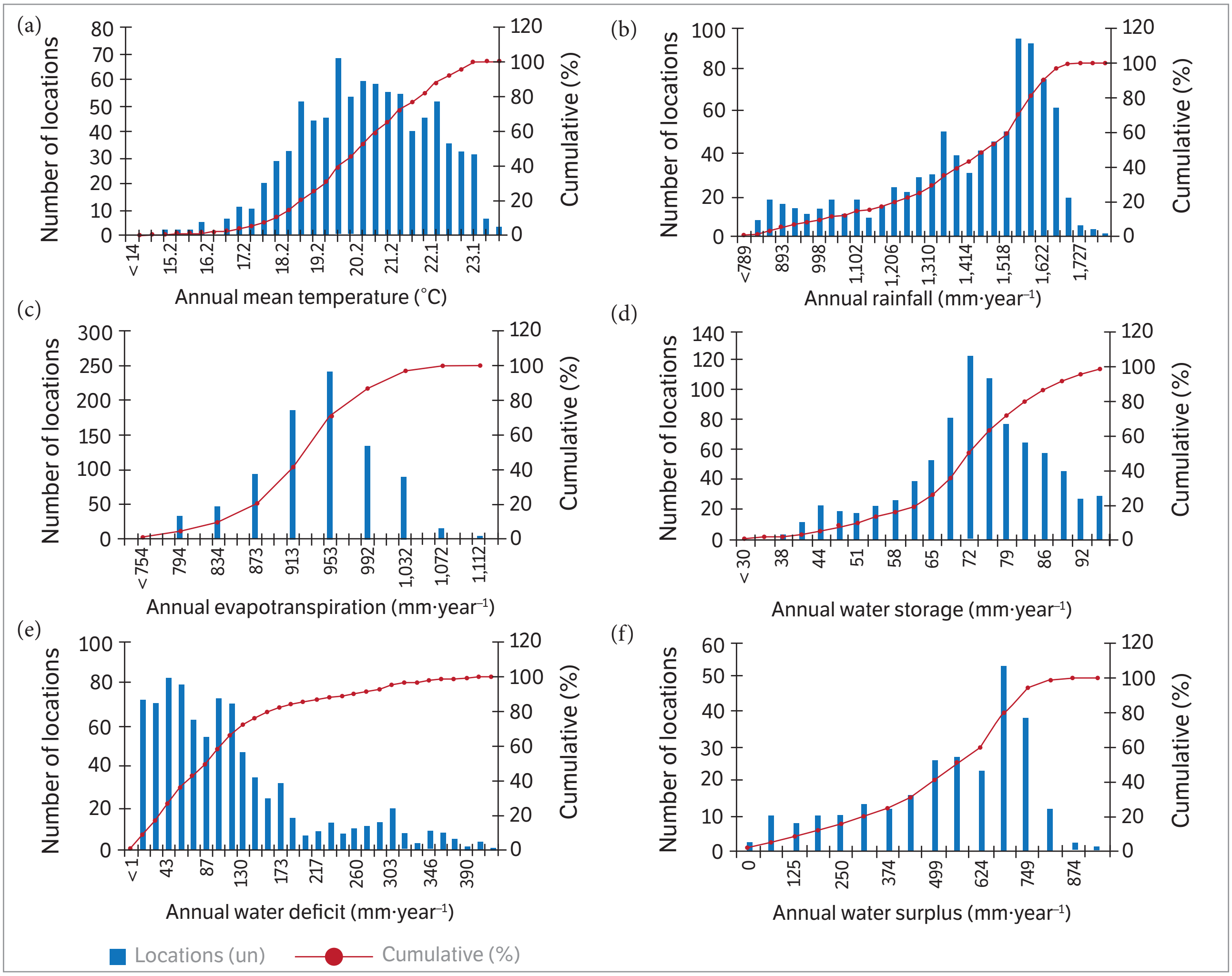

Figure 5. Number of locations and their relative frequencies in the different classes of (a) annual average temperature, (b) total rainfall, (c) potential evapotranspiration, (d) water storage, (e) water deficit and (f) water surplus in the State of Minas Gerais, Brazil.

The meteorological information from the 852 meteorological stations allowed us to propose an accurate agroclimatic zoning for urucum (Figure 6), which shows that *B. orellana* can be cultivated in much of Minas Gerais. The present climatic conditions in the north, west (Minas Gerais Triangle), northwest, and east were considered suitable for the development and production of urucum. This result is very important, because few of the crops in the north are well adapted to the low water conditions (Meira et al. 2013), so the introduction of a new adaptive regional crop is socio-economically important as an optional new income for the farmers in the region (Silva et al. 2007). Unaí, Janaúba, Nanuque, Iturama, and Manhuaçu were considered suitable regions for cultivation and Minas Gerais did not contain any marginally suitable regions.

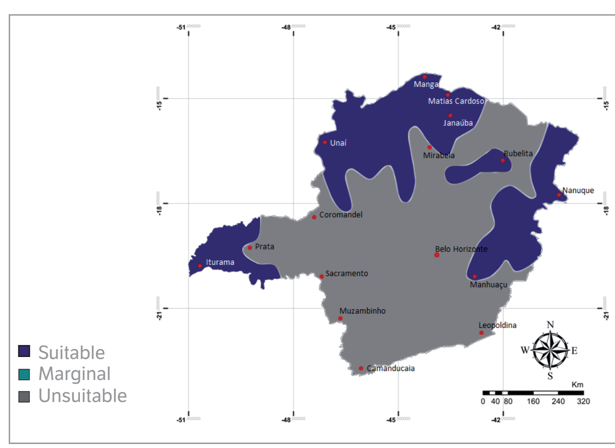

Figure 6. Agroclimatic zoning for *Bixa orellana* L. in the State of Minas Gerais, Brazil.

The southern, southeastern, southwestern, and west-central regions were classified as unsuitable for the cultivation of urucum, due to the low air temperatures, often < 18 °C, mainly in the south. Rainfall was also high, around 1800 mm·y^{-1}, in the southwest and south (Figure 6). Cities like Belo Horizonte, the capital of Minas Gerais, and Sacramento, Muzambinho, Leopoldina, and Camanducaia are located in the regions mentioned and, therefore, were classified as unsuitable for *B. orellana* cultivation.

Climatic regions suitable for the cultivation of *B. orellana* had higher air temperatures, lower rainfall, and severe annual water deficits (Figure 7). Summer air temperatures

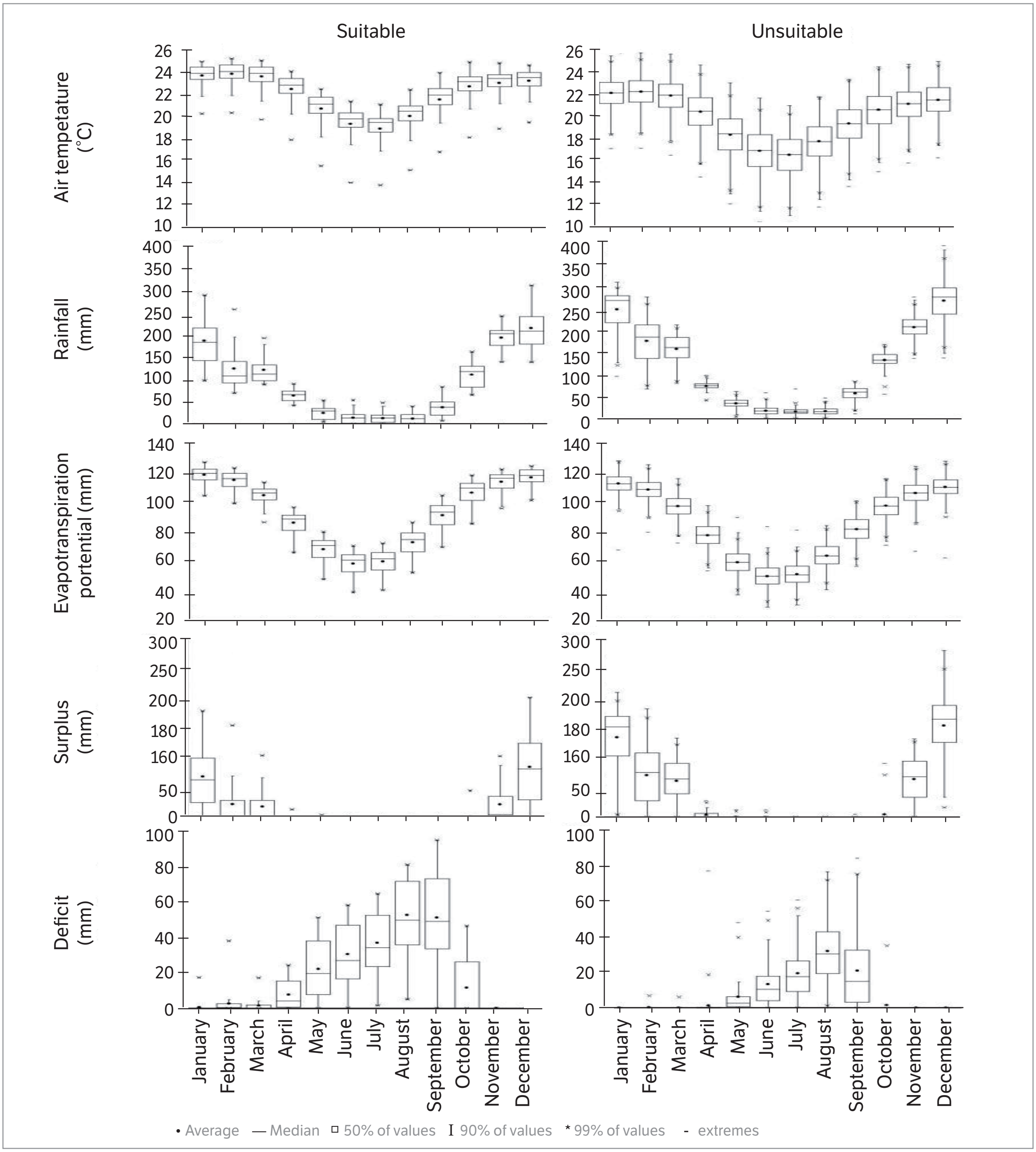

Figure 7. Distribution of monthly values: (a,b) Air temperature, (c,d) Rainfall, (e,f) Potential Evapotranspiration, (g,h) Surplus and (i,j) Deficit for suitable and unsuitable area of the Agroclimatic zoning for *Bixa orellana* L. in the State of Minas Gerais, Brazil.

averaged 22 and 24.5 °C in the unsuitable and suitable regions, respectively, and winter air temperatures averaged 16.6 and 19.9 °C, respectively (Figure 7a,b).

DEF was common in the regions climatically suitable to urucum from February to October, with an average high intensity of 78 mm·mo^{-1} in August and September (Figure 7i). *DEF* occurred during a shorter period (May to September) in the unsuitable regions, with average intensities of 40 mm·mo^{-1} in August (Figure 7j). This information is important for accurately identifying climatic zones in other areas.

CONCLUSION

The state of Minas Gerais has great potential for the production of urucum. Agroclimatic zoning enabled the classification of regions by climatic suitability and indicated that the northern, western, and northwestern regions and parts of the east of the state had climatic conditions favourable for the cultivation of *B. orellana*. Urucum is a crop adapted to low water levels and should be cultivated in areas with extended and intense periods of water stress (February to October).

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