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ANIMAL PRODUCTION

Bioclimatic spatial zoning for small ruminants in the state of Paraíba, Brazil

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ABSTRACT. This study aimed to carry out bioclimatic zoning based on the historical series of climatic variables such as air temperature, maximum, minimum and relative humidity collected in six conventional meteorological stations in the state of Paraíba, Brazil and from this to determine whether or not the animals are in thermal comfort by comparing with the results obtained in scientific research in each mesoregion in the rainy and dry periods. Then based on this the comfort conditions for small ruminants in the rainy and dry seasons of the mesoregions of Paraíba were observed using data from the literature, and demonstrated in spatial distribution maps. The variables air temperatures, maximum and minimum and relative humidity varied throughout the state for the rainy season between 22 to 27, 18 to 21, 25 to 31ºC and 64 to 82%, respectively, and in dry season is 23 to 27, 28 to 35, 19 to 23ºC and 49 to 76%, respectively. However, it is concluded that raising sheep and goats is viable in all mesoregions of the state of Paraíba in both periods.

Keywords: welfare; caprinovinoculture; environmental comfort; mapping.

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Introduction

Due to climatic variations existing in each region, thermal comfort should be one of the main concerns considering that consumers are increasingly demanding, choosing to purchase animal foods which have been in comfortable conditions throughout their life cycle, providing greater profitability (Azevedo et al., 2020).

Livestock farming is important in the Brazilian semiarid, especially the raising ruminants. Small ruminants husbandry conditions can directly affect their adaptation to the environment, as well as their well-being. When not properly controlled, external environmental factors and microclimates promote thermal stress, exerting negative effects on the animals, challenging them in maintaining body thermal balance, in turn causing decreasing production and generating economic losses consequently (Salama et al., 2014; Leite et al., 2017; Ribeiro, Ribeiro, Bozzi, & Costa, 2018; Lima et al., 2019).

Bioclimatological studies are necessary in order to identify negative and positive environmental impacts for raising small ruminants since they contribute to selecting the most suitable regions, thus becoming an important tool to assist producers in choosing the most suitable means of thermal conditioning for facilities (Pastal, Cristo, Fujisawa, Maier, & Guirro, 2015; Tavares et al., 2016; Oliveira, Silva, Souza, Link, & Bottega, 2018).

Therefore, this study aimed to conduct bioclimatic zoning based on a historical series of climatic variables, air temperature, maximum, minimum and relative humidity collected in six conventional meteorological stations in the state of Paraíba-Brazil, and from there determine whether the small ruminants are in thermal comfort by comparing with the results obtained in scientific research in each mesoregion in the rainy and dry periods.

Material and methods

Study area

The spatial zoning was performed for the state of Paraíba, located in the Northeast region of Brazil, which has an area of 56.440 km² corresponding to 0.662% of the national territory. Its positioning lies between the parallels 6°02'12" and 8°19'18" south latitude, and between the meridians of 34°45'54" and 38°45'45" west longitude. According to Nobrega, Santos, Gomes, Bezerra, & Brito, (2014), Paraíba State is divided into four distinct mesoregions: Mata Paraibana; Agreste Paraíbano; Borborema and Sertão Paraíbano.

Koppen climate classification for the mesoregions of Paraíba state

Paraíba State has four different climate classifications: Aw (451.52 km²), characterizes the region as Tropical with a dry season in winter; Am (677.28 km²) is characteristic of monsoon climate regions and is the climate related to the regions with high annual precipitation volume, as is the case of Zona da Mata paraibana; As (32,340.12 km²) is found in the Zona da Mata paraibana, Agreste and Sertão paraibano; and finally, the Bsh climate type (22,971.08 km²), which extends throughout the Borborema mesoregion, and part of the Sertão paraibano (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013; Francisco, Medeiros, Santos, & Matos, 2015).

Climate variables

The climatic data were obtained from conventional meteorological stations of the National Institute of Meteorology (Instituto Nacional de Meteorologia [INMET], 2017) of the federal government. The data were available in the Meteorological Database for Teaching and Research (*BDMEP*), which covers monthly values of air, maximum and minimum temperature and relative humidity (RH) climate variables in the period from 1961 to 2015, with stations located in the cities of Areia, Campina Grande, João Pessoa, Monteiro, Patos and São Gonçalo (Figure 1).

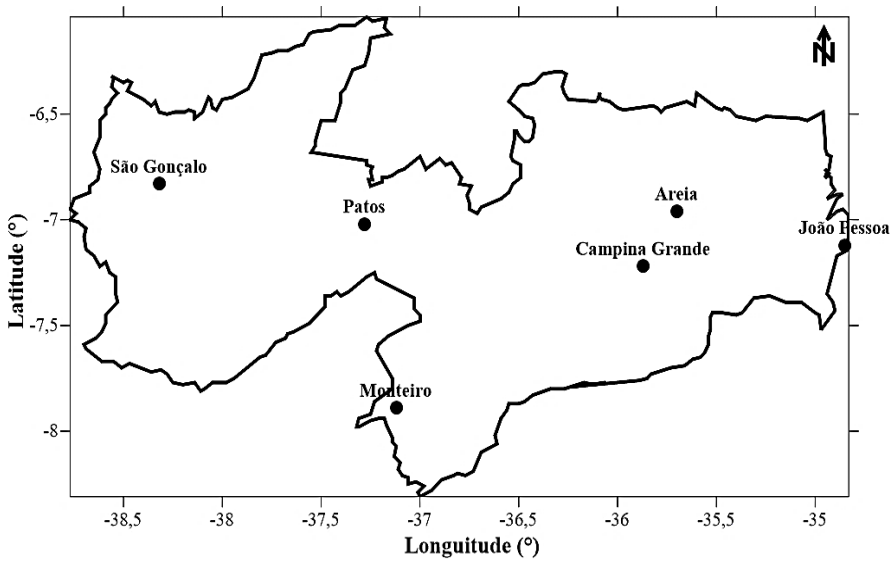

Figure 1. Location of meteorological stations.

Data processing

Maps were elaborated from the spatial distribution of the monthly data of air temperature (AT, °C) and relative humidity (RH, %) using SURFER Software® demo version 13.6 for the state of Paraíba. Data interpolation was performed by the Kriging method.

The study was divided into two distinct seasons: rainy and dry. The Northeast region and consequently Paraíba State do not have defined seasons with only the rainy and dry periods existing, so these periods were defined in the present study as the four wettest months and the four least rainy months from the rainfall historical series, respectively (Table 1).

Table 1. Wettest and drier months for the seasons under study.

Meteorological Station	Season	Rainy	Dry
João Pessoa	1961 – 2015	April – July	September – December
Areia	1974 – 2015	April – July	September – December
Campina Grande	1961 – 2015	April – July	September – December
Monteiro	1962 – 2015	February – May	August – November
Patos	1976 – 2015	January – April	August – November
São Gonçalo	1961 – 2015	January – April	August – November

Analysis of the relationship of animals with the environment

Results of scientific research with sheep and goats were collected after elaborating the spatial distribution maps of air, maximum and minimum temperature (°C) and relative humidity (%) climatic

variables for all mesoregions of the state of Paraíba in order to evaluate the values found in the studies and validate whether or not the animals were in thermal comfort within each analyzed mesoregion.

We subsequently observed the comfort zone recommended for breeding these animals in the literature with the aim to perform bioclimatic spatial zoning for breeding them. This included verifying the mesoregion(s) within the state of Paraíba, Brazil, best suited for breeding each of them. The animals were chosen because they are the most studied production animals in scientific research which covers these mesoregions, in addition to presenting high production potential.

Results and discussion

Spatial distribution of climatic variables in the rainy season

The air temperature in the state of Paraíba ranges from 22 to 27°C, with a maximum of 25 to 31°C and a minimum of 18 to 21°C during the rainy season. By analyzing the state by its mesoregions, it is possible to observe air temperature ranging from 23 to 25°C in the Zona da Mata Paraibana, 22 to 24°C in Agreste Paraíbano, 22 to 26°C in Borborema and 25 to 27°C in the Sertão Paraíbano. The maximum temperature ranges from 27 to 29°C, 25 to 28°C, 27 to 31°C and 30 to 31°C, respectively, in the Zona da Mata paraibana, Agreste, Borborema and Sertão, while the minimum varies from 20 to 21°C in Zona da Mata, 19 to 20°C in Agreste, 18 to 20°C in Borborema and 19 to 21°C in Sertão (Figure 2).

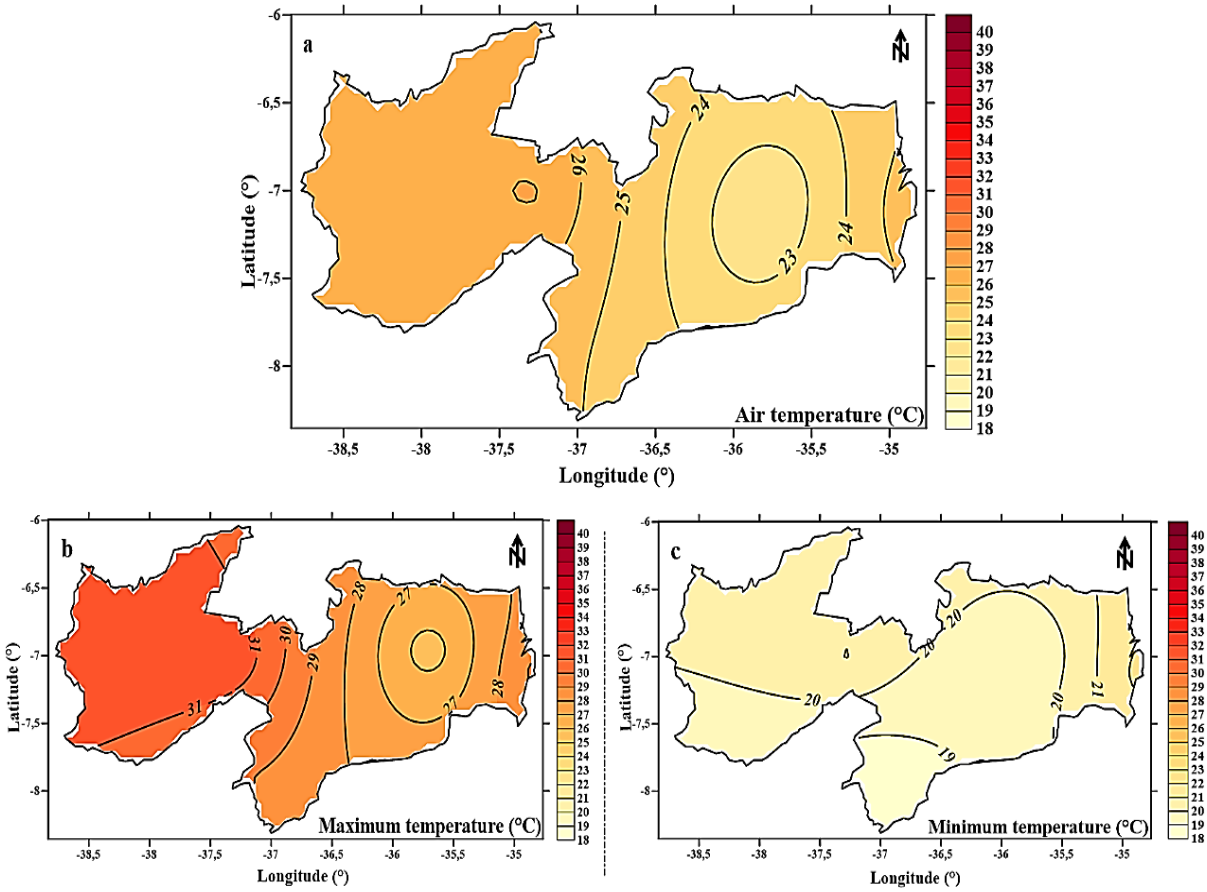

Figure 2. Temperatures in degrees Celsius for the rainy season in the state of Paraíba: (a) Air temperature; (b) Maximum temperature; and (c) Minimum temperature.

The relative humidity in the state of Paraíba ranges from 64 to 82%, while this variation in Zona da Mata is from 79 to 82%, in Agreste it is 76 to 82%, in Borborema from 64 to 79% and in Sertão from 64 to 76% (Figure 3).

Spatial distribution of climatic variables in the dry season

The air temperature in the state of Paraíba ranges from 23 to 27°C, with a maximum of 28 to 35°C and the minimum of 19 to 23°C during the dry season. By analyzing the state by its mesoregions, it is possible to observe air temperature ranging from 24 to 26°C in Zona da Mata, 23 to 24°C in Agreste, 23 to 27°C in

Borborema and 26 to 27°C in Sertão. The maximum temperature ranges from 28 to 29°C, 28 to 31°C, 29 to 34°C and 33 to 35°C, respectively in Zona da Mata, Agreste, Borborema and Sertão. While the minimum varies from 20 to 23°C in Zona da Mata, 19 to 21°C in Agreste, 19 to 21°C in Borborema and 20 to 21°C in Sertão (Figure 4).

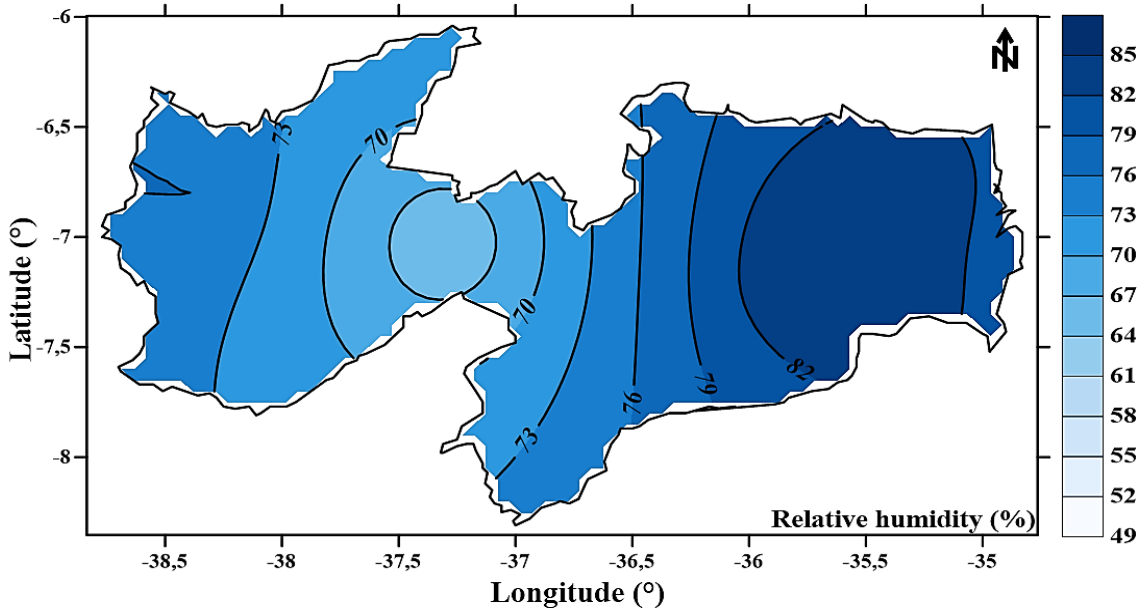

Figure 3. Relative humidity (%) for the rainy season in the state of Paraíba.

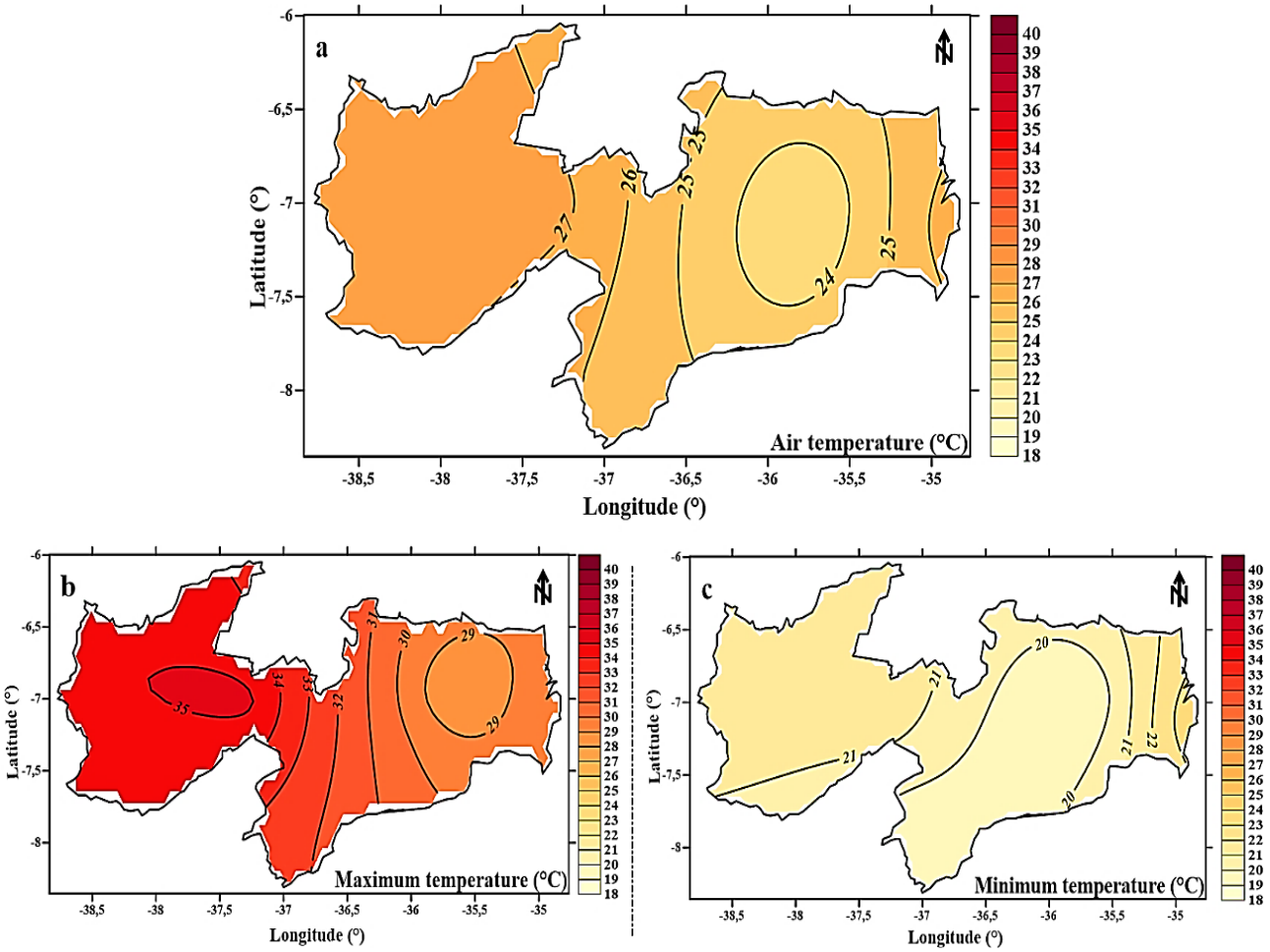

Figure 4. Temperatures in degrees Celsius for the dry season in the state of Paraíba: (a) Air temperature; (b) Maximum temperature; and (c) Minimum temperature.

Relative humidity in the state of Paraíba ranges from 49 to 76 %, while in Zona da Mata it is around 73 %, in Agreste it ranges from 64 to 76 %, in Borborema from 52 to 72 % and in Sertão from 49 to 73 % (Figure 5).

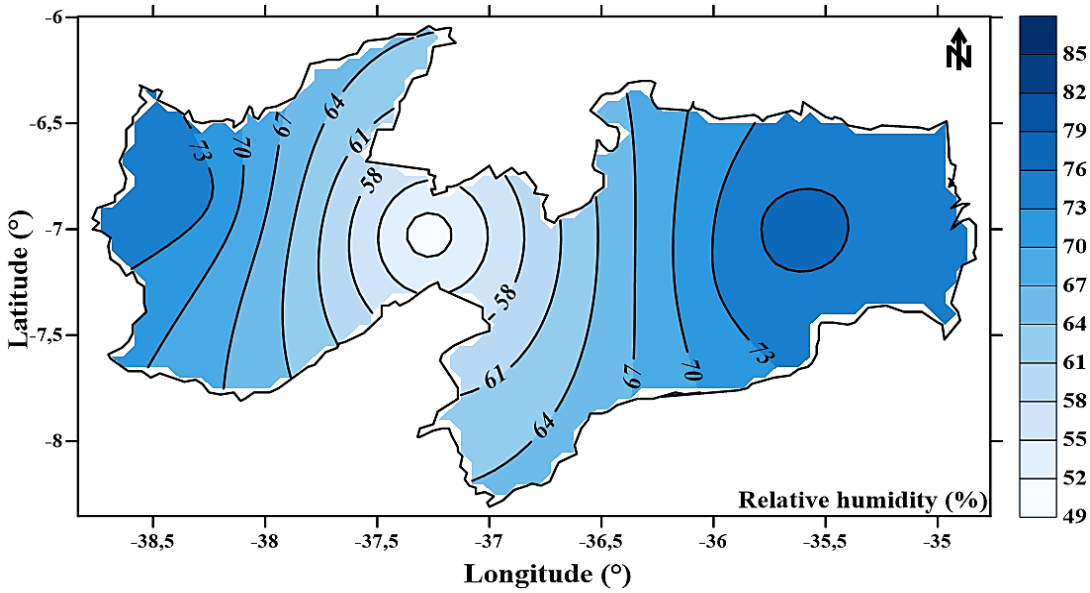

Figure 5. Relative humidity (%) for the dry season in the state of Paraíba

Rainy season

Sheep

A temperature range of 15 to 30ºC is recommended for adult sheep, with relative humidity of 50 to 70% according to Baêta and Souza (2010). Thus, air temperature and minimum temperature are observed within the comfort zone for sheep rearing within the state of Paraíba, but the maximum temperature in the transition between the mesoregions of Borborema and Sertão are higher than those recommended. It is also possible to find thermal comfort areas in these same mesoregions, especially in most parts of Borborema (Figure 6).

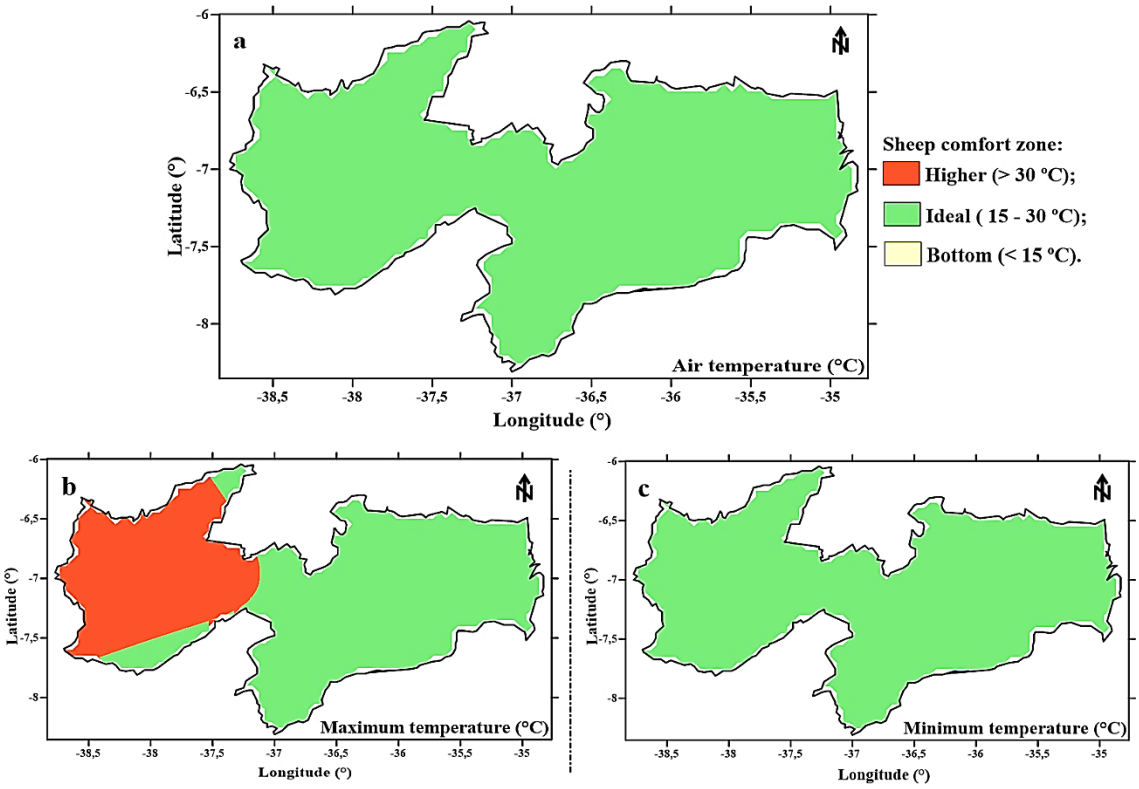

Figure 6. Air temperatures, maximum and minimum thermal comfort for sheep in the rainy season.

However, there is no need for major modifications for these two mesoregions considering that the variation is only 1ºC above the comfort for animals, which does not represent a danger to them as primary modifications such as the use of natural shading helps in reducing the effect of direct insolation, providing greater comfort.

Regarding relative humidity, it is observed that the mesoregions of Sertão and Borborema present values within the recommended comfort for sheep, as well as lower values, but the mesoregions of Zona da Mata and Agreste present lower values than those recommended for these animals throughout their territory (Figure 7).

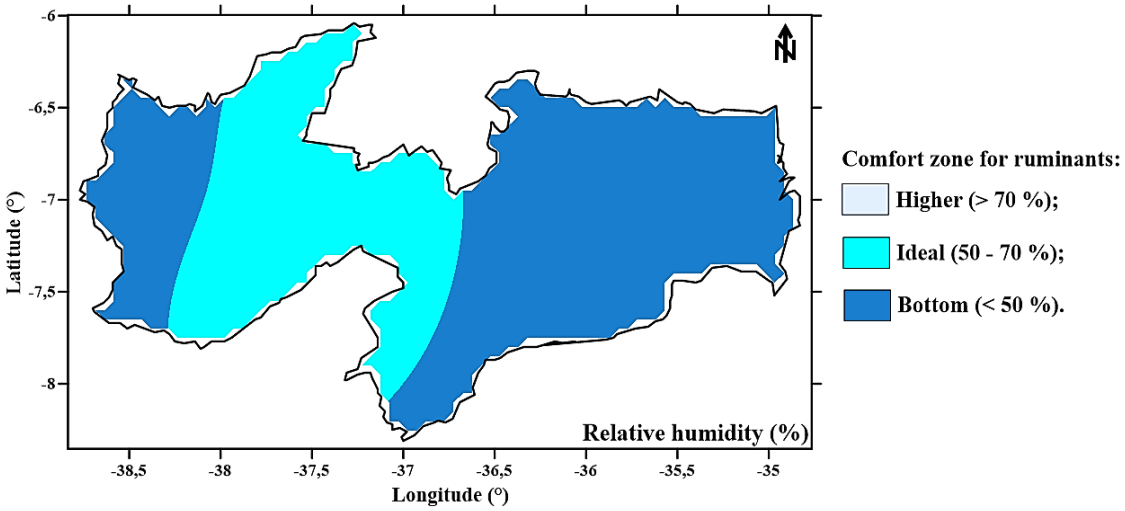

Figure 7. Relative humidity of thermal comfort for ruminants in the rainy season.

A solution to this problem would be the use of suspended facilities in these locations (Lopes Neto, 2017), thus facilitating the reduction of humidity inside them since the animals do not get direct contact with the soil, in turn reducing the effects of humidity of animals against pathogenic microorganisms and facilitating hygiene.

Silva, Lopes Neto, Costa, Furtado, and Miranda (2018) found an air temperature of 27.5ºC, maximum of 34.2ºC and minimum of 20.8ºC, with relative humidity of 66.9% when experimenting with sheep of the Santa Inês and Dorper breeds evaluating the adaptability of the animals in the rainy season of 2012, in the City of Caturité, Borborema Mesoregion. According to the authors, the climatic elements exceeded the thermal comfort zone of the animals, but the sheep maintained their natural behaviors even at high temperatures, thus demonstrating this adaptability to the climatic conditions of the locality.

The temperature data observed by Silva et al. (2018) are above those obtained in the historical series for this period, and it is possible to find the same situation when particularly verifying the year 2012 in the series. However, humidity is within the values of the series, but above them in relation to the analysis of the year for the Borborema mesoregion; therefore, a more careful analysis of the data is necessary. In view of this, it is not correct to state that the animals are in comfort, since there is a probability that the animal is in the transition between comfort and discomfort. This is because even with the rusticity and tolerance they have at higher temperatures, there were moments when the temperature was above the recommended, so a more detailed evaluation of other physical or environmental factors that may contribute to the discomfort of these animals and which were not taken into account is necessary.

When evaluating productive performance and thermoregulation of sheep in Patos, located in the mesoregion of the Sertão paraibano, Nobre et al. (2016) found air temperature of 26.8ºC, maximum of 32.9°C and minimum of 20.8°C with average relative humidity of 61%, and concluded that the animals were found in thermal stress mainly due to the high temperatures and relative humidity, especially in the afternoon, as demonstrated by the elevation of physiological variables.

However, the air temperature, minimum temperature and relative humidity were within the comfort recommended by Baêta and Souza (2010), and there was a need to analyze other factors which may be causing discomfort in these animals, since the maximum temperature can be mitigated with small corrective measures such as natural or even artificial shading.

The air temperature and minimum data observed by the authors were found within those obtained in the historical series for this mesoregion, while the maximum temperature was 1.9ºC above the value recorded in the present study. In turn, relative humidity was 3% below the series. The differences observed in the

comparison of the data obtained by the authors with the historical series can be justified by the smaller amount of data since they were only collected for one year.

From the bioclimatic spatial zoning it was possible to identify that all the mesoregions of the state of Paraíba are suitable for sheep rearing in the rainy season, however requiring small corrective measures to mitigate the maximum temperature in the mesoregion of Sertão and its transition with Borborema and relative humidity in all mesoregions, since only a part of Borborema and the Sertão present ideal humidity for breeding these animals.

Goats

Air temperature within the comfort was observed for raising goats in the rainy season in the state of Paraíba, while the minimum temperature showed comfort throughout the mesoregion of Zona da Mata, in a small part of the transition from Agreste to Zona da Mata and Borborema, as well as in most of Sertão and in the transition with Borborema. On the other hand, the maximum temperature showed discomfort in almost the entire Sertão Region, and temperatures in the other mesoregions were observed within the thermal comfort recommended for the production of these animals (Figure 8).

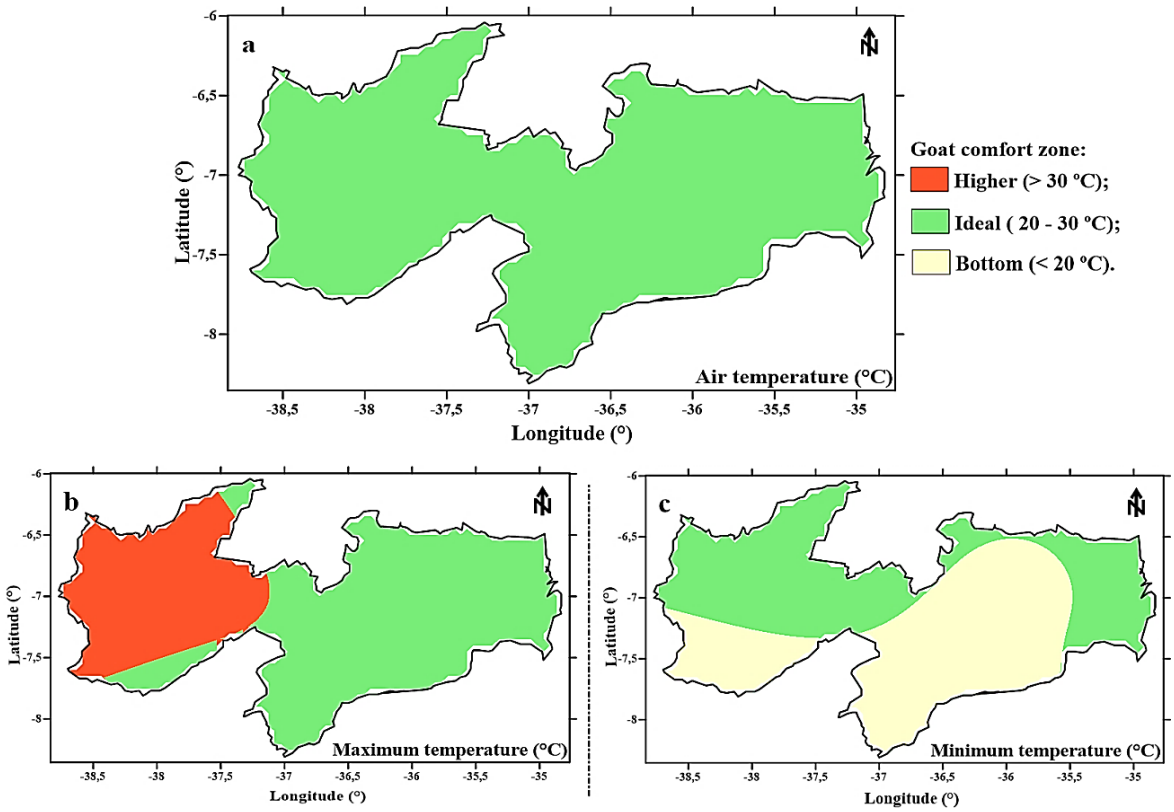

Figure 8. Air temperatures, maximum and minimum thermal comfort for goats in the rainy season.

Regarding relative humidity, the recommended range for these animals is the same for adult sheep, as it can be observed in Figure 7, so the same corrective measures mentioned above should be adopted. There are minimal corrective measures which need to be taken in order for the animals to maintain their homeothermia.

Thus, Zona da Mata and part of Agreste are the most suitable mesoregions to raise goats in this period, but the other mesoregions require going through small corrective measures to mitigate the maximum temperature and relative humidity in order to suit the ideal conditions, making it feasible to rear these animals throughout the state of Paraíba.

Dry season

Sheep

Air temperature and minimum temperature in the dry season in the state of Paraíba are observed within the comfort for sheep, but the maximum temperature showed comfort throughout the mesoregion of the Paraiba Zona da Mata, part of Agreste and in the transition with Borborema, while temperatures in the other areas are observed to be higher than those recommended for sheep breeding (Figure 9).

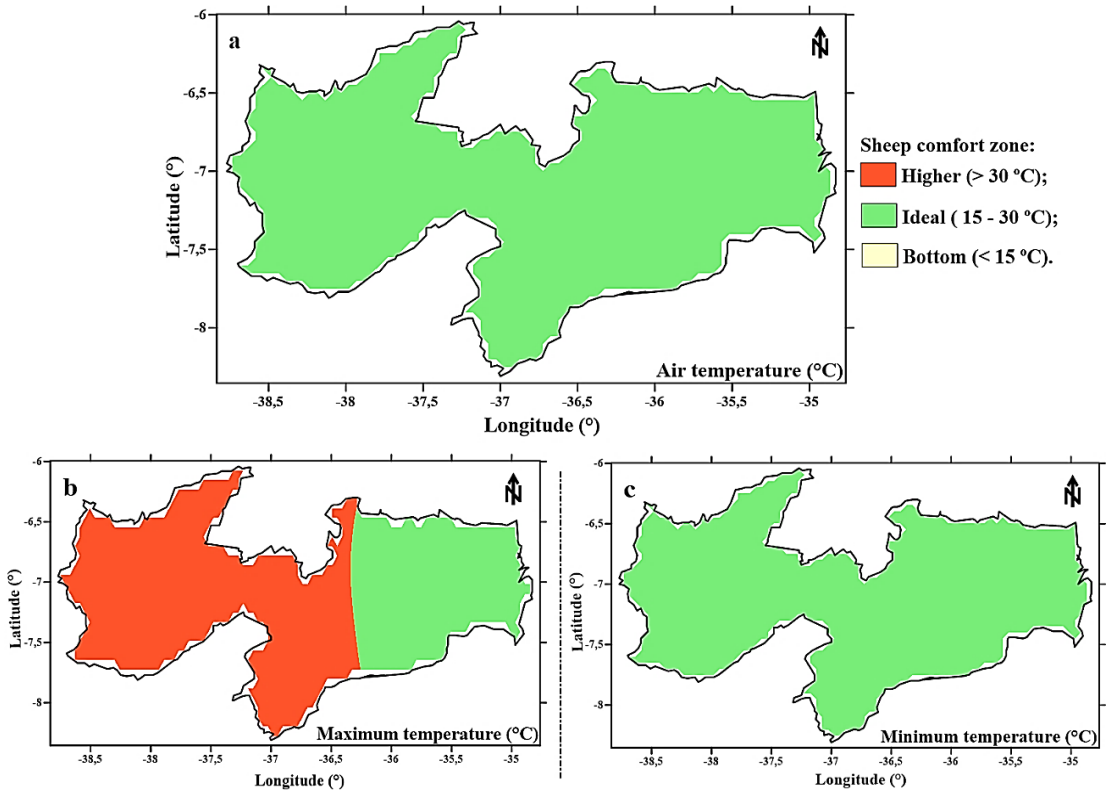

Figure 9. Air temperatures, maximum and minimum thermal comfort for sheep in the dry season.

The maximum temperature rises from 2 to 5°C above the recommended comfort for sheep, thus requiring primary modifications such as natural shading, in addition to an adequate quantity and quality of water supply in order to mitigate the effects of high temperatures for these animals.

Regarding relative humidity, it is observed that most of the mesoregion of Sertão, as well as all Borborema and part of Agreste present values within the recommended comfort for sheep, but Zona da Mata, Agreste and a small part of Sertão have humidity of 3 to 6% above the recommended comfort for these animals, and may adopt the same measures suggested for sheep in the rainy season for high humidity (Figure 10).

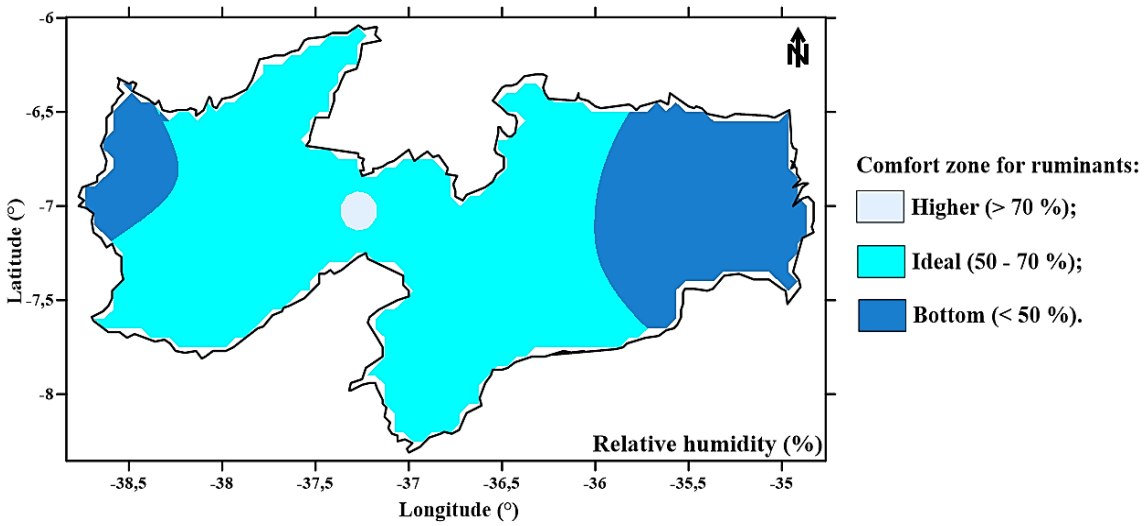

Figure 10. Relative humidity of thermal comfort for dry season ruminants.

In a study evaluating the sexual behavior of Morada Nova sheep in the city of São João do Cariri, located in the Borborema mesoregion, Santos et al. (2017) observed air temperature of 28.6°C, maximum temperature of 32.7°C and minimum of 24.4°C, and humidity of 46.1%, therefore being above the thermal comfort zone according to the authors, and such climatic changes may affect the sexual behavior of males, since this behavior is reduced in hot climates.

The air temperature and minimum observed by the authors during the experimental period are above those obtained in the present study, the maximum temperature is within the values of the historical series, while the relative humidity is 5.9% lower for this period in this mesoregion, and may be justified by the same reason as in the study by Fonseca et al. (2016), namely the amount of data, which is much lower.

When evaluating physiological variables in sheep in the city of Patos, in the Sertão mesoregion of Paraíba in 2015, Dantas et al. (2019) found air temperature of 32.3ºC, maximum temperature of 35.3ºC and minimum of 29.4ºC, and average humidity of 48.2%. These values were considered by the authors as being above the comfort zone recommended for these animals, but the genetic groups studied were adapted and tolerant to climatic conditions. The data found by the authors differ from the data obtained in the historical series for the mesoregion, as well as they differ from the data found for the year 2015 in monthly evaluation.

These differences observed in comparing the data obtained by the authors with the series can be justified by the smaller amount of data they recorded, as well as in the study by Fonseca et al. (2016). They only evaluated the data of one month within one year alone, thus making an analysis with a greater number of data necessary in order to provide more reliability to the research and predict that the animals were able to adapt to the climate change conditions, given that there were times when the temperature was above that recommended for these animals.

In view of the bioclimatic spatial zoning, it is observed that all the mesoregions of the state of Paraíba are suitable for sheep breeding in the dry season, requiring small corrective measures to mitigate the maximum temperature in the mesoregions of Sertão, Borborema and part of Agreste, and the relative humidity throughout Zona da Mata, part of Agreste and in a small portion of Sertão.

Goats

Air temperature within the comfort for rearing goats is observed in the dry season in the state of Paraíba. In turn, the minimum temperature presents comfort in much of the state of Paraíba, except in much of Borborema and Agreste which present temperature 1ºC lower than that recommended for these animals, which can be solved by housing them in closed facilities at lower temperatures, thus avoiding air currents (Figure 11).

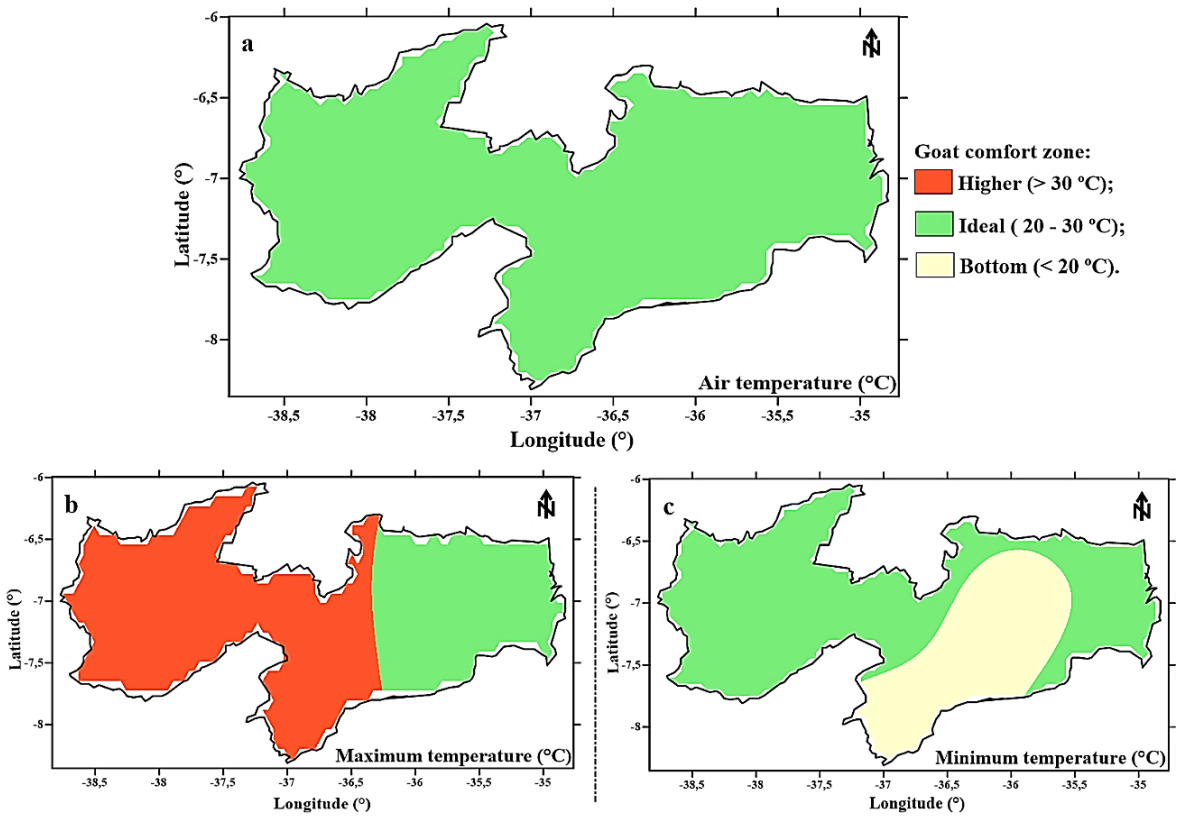

Figure 11. Air temperatures, maximum and minimum thermal comfort for goats in the dry season.

The maximum temperature presents comfort throughout the mesoregion of Zona da Mata of Paraíba, in almost all of Agreste and in a small part of Borborema in transition with Agreste, while temperatures higher than those recommended for rearing goats up to 5°C are observed in the other mesoregions.

The same is observed for relative humidity (Figure 7), which has the same recommended range for ruminants, therefore being within the comfort for most of the state of Paraíba, and the same corrective measures mentioned above should be adopted to solve high temperatures and relative humidity.

When evaluating the physiology of native goats in São João do Cariri, Borborema mesoregion, Paulo, Santos, Furtado, Medeiros, & Saraiva (2015) observed air temperature of 27.2ºC, maximum of 32.0ºC and minimum of 22.5ºC, with a relative humidity of 51.4%. According to the authors, Canindé and Moxotó animals did not present thermal stress due to the fact that they had a high degree of adaptability to the environmental conditions in the region under study. The rusticity of these animals and critical higher temperature recommended by Baêta and Souza (2010) of 34ºC may explain the comfort of these animals, since only the maximum temperature differed from the comfort zone data, however being below the critical higher temperature.

The air temperature and maximum data recorded by the authors are within the range obtained in the history series, differing only by 1.5ºC above the minimum temperature. Relative humidity is less than 1% lower than historical series data in this mesoregion, therefore being considered within the range of the series due to the small variation which occurred between the data.

In view of the bioclimatic spatial zoning, it is observed that the transition between Agreste and Borborema is the most suitable area for raising goats in the dry season, followed by Zona da Mata which only requires modifications to reduce local humidity, but the other mesoregions only require small corrective measures such as shading and the use of suspended facilities in order to soften the maximum temperature and relative humidity, making it feasible to rear these animals throughout the state of Paraíba.

Conclusion

The production of sheep and goats is feasible in all mesoregions of the state of Paraíba in both seasons, only requiring minor corrective measures such as quantity and quality water supplementation, suspended facilities and shading in the attempt to mitigate the effects of air temperature and humidity.

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