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Climate risk assessment for *Cannabis* spp. in Santa Catarina State, Brazil

Priscila Camargo[1(*)], Cristina Pandolfo[2] and Leosane Cristina Bosco[3]

[1]Universidade Federal de Santa Catarina (UFSC). Rodovia Admar Gonzaga, 1346, Bairro Itacorubi, Caixa Postal 476, CEP 88040- 900 Florianópolis, SC, Brazil. E-mail: mskpri@gmail.com
[2]Centro de Informações de Recursos Ambientais e de Hidrometeorologia de Santa Catarina (CIRAM/EPAGRI). Rodovia Admar Gonzaga, 1347, Bairro Itacorubi, CEP 88034-901 Florianópolis, SC, Brazil. E-mail: cristina@epagri.sc.gov.br
[3]UFSC - Campus Curitibanos. Rodovia Ulysses Gaboardi, km 03, CEP 89520-000 Curitibanos, SC, Brazil. E-mail: leosane.bosco@ufsc.br
[(*)]Corresponding author.

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ABSTRACT

Interest in the medicinal use of *Cannabis* spp. has been increasing due to scientific evidence demonstrating its therapeutic potential. However, in Brazil, agronomic studies on its cultivation are incipient. This study aimed to perform a climate risk analysis for the cultivation of *Cannabis* spp. in the state of Santa Catarina (SC), Brazil. From the bibliographic review and the systematization of meteorological data of the state, the critical parameters of photoperiod (< 14 h), probability of occurrence of minimum temperatures (< -6°C) and thermal sum (< 2500 GDD) were considered. The *Cannabis* spp. may be cultivated in all regions of SC, provided that the technical guidelines according to the inherent risks in each region are observed. Within the ten-day period from 33 to 8 (November 21 to March 20), the photoperiod and absolute minimum air temperature criteria were not restrictive in any region of the state. For the critical parameter of thermal sum, in regions where the risk is elevated due to a thermal sum below 2500 Growing Degree Days (GDD), this limitation may be mitigated by advancing the timing of plant establishment. This research offers valuable insights for researchers, policymakers, and those interested in cultivating *Cannabis* spp. in Brazil, with a strategic perspective aimed at fostering initiatives that consider the potential for producing *Cannabis* spp. in the Santa Catarina territory.

Introduction

Cannabis spp. is belonging to the Cannabaceae family, known for at least 12,000 years, and it has historically been a versatile plant, being used in the production of fiber, oil, medicine, fabric, paper, biofuel, cosmetics, food, and construction material, among other purposes (Bonini, 2018). The plant contains phytochemicals, with about 125 types of cannabinoids and 400 non-cannabinoids, such as flavonoids, alkaloids, phenols, terpenes, and fatty acids omega-3 and 6. Accumulated in the trichomes of female flowers, the cannabinoids, such as THC (Delta-9-tetrahydrocannabinol) and CBD (cannabidiol), have been used to characterize the three chemotypes of *Cannabis* spp.:

i) the predominant cannabinoid is THC; ii) intermediate, in which the predominant cannabinoids are THC and CBD; and iii) the predominant cannabinoid is CBD, also known as hemp (Broséus et al., 2010; Piluzza et al., 2013; Al Ubeed et al., 2022).

Interest in the medicinal use of *Cannabis* spp. and its derivatives has been increasing due to scientific evidence demonstrating its therapeutic potential in treating diseases in humans and animals (Hartsel et al., 2019; Fiocruz, 2023). However, there is a need to expand agronomic knowledge regarding the genotypes, climatic conditions, and management practices of this species for viability and legalization of industrial crops, given that several environmental elements may influence the growth and development of *Cannabis* spp. plants and, consequently, their chemical profiles (Spano et al., 2022; Trancoso et al., 2022). In Brazil, more than 80% of the research published to date is in the field of Health Sciences (Kaya Mind, 2022), with incipient publications on the cultivation of medical and industrial *Cannabis* spp. in Brazil (Fraga & Iulianelli, 2011; Adwa, 2021).

Cannabis sativa L. is a herbaceous, annual, predominantly dioecious plant, and the flowers of the female plants are of the inflorescence type, while the male flowers are of the panicle type (López, 2014). It has significant phenotypic flexibility and shows better development in well-drained, deep, and fertile soils, although it has a remarkable ability to survive in nitrogen-deficient soils (Small et al., 2015).

The cultivation practices adopted will depend on the intended purpose and the cultivation system. In the *Cannabis* spp. cultivated for obtaining fibers (hemp), low-branched, high-sized varieties are used, and field cultivation is recommended. Harvesting should be carried out at the full flowering stage of male flowers to maximize productivity and fiber homogeneity (Amaducci et al., 2015). Hemp intended for grain production also requires field planting, with varieties with a cycle of 120 days or more (Vergara et al., 2023).

Finally, *Cannabis* spp cultivated to produce inflorescences may be grown in the field or in a protected environment in which the conditions of air temperature and humidity and the photoperiod are controlled, depending on the desired cannabinoid composition, whether for medicinal, psychoactive, or cosmetic purposes. Varieties, in this case, have more significant branching and smaller sizes. The planting is carried out from seedlings or clones in low density, and the harvest is usually performed manually since these are products with high added value. In this case, the presence of male plants must be prevented since the pollination process may occur, compromising the exclusive production of seedless female flowers (Vergara et al., 2023).

The phenology of *Cannabis* spp. is characterized by the phases of germination and emergence, leaf development, formation of lateral shoots, stem elongation, flower bud formation, flowering, fruit development (achenes), fruit ripening, and senescence (Mishchenko et al, 2017). The most important phase for cultivation for medicinal purposes is that between the formation of the flower bud and the blooming of the female flowers, with cycle duration of 60 to 120 days (Vergara et al, 2023). The duration of the vegetative phase of *Cannabis* spp. is genotype-dependent, but the duration of the reproductive phase is dependent on environmental conditions such as photoperiod and air temperature (Ferfuia et al., 2024).

The agroclimatic requirements reported in several publications as being important for *Cannabis* spp. are photoperiod, air temperature, and water availability, each of these factors having greater or lesser importance depending on the phase or phenological stage of the species.

Cannabis spp. is a short-day plant (SDP), with flowering being triggered when the plant is exposed to the effect of the shortening days, i.e., flowering is typically induced by a necessary duration of days with a minimum uninterrupted period of darkness of 10 h to 12 h or daylight of 14 h to 12 h in most varieties. This effect included the civil twilight that is biologically effective in regulating *Cannabis* spp. flowering (Zhang et al., 2021). However, in some cases, flowering may occur independently of the light regime in photoperiod-insensitive varieties. To prevent prolonged growing seasons or premature flowering under uncontrolled conditions, it is advisable to opt for varieties adapted to the latitude and climate of the cultivation region.

Cannabis spp. has high plasticity, and there is no unanimity in the literature about the ideal temperature ranges for its cultivation, varying from 5.6°C to 27.5°C (Duke, 1982). The minimum temperature range that plantlets can withstand ranges from -8°C to -10°C, while adult plants are more sensitive, tolerating temperatures from -5°C to -6°C (Fassio et al., 2013). Galic et al. (2022) stated that *Cannabis* spp. can be quite tolerant of short periods of frost before harvest, although prolonged cold may reduce production. In Uruguay, for example, the harvest is carried out in April, before freezing temperatures, and the planting window varies from September to November. Hall et al. (2013) suggested that the ideal planting time for hemp fiber is late November at the low latitudes of the southern hemisphere, based on productivity, plant height, and phenological development. Therefore, by extending the period between planting and harvesting dates, the yield of dry matter may be enhanced, but the risk of yield loss increases due to injuries caused by low air temperatures.

Cannabis spp. requires approximately 90°C growing degree days (GDD) (Tb 0°C) to achieve 50% of plant emergence (Fassio et al., 2013) and 400 GDD to achieve complete soil cover (Struik et al., 2000). Fiber production requires 2000 GDD (Merfield, 1999), while seed production requires 3000 GDD (Fassio et al., 2013). Sikora et al. (2011) found a positive correlation between GDD and the production of THC and CBD. However, the optimal GDD requirements for high-yielding CBD *Cannabis* spp. still need further investigation (Adesina et al., 2020).

To date, few studies accurately assess the water demand for *Cannabis* spp. cultivation. Fassio et al. (2013) pointed out that, for the hemp variety, 250 mm to 700 mm are required for the plant cycle, including the available soil moisture. Amaducci et al. (2015) suggested that hemp requires from 500 mm to 700 mm of available moisture for optimal yield and that 250 mm to 300 mm should be available during the vegetative growth phase. According to Trancoso et al. (2022), although some studies indicate that *Cannabis* spp. is a species of high-water demand, this demand is highly linked to the plant genotype, the agronomic management, and the edaphoclimatic factors of the cultivation area. In addition to soil water, atmospheric humidity should be considered. To Fassio et al. (2013), the ideal relative humidity range would be 40% to 60%, especially during the flowering period.

Adverse events such as intense storms and hail may cause superficial or severe damage, depending on the intensity, variety, and phase of the plants. Smaller varieties (flower/cannabinoid purposes) are less susceptible to damage than fiber varieties, which are less branched and over 3 m tall.

Brazil needs to advance in the research and innovation movement related to *Cannabis* spp. to obtain scientific results that agronomically help in the sustainable commercial production of this species that emerges as an opportunity for diversification and socioeconomic development. One of the essential agricultural tools for species cultivation indication is the *Zoneamento Agrícola de Risco Climático* (ZARC, Agricultural Climate Risk Zoning). The ZARC aims to indicate dates or periods of planting/sowing per culture and per municipality by considering the characteristics of the climate, soil type, and cultivar cycle to prevent climatic adversities from coinciding with the most sensitive phases of the plants, thus minimizing agricultural losses (Embrapa, 2017). Some species of interest, such as *Cannabis* spp., are not listed in the ordinances of the Brazilian Ministry of Agriculture and Livestock (MAPA), often because there is not enough research on them in this line of risk analysis or because such research is restricted to regional institutions.

The initial phase of agricultural zoning methodologies to reduce climatic risks is quantifying the risks to which a species is subjected according to the parameters chosen for the analysis. This analysis may be performed from data found in the literature and consists of identifying areas of higher and lower climatic risks for the cultivation of a given species, considering the agroclimatic requirements of the plants and the macroclimatic information of the region. Combining the bioclimatic requirements of *Cannabis* spp. with the existing microclimatic variability in Santa Catarina, Brazil, brings the possibility of discussing the climatic risks to this species when cultivated in the field in different regions of the state.

The hypothesis that triggered this work was that the state of Santa Catarina presents favorable agroclimatic conditions for cultivating *Cannabis* spp. in its different regions, considering the critical parameters of photoperiod, minimum temperature, and thermal sum. Therefore, this study aimed to perform a climate risk analysis for cultivating *Cannabis* spp. in Santa Catarina. This study is part of a strategic perspective to promote scientific, governmental, and business initiatives that take into account the potential for promoting the species of *Cannabis* spp. in the Santa Catarina territory.

Material and Methods

The data used for the climate risk analysis relating to the bioclimatic characteristics and requirements of *Cannabis* spp. were derived from bibliographic research carried out from June to October 2023 and from observations made by the authors in the field in authorized commercial crops in Uruguay, Brazil, Colombia, and Colorado/USA.

The location chosen for the climate risk analysis was the state of Santa Catarina, a territory of 95.4 thousand km^2 that borders the states of Paraná (to the north) and Rio Grande do Sul (to the south), the Atlantic Ocean (to the east), and Argentina (to the west). The Brazilian Institute of Geography and Statistics (IBGE) geographically divided the state into six mesoregions: West, Serrana, South, Greater Florianópolis, Itajaí Valley, and North.

The predominant climate in Santa Catarina is the humid subtropical, with two climate subtypes according to the Köppen classification: Cfa (humid subtropical climate, with well-distributed rainfall, warm summers, and mild winters) and Cfb (temperate oceanic climate or subtropical highland climate, with well-distributed rainfall, mild summers, and severe winters). The Cfa climate in Santa Catarina is observed in the West region, with altitudes of up to 700 m. To the east of this region, the Cfa climate comprises the Uruguay River Valley at altitudes up to 650 m and throughout the coastal region at altitudes from 500 m to 600 m. The Cfb climate may be observed in the rest of the state in areas with higher altitudes, such as the Santa Catarina Mountain Range (Alvares et al., 2013).

The bioclimatic variables chosen to be used in the climate risk analysis for the *Cannabis* spp. were photoperiod in the flowering induction phase, thermal sum from the vegetative period to full flowering, and the absolute minimum air temperature during the entire plant cycle (Table 1).

The rainfall variable was not considered a climatic risk for Santa Catarina because, according to Pandolfo et al. (2018), the state has total annual rainfall ranging from 1450 mm to 2400 mm per year, which, generically, would not be a limitation to the species considering that it is cultivated in regions with much lower availability and higher temperatures. The water demands for the plants need to be tested and quantified in future regional experiments in Santa Catarina so that a detailed water balance may be obtained, making it possible to identify whether there are differences between the regions and how they could impact cultivation.

For the joint analysis of climate risks, we chose to work with 20% and 30% probabilities as delimiters of low (under 20%), moderate (20% to 30%), and high (above 40%) risks, values usually employed in consultation work for access to rural credit and agricultural insurance.

The phenological cycle adopted for the risk analysis was the *Cannabis* spp. crop cycle for flower production, comprising ten-day periods 33 to 8 (November 21 to March 20), which corresponds to an intermediate cycle. The need to accumulate a thermal sum for varieties with inflorescence production purposes is intermediate compared to cultivation for fiber and seeds purposes. Within the limits of this research, the intermediate cycle was chosen, which does not prevent the equations, maps, and analyses of the phenological cycles of the varieties for grain and fiber production from being carried out using the same methodology.

The photoperiod was estimated based on the astronomical variables for Santa Catarina, and was calculated using the SISAGRO II software, which considers the period of light relative to twilight (Pereira et al., 2004) using the detailed methodology described in Carvalho et al. (1985), who define photoperiod as the number of hours of daylight including twilight time for each location. To illustrate the distribution of photoperiod throughout the year with and without twilight and to identify the dates associated with its different values, data was plotted for three municipalities in Santa Catarina located in the extreme north, west and south of the state: Itapoá, São Miguel do Oeste and São João do Sul.

From the survey and systematization of meteorological data available in the Epagri/CIRAM database, the historical series of the variables of minimum and maximum air temperature were systematized. Only stations with 15 years or more of observations were used, such as those installed in the municipalities of the West (Chapecó, São Miguel do Oeste, Joaçaba, Videira, Caçador, and Ponte Serrada), Serrana (Lages, Campos Novos, and Campo Belo do Sul), South (Araranguá, Urussanga, and Orleans), Greater Florianópolis (Florianópolis and São José), Itajaí Valley (Blumenau, Itajaí, Ituporanga, Indaial), and North (Major Vieira, Rio Negrinho, and Porto União) mesoregions (Figure 1).

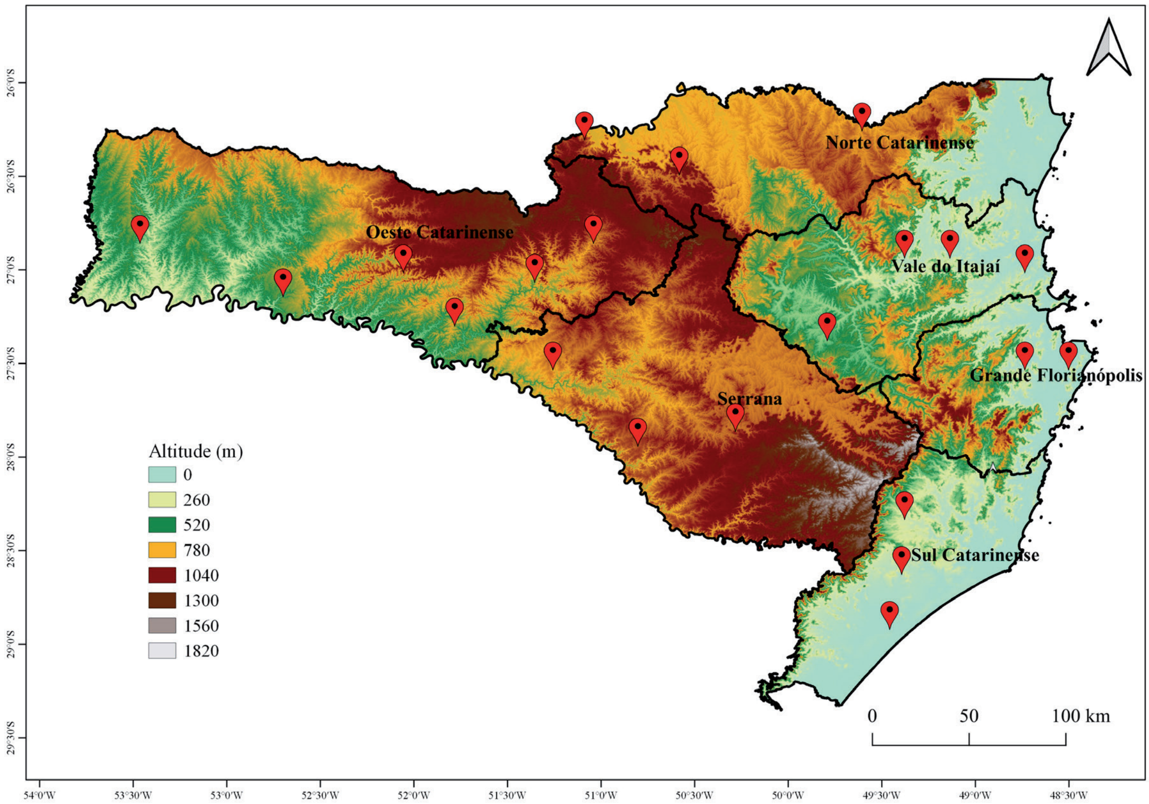
For analyzing the risks associated with minimum temperature extremes, linear regression equations were used according to the altimetry and geographical coordinates proposed by Pandolfo et al. (2021). The analysis of the risk of minimum temperatures harmful to the *Cannabis* spp. plants is based on the probability maps of the occurrence of absolute minimum temperatures in ten-day periods 15 to 23 (May 21 to August 20). The maps were used to spatially identify the periods of frost occurrence above or below a predefined cutoff criterion, identifying the ten-day periods in which there is risk to the plants at the time of implantation or harvest (Pandolfo et al., 2021). The occurrence of -3°C in the weather shelter means that the temperature reaches -6°C close to the ground, which poses a risk of damage, especially from the adult phase of the plant. In this way, the minimum temperature criterion used was -6°C that will define the planting window, delimiting the beginning of sowing/planting and the harvest date.

The minimum base temperature of 1°C (Tb) and maximum base temperature of 40°C (TB) were used to calculate the thermal sum of the ten-day periods (Amaducci et al., 2008; Fassio et al., 2013). The estimated thermal sum values were accumulated from ten-day periods 33 to 8, i.e., November 21 to March 20, because this is the period when the absolute minimum temperature and photoperiod conditions will be met, ensuring that the climatic risk is minimal during plant growth and flowering phases. The risk parameter used was an accumulated thermal sum below 2500 GDD. The thermal sum was calculated

Table 1. Risk parameters for *Cannabis* spp. plants.

Phenological Phase	Agroclimatic Parameter	Risk Criterion
Flowering Induction	Photoperiod	< 14 h
Vegetative phase until full flowering	Thermal sum	< 2500 GDD
Total cycle	Absolute minimum temperature (cold injury)	< = -6°C in soil level or < = -3°C in weather shelter

Figure 1. Relief and geographical division of the mesoregions of the state of Santa Catarina associated with the distribution of the 21 meteorological stations used to prepare this study.



considering the growing degree days (GDD) criterion, which considers five premises described by Bergamaschi & Bergonci (2017) and represents the integration of air temperature in time between the limits of the upper and lower base temperatures of the species.

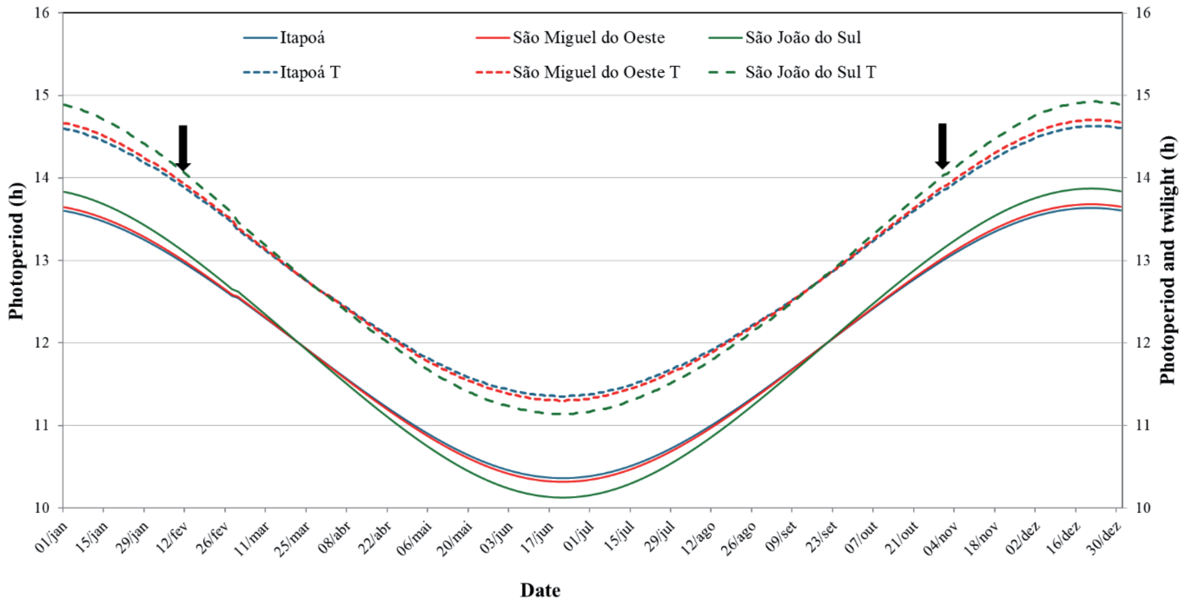
Multiple linear regression equations were adjusted for the mean and standard deviation of the thermal sum variable and used to map the occurrence of thermal accumulation according to the latitude, longitude, and altitude, with a spatial resolution of 90 m, using the base in the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) (USGS, 2006). Stepwise forward multiple linear regression equations were adjusted for the mean and standard deviation values of the thermal sum (ten-day periods 33 to 8) according to the latitude, longitude, and altitude. The data set was tested for normality (Shapiro-Wilk test) and homoscedasticity (Bartlett's test), with no cases of the rejection of the hypotheses with 5% significance. The consistency, systematization, historical series analysis, and results spatialization were performed using R and ArcGis 10.6 software.

Results and Discussion

The three municipalities in Santa Catarina used as a reference for latitude extremes have similar photoperiod values, as the latitudes vary by a maximum of 3.1° (~370 km). São João do Sul presented the highest amplitude in the photoperiod due to being located further south in the state. When the twilight period is considered, the minimum photoperiod is 11.1 h and the maximum 14.9 h. Without twinlight the photoperiod varies between 10,1 h and 13,9 h (Figure 2). Twilight is the period before sunrise and after sunset during which the atmosphere is partially illuminated by the sun and is neither totally dark nor totally illuminated. Recent research has demonstrated that the duration of twilight exerts a modulating influence on plant growth and the onset of flowering (Mehta et al., 2024). This suggests that a photoperiodic discrepancy as minor as 15 minutes can exert a considerable impact on the floral initiation of certain cultivars (Zhang et al., 2021). It is therefore essential to consider this factor when timing the crop to optimize both the vegetative and flowering responses.

Considering the latitudes comprised in SC and the information in Figure 2, the critical photoperiod of 14 h was established as a risk parameter. This means that, as it is a short-day plant, *Cannabis* spp. has the potential to flowering in any region of SC when the photoperiod is 14 h or less. If we consider the length of the day without twilight, this parameter is met in all regions at any time of year. However, studies show that the length of twilight

Figure 2. Seasonal photoperiod with and without the period relative to twilight (T) for three sample points in Santa Catarina: Itapoá (latitude = 26°07'03" S); São Miguel do Oeste (latitude = 26°43'33" S); and São João do Sul (latitude = 29º13'24" S). The black arrows indicate the critical photoperiod risk parameter of 14 hours when considering twilight periods.



can influence the development of some *Cannabis* spp. cultivars (Zhang et al., 2021). In this case, in SC the critical photoperiod of 14 h occurs from February 13 to October 31 (Figure 2). For example, if the sowing/planting of *Cannabis* spp. is carried out in São João do Sul in November, the flowering induction will occur from the moment the photoperiod lasts 14 h or less. Given this, from February, the flowering phase can begin. But, if a specific cultivar were induced by a critical photoperiod of 12 hours, the plants would begin flowering in March or April. During this time, temperatures would be decreasing, increasing the risk of cold stress, particularly in higher altitude regions.

However, it was established that the need for flower induction occurs from the second half of February until the end of March, when the photoperiod with twilight is equal to or less than 14 hours and the air temperature is suitable for the development of *Cannabis* spp. plants. In any case, even if the photoperiod risk criterion is met in the different regions of Santa Catarina, it is essential that it is analyzed alongside genotypic characteristics of each cultivar and with the air temperature criterion, since plant development is the result of genotype x environment interactions.

Cannabis spp. may exhibit some cold tolerance shortly before harvest, but this tolerance depends on the plant's age, cultivar, and the duration of cold temperatures. According to Galic et al. (2022), while cold stress had minimal impact on the plant's biomass, it did lead to a reduction in cannabinoid content. Based on this, we defined a minimum temperature of -3°C in the weather shelter as a risk criterion. Our analysis showed that during the ten-day period from May 21 to 31, there is up to a 13.4% chance of temperatures reaching or falling below -3°C in higher altitude regions such as the Serrana region (Figure 3A). Hence, until ten-day period 18 (June 21 to 30), the risks of occurrence of minimum temperature are classified as low (≤ 20%). In ten-day period 19 (Figure 3B) and 22 (Figure 5A), the risk is moderate (20% to 30%). The highest risk areas (> 40%) are found in the ten-day periods 20 and 21 that occur between 11 and 31 July (Figure 4).

From ten-day period 23 (August 11 to 20) (Figure 5B), the minimum temperatures do not offer risk for crop implantation at the levels parameterized in this work, and the thermal availability starts to be evaluated within an expected pattern of growth and development of the *Cannabis* spp. plants. However, it is important to emphasize that the occurrence of extreme temperatures in certain years is an inherent aspect of probability. This is because meteorological factors, such as air temperature, exhibit inter-annual variability, which is likely to increase due to climate change.

The periods of most significant risk of damage due to low temperatures do not coincide with the estimated cycle for establishment and development of the *Cannabis* spp. plants, comprised between ten-day periods 33 and 8 (November 21 to March 20), a period in which the probability of minimum temperatures would be low. Once this window is adopted, the absolute minimum temperature would not be a restrictive factor for cultivating *Cannabis* spp. in Santa Catarina.

The thermal requirements for *Cannabis* spp. development vary depending on the cultivar's precocity

Figure 3. Probability of occurrence of minimum temperatures of -3°C in the weather shelter in ten-day periods 15 (May 21 to 31) and 19 (July 1 to 10) in Santa Catarina.

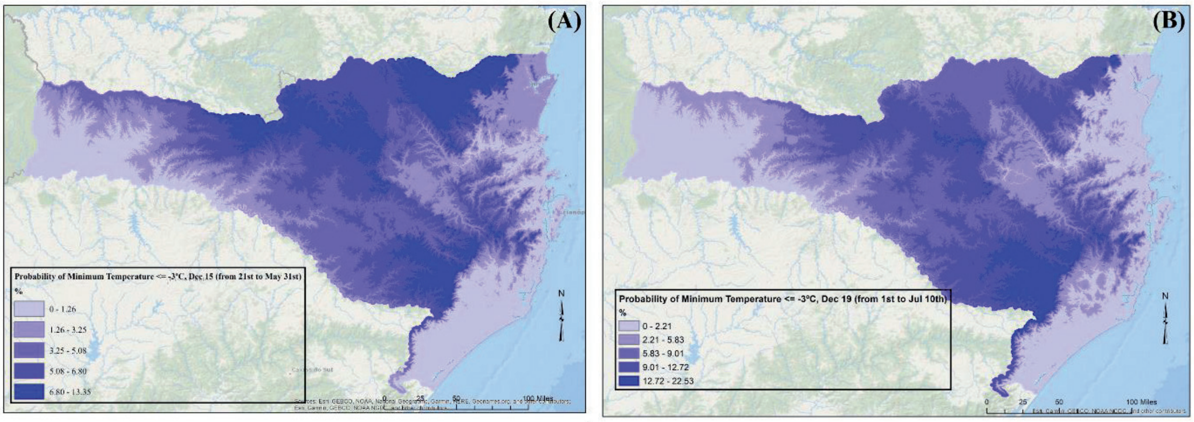
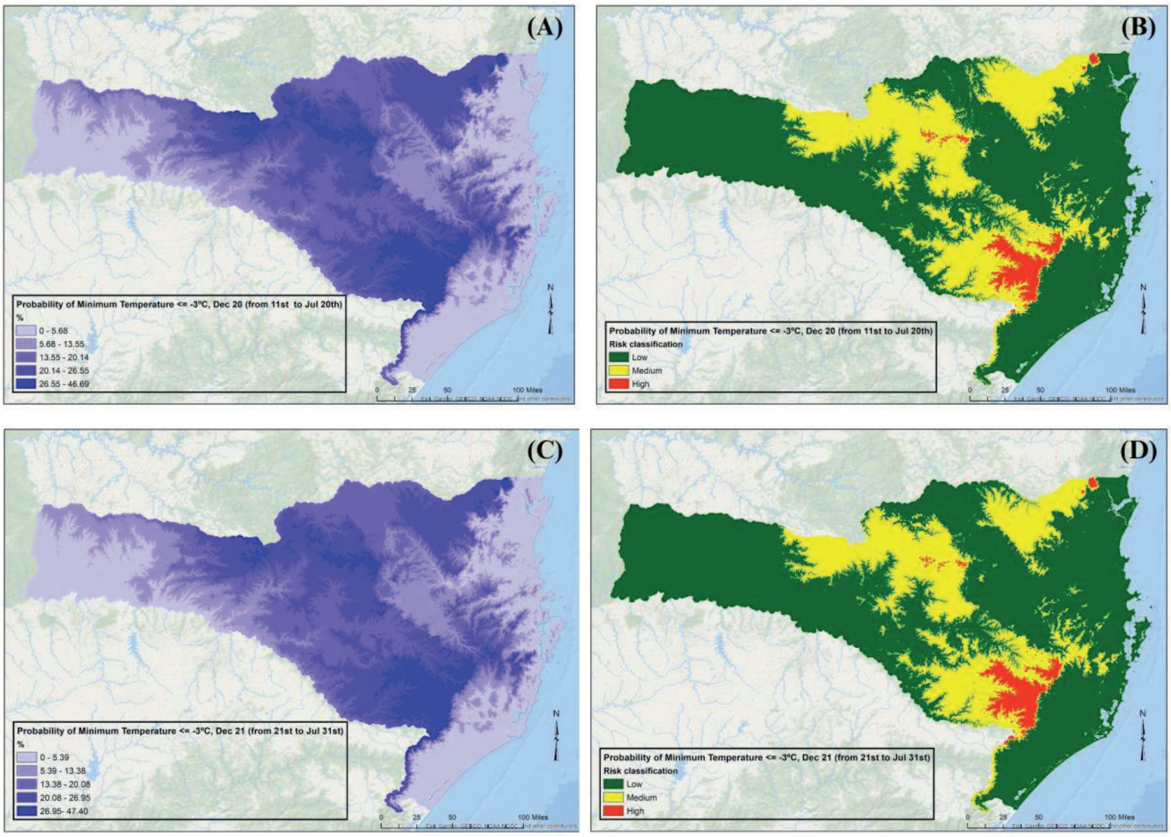


Figure 4. Probability of occurrence of minimum temperatures of -3°C in the weather shelter and risk classification in ten-day periods 20 (A and B, July 11 to 20) and 21 (C and D, July 21 to 31) in Santa Catarina.



and production goals, ranging from 2000 to 3000 Growing Degree Days (GDD). When met, these requirements can enhance THC and CBD production (Sikora et al., 2011; Adesina et al., 2020). In this study, the risk parameter was defined as an accumulated thermal sum of less than 2500 GDD. This implies that a minimum of 2500 GDD is required to achieve optimal *Cannabis* spp. production for flowering purposes. In the test procedure of the thermal sum data used, it was observed that the accumulated thermal sum variable for the period followed a normal distribution, and the variability of the residuals (estimation errors) was constant in all ranges of values of the independent variables (Table 2).

The West, South, and Itajaí Valley regions and part of the Coast showed an accumulated thermal sum above 2500 GDD during ten-day periods 33 to 8 (November 21 to March 20), which corresponded to the development of plants in the field through the flowering period. On the other hand, the regions with higher altitudes, located in part of the Serrana, North, and Midwest regions, did not reach the required thermal sum (Figure 6).

The classification of Santa Catarina considering this

Table 2. Equations used for the spatial representation of the accumulated thermal sum (TSa) and standard deviation (SD) values in the period from ten-day periods 33 to 8 (November 21 to March 20), with latitude (lat) and longitude (lon) in negative decimal degrees and altitude (alt) in meters.

Variable	Equation	R2 and p-value
TSa	y = 2465.44067* + 75.29983.lat **-51.09938.lon** -0.63400.alt***	0.9067
SD	y = 72.27	1.41e-10

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'

Figure 5. Probability of occurrence of minimum temperatures of -3°C in the weather shelter in ten-day periods 22 (A, August 1 to 10), and 23 (B, August 11 to 20) in Santa Catarina.

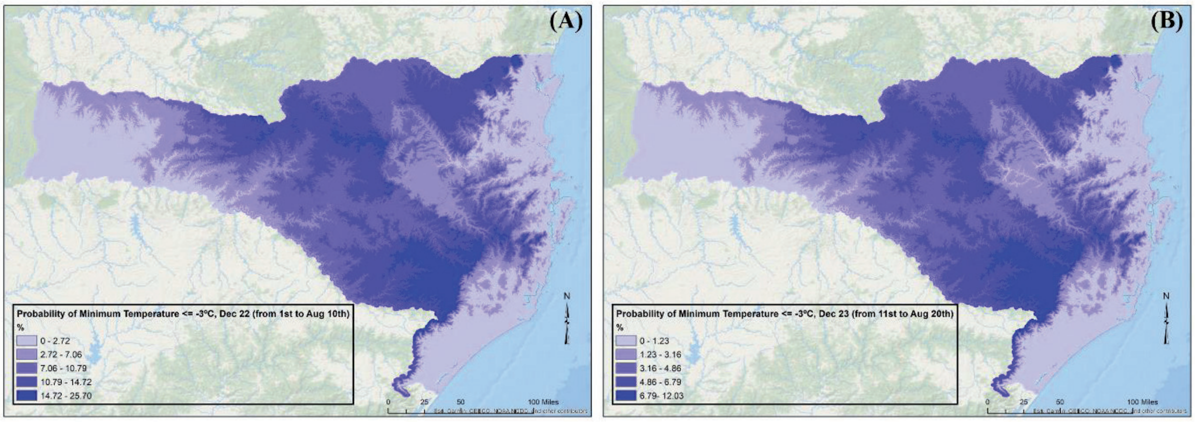
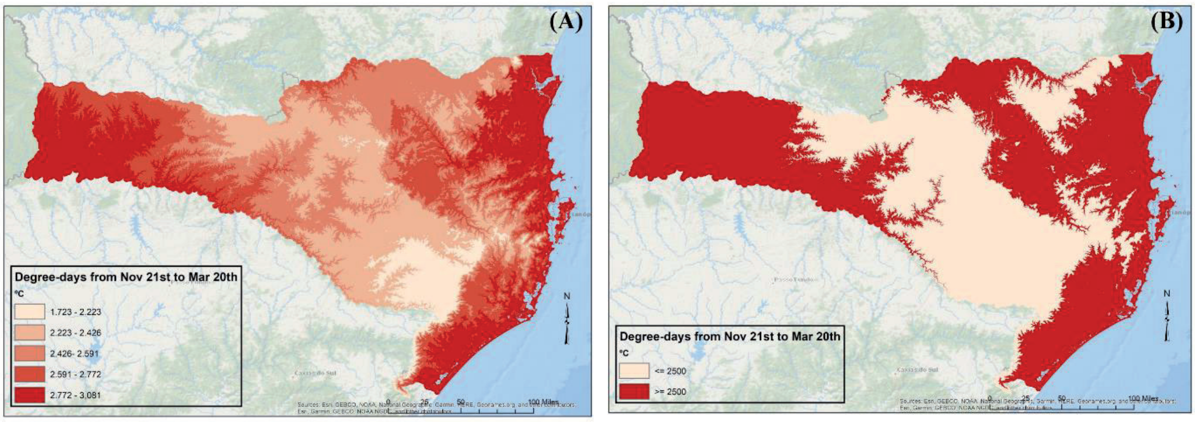


Figure 6. Accumulated thermal sum (A) in ten-day periods 33 to 8 (November 21 to March 20) and (B) classification of the state of Santa Catarina in areas with and without availability of thermal sum considering the minimum of 2500 GDD for Tb = 1°C and TB = 40°C.



parameter indicates the potential for cultivating *Cannabis* spp. in the state distinguishing two regions: the regions of lower altitudes (up to 700 m) have no restrictions regarding the thermal sum, while the regions of higher altitudes have more significant risks for this parameter. The areas with a high risk of accumulated thermal sum deficit from ten-day periods 33 to 8 (November 21 to March 20) coincide with the Cfb region (Figure 1; Figure 7). For these regions, provided not tied to late frosts, there is a possibility of anticipating the establishment of the *Cannabis* spp. plants to early November (ten-day period 31) or maintaining planting from November 21, choosing cultivars that produce quality flowers with a lower thermal sum requirement than that adopted as a risk criterion for this work.

The climate risk analysis for cultivating *Cannabis* spp. for flower production in the state of Santa Catarina identified the critical parameters for plant development as a photoperiod of 14 hours or less, the probability of minimum temperatures falling below -3°C in meteorological shelters, and a minimum thermal requirement of 2500 GDD. Based on these criteria, *Cannabis* spp. can be cultivated across all regions of Santa Catarina, provided that the risks associated with minimum temperatures and thermal accumulation, particularly in higher altitude areas such as the Serrana region, are carefully managed.

The absence of field experiments or commercial crops in Santa Catarina does not favor the result validation part of the methodology, so caution must be present in the analysis.

There are spatial resolution limitations in the climatic database; therefore, risk assessment should be contextualized with regional technical knowledge for regions with significant variation in altimetry and relief. In addition, to deepen the global understanding of the risks associated with the *Cannabis* spp. in SC, it is suggested to consider edaphic, pests and diseases factors that affect this species.

This study did not take into account the specificities of the different genetic varieties and was developed with information researched in the specialized literature, systematization of technical data; therefore, it represents a possibility for the state and should be revised according to data that may come to be generated from field experiments and based on the responses of cultivars under commercial conditions, once regulated.

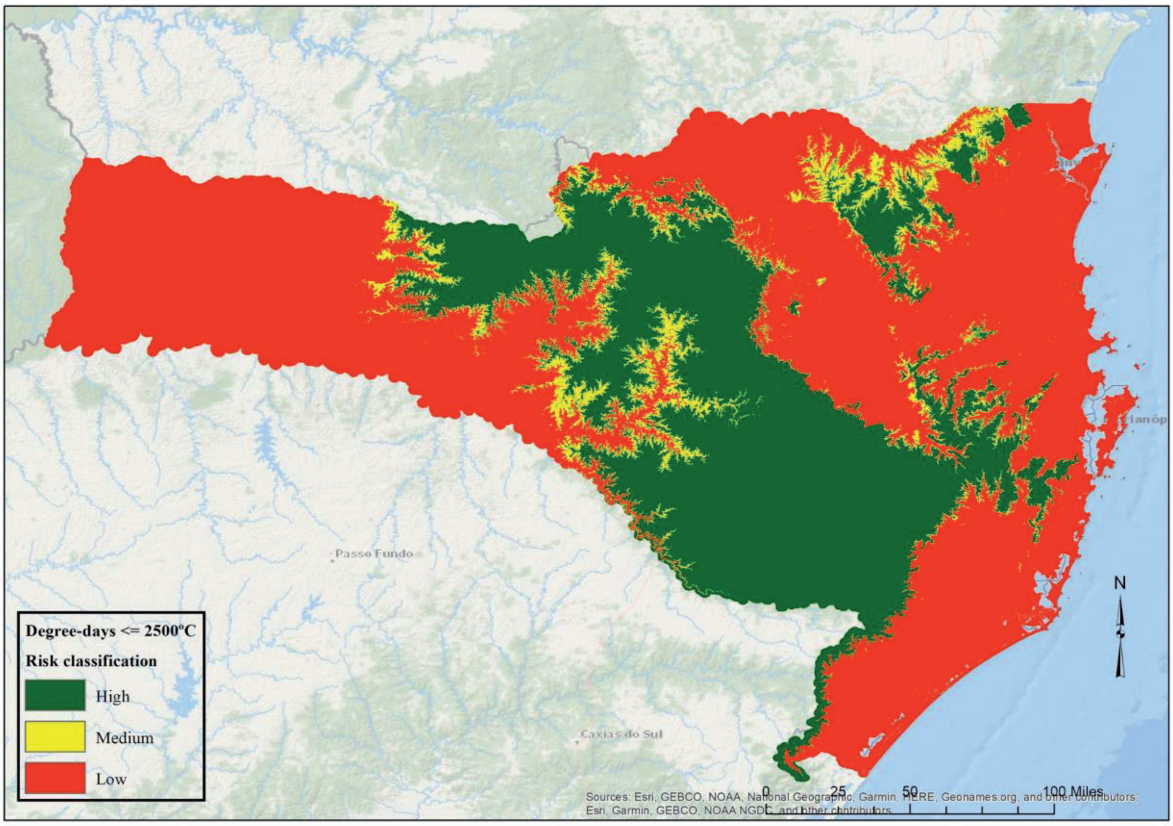
Conclusion

The *Cannabis* spp. has the possibility of cultivation in all regions of the state of Santa Catarina, provided that the technical guidelines regarding the choice of genotypes, planting and harvesting windows, among others, are observed, according to the risks inherent to each region. Within the period chosen for the establishment and development of the *Cannabis* spp. plants (November 21 to March 20), the criteria of photoperiod and absolute minimum temperature (cold injury) were not limiting in any region of the state. For the critical parameter of thermal sum, there are regions in which the risk is high, with this limitation being overcome with the possibility of anticipating the establishment of the plants.

Author contributions

P. CAMARGO and C. PANDOLFO article conception and writing. C. PANDOLFO data acquisition and analysis. L.C. BOSCO article writing and revision.

Figure 7. Classification of the state regarding the risk of occurrence of accumulated thermal sum < 2500 GDD in ten-day periods 33 to 8 (November 21 to March 20) in Santa Catarina.



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Análise de risco climático para *Cannabis* spp. para Santa Catarina

Priscila Camargo[1(*)], Cristina Pandolfo[2] e Leosane Cristina Bosco[3]

[1]Universidade Federal de Santa Catarina (UFSC). Rodovia Admar Gonzaga, 1346, Bairro Itacorubi, Caixa Postal 476, CEP 88040- 900 Florianópolis, SC. E-mail: mskpri@gmail.com

[2]Centro de Informações de Recursos Ambientais e de Hidrometeorologia de Santa Catarina (CIRAM/EPAGRI). Rodovia Admar Gonzaga, 1347, Bairro Itacorubi, CEP 88034-901 Florianópolis, SC. E-mail: cristina@epagri.sc.gov.br

[3]UFSC - Campus Curitibanos. Rodovia Ulysses Gaboardi, km 03, CEP 89520-000 Curitibanos, SC. E-mail: leosane.bosco@ufsc.br

[(*)]Autor para correspondência.

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RESUMO

O interesse no uso medicinal da *Cannabis* spp. vem aumentando em função das evidências científicas que demonstram seu potencial terapêutico. No entanto, no Brasil, são incipientes os estudos agronômicos referentes ao seu cultivo. O objetivo deste estudo foi realizar análise de risco climático para o cultivo da *Cannabis* spp. em Santa Catarina (SC), Brasil. A partir de uma revisão bibliográfica e da sistematização de dados meteorológicos de SC, foram considerados os parâmetros críticos de fotoperíodo (< 14h), probabilidade de ocorrência de temperaturas mínimas (< -6ºC) e soma térmica (< 2500ºC dia). A *Cannabis* spp. tem possibilidade de cultivo em todas as regiões do estado, desde que observadas as orientações técnicas de acordo com os riscos inerentes a cada região. Dentro do período decendial de 33 a 8 (21/nov a 20/mar), os critérios de fotoperíodo e de temperatura mínima absoluta do ar não foram restritivos em nenhuma região do estado. Para o parâmetro crítico da soma térmica, em regiões onde o risco é alto devido a soma térmica ser inferior a 2500°C dia, essa limitação poderá ser superada com a possibilidade de antecipação do estabelecimento das plantas. Esta pesquisa fornece informações úteis para pesquisadores, legisladores e interessados no cultivo de *Cannabis* spp. no Brasil, com uma perspectiva estratégica destinada a fomentar iniciativas que considerem o potencial de produção de *Cannabis* spp. no território catarinense.

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