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Assessing current environmental conditions and Climate Change Influences on Syngonanthus nitens (Bong.) Ruhland: An Endemic Species and Economic Resource for Extractive Communities as Globally Important Agricultural Heritage Systems

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Abstract

Capim dourado, also known as sedinha, refers to the everlasting flower *Syngonanthus nitens* (Bong.) Ruhland (Eriocaulaceae), prized for its use in crafting and as a significant income source for communities in Minas Gerais, Bahia, and Tocantins, Brazil. This plant is also utilized in the creation of highly valued jewelry and accessories on the global market. This study aims to ascertain the thermal and humidity thresholds of *S. nitens* while mapping and predicting its current and future distribution. Initially, distribution data was gathered through a literature review, supplemented by biological temperature and humidity data collected from the Quilombola Raiz Community in Minas Gerais and a germination experiment conducted at the Integrated Multi-User Research Laboratory of the Jequitinhonha and Mucuri Valleys (LIPEMVALE). Climate Index (CLIMEX) parameters were defined using biological information and occurrence locations. Maps were generated using ArcGIS. The optimal temperature range for *S. nitens* development is between 18°C and 24°C, with minimum and maximum thresholds of 5°C and 40°C respectively. Ninety-two occurrence records were found, all situated in South America, aligning with high climate suitability regions as per the model predictions. Future projections for 2050 and 2100 indicate a decrease in areas suitable for S. nitens. These findings provide crucial insights for decision-making, necessitating measures such as widespread monitoring, collaborative conservation efforts, and the establishment of sustainable use zoning to manage *S. nitens* effectively.

1. INTRODUCTION

“Sempre-vivas” (always-alive) is the name given in Brazil to plants that, after being collected and dried, retain the appearance of their structures unchanged, as if they were alive. They are significant species managed by traditional communities in the cerrado of the Central-West and Southeast regions, mainly in the rocky fields of Serra do Espinhaço, covering the states of Minas Gerais and Bahia (GIULIETTI et al., 1996). They are widely used in the manufacture of artisanal products, serving as essential sources of income".

In 2020, the Food and Agriculture Organization of the United Nations (FAO) acknowledged sempre-vivas collecting communities as Globally Important Agricultural Heritage Systems (GIAHS). This recognition was attributed to their agrobiodiversity and traditional knowledge. Moreover, these communities are crucial as custodians of native flora diversity and animal breeds (FAO, 2020).

The name “sempre-viva” encompasses *Syngonanthus nitens* (Bong.) Ruhland (Eriocaulaceae), commonly known as capim-dourado or sedinha, which is widely distributed in Central Brazil. It mainly thrives in humid fields adjacent to veredas and floodable gallery woodland forests (SANTANA, 2013). A notable feature of this species is its golden scapes that emerge from a rhizome, bearing the inflorescences at the apex (WATANABE, 2009). These scapes are utilized in crafting handmade goods, highly valued in both the Brazilian and international markets, serving as a vital source of income for communities in Minas Gerais, Bahia, and Tocantins. While these communities harmoniously coexist with their environment,

future changes in climatic conditions may potentially impact the distribution, phenology, and diversity of *S. nitens* (BERGAMASCHI, 2007) (Fig. 1).

Plant phenology changes primarily due to shifts in the thermal regime. Numerous studies indicate that global warming manifests as a more significant increase in minimum temperatures, notably at night (IPCC AR6, 2021). This effect, attributed to greenhouse gases, curtails nighttime heat dissipation from the Earth's surface, consequently elevating nocturnal temperatures. This accelerated cycle of plants and heightened nighttime respiration result in decreased plant production, impacting biomass and fruit yield (BERGAMASCHI, 2007). Alterations or reductions in geographic distribution represent the most common response of plants to climate change. These shifts affect species' distribution and abundance, thereby influencing ecological groups' spatial composition and ultimately reducing their diversity (SOCOLAR et al., 2016; BERGAMASCHI, 2007).

To assess the influence of climate and climate change on the distribution and relative abundance of vegetation communities, ecological niche models are gaining popularity (SALAZAR et al., 2006). This tool provides prompt and well-founded information to guide conservation and environmental preservation efforts, thereby mitigating the accelerated loss of biodiversity (GIANNINI et al., 2012).

Among the ecological niche models is Climex (KRITICOS et al., 2015), a software that offers tools to estimate a species' potential spatial and temporal distribution concerning climate (SUTHERST et al., 2007). This program simulates the mechanisms limiting the distribution of a given species based on ecophysiological parameters (KRITICOS et al., 2015). This approach operates under the assumption that understanding where an organism inhabits and the climatic conditions it can tolerate makes it feasible to predict other regions globally where the species could survive and reproduce (KRITICOS et al., 2015).

Therefore, it is crucial to understand how climate change can impact the species, dynamics, and composition of local ecosystems and how these ecosystems will adapt to these changes. Hence, identifying the climatic characteristics that could render species more vulnerable becomes paramount. Acquiring knowledge about the period of highest density of *S. nitens* is also essential for developing management plans to preserve and sustain the species, including cultivation. Consequently, a deeper understanding of the spatiotemporal dynamics under specific climatic conditions for *S. nitens* is imperative.

Research on *S. nitens* regarding the impact of climate change on its distribution is still at an early stage. Therefore, the objective of this study is to determine thermal and humidity limits, as well as to map and predict the current and future distribution of *S. nitens*.

2. MATERIAL AND METHODS

2.1. Biological data of the sempre-viva *Syngonanthus nitens*

2.1.1. Thermal thresholds for germination of the sempre-viva *Syngonanthus nitens*

The seeds used in this study were donated by evergreen collectors from the Raiz Community in Presidente Kubistchek, municipality of Minas Gerais, Brazil. The experiment was carried out at the Integrated Multi-User Research Laboratory of the Jequitinhonha and Mucuri Valleys (LIPEMVALE), using a BOD (Biochemical Oxygen Demand) germinator.

The plant material was identified by Fabiane N. Costa, André C. Muniz, Darliana C. Fonseca and Elaine C. Cabrini, and a voucher specimen was deposited in the DIAM – UFVJM herbarium with identification 4092.

The inflorescences of *S. nitens* were dissected to extract seeds, employing a scalpel for this purpose. The seeds were then separated from the remaining residue and disinfected with 2% sodium hypochlorite for 15 minutes, followed by three washes with distilled water. Each test comprised four replications of 50 seeds placed in a petri dish containing two sheets of filter paper. Evaluations were conducted every seven days using the OPTON AC100V-240V stereoscopic magnifying glass, concluding after 31 days, specifically seven days following germination stabilization. Temperatures ranging from 3 to 45°C, with continuous exposure to light, were employed in the tests. The germination rate (%) was assessed.

The effects of various temperatures were assessed utilizing analysis of variance (ANOVA), with the seeds distributed in a completely randomized design. Mean comparisons were conducted using the Tukey test at a significance level of 5%.

2.1.2. Soil moisture and temperature data at field study

The data collection site (18°36'47" S and 43°37'18" W) spans an area of approximately 3 hectares and is situated within the Quilombola Raiz Community, located 6 km from the city of President Kubitschek, Minas Gerais, Brazil. The region's climate, influenced by high altitudes, features mild temperatures for a significant part of the year. According to the Köppen-Geiger climate classification, the area's climate is categorized as mesothermal (Cwb), with an average annual temperature of 18ºC and an average precipitation of 1,404 mm per year (VIEIRA et al., 2010; CAMPOS et al., 2012).

The phytophysiognomy of the study area represents a humid, clean field (Fig. 2) primarily populated by herbaceous species alongside a few shrubs. Within this Pedoenvironment, the combination of low natural fertility, elevated aluminum levels, and inadequate soil drainage dictates the survival of only robust species equipped with adapted root systems to thrive in these conditions (SILVA, 2005).

Soil moisture levels were assessed throughout the year using the greenhouse method. Sampling involved removing the vegetation cover from the surface layer, and before packaging the samples, any excess roots within the collected soil were manually eliminated. Collection took place using a straight shovel in randomly selected representative locations at depths of 0–10 cm, 0–20 cm, and 20–40 cm. The samples

were then packed into aluminum cans and dispatched to the Integrated Multi-User Research Laboratory of the Jequitinhonha and Mucuri Valleys – LIPEMVALE.

The oven method test adhered to the procedures outlined in the Brazilian Regulatory Standard – NBR 6457 of the Brazilian Association of Technical Standards – ABNT (1986). In summary, this method involves weighing the wet soil sample, drying it in an oven for 24 hours at 105°C, and subsequently reweighing the dry soil.

The calculation of soil moisture percentage (h) for various months of the year was determined by the ratio between the mass of water (Ma) present in the soil volume and the mass of the solid part (Ms) within the same volume, as shown in Eq. 1 (CAPUTO and CAPUTO, 2017).

$$h(\%) = \frac{Ma}{Ms} . 100 \quad (1)$$

The minimum and maximum temperatures of the region were determined by averaging the daily temperatures recorded at the collection site using an Incoterm thermo-hygrometer. This data was collected between June 2022 and May 2023.

2.1.3. Survey of the productivity of the sempre-viva *Syngonanthus nitens* in the different months of the year

The estimation of capim dourado productivity was carried out in an area of 1 m² delimited with stakes and string in the Quilombola Raiz Community, Presidente Kubitschek, Minas Gerais, Brazil (Fig. 3).

Assessments were carried out monthly, starting in July 2022 and ending in June 2023. Photographic records were taken with the help of an Apple iOS smartphone, model iPhone 11, equipped with a 12-megapixel camera.

Photographic records from each month were utilized to count inflorescences with the assistance of the computational graphic annotation tool LabelImg. This tool is coded in Python and employs Qt for its graphical interface. All inflorescences within the defined area were manually selected. The annotations were saved in YOLO format (text document) to determine the quantity of inflorescences (Fig. 4).

2.2. Current distribuition of the sempre-viva *Syngonanthus nitens*

The distribution map of *S. nitens* was generated in ArcGIS using species occurrence records obtained from published literature and the Global Biodiversity Information Facility online database (https://doi.org/10.15468/dl.pgvw44) (GBIF, 2022). The search terms employed in GBIF were: "*Syngonanthus nitens*", "capim dourado", and "sedinha”. A total of 92 species records were found, all of which were located on the South American continent.

2.3. Climex

To assess the potential geographic distribution of *S. nitens* based on climatic conditions, we utilized version 4.0 of the Climex software. This tool enables visualization of how climatic suitability changes both spatially and temporally (KRITICOS et al., 2015).

Climex records the response of a biological organism to the temperature, humidity, and light conditions of a given environment. Several indices are utilized to estimate the potential growth and survival of the population. These include the annual growth index (GIA), weekly growth index (GIw), temperature index (TI), soil moisture index (MI), diapause index (DI), and luminosity index (LI). Additionally, there are stress indices: cold stress (CS), heat stress (HS), drought stress (DS), and moisture stress (WS).

Combining the growth indices with the stress indices, the ecoclimatic index (EI) is obtained, which varies from 0 to 100, which characterizes the organism's potential for climatic establishment in different regions of the globe. The closer the EI value is to 100, the better the climatic conditions for the establishment of the species. In this work, classifications were defined based on the Climex Manual (KRITICOS and BRUNEL, 2016), which establishes that areas with EI = 0 unsuitable, $0 < EI < 30$ low suitability, and $30 \leq EI \leq 100$ high suitability.

2.4. Parameter adjustments and model validation in Climex software

The climate suitability model for *S. nitens* was developed using biological data collected from field observations and laboratory experiments. Temperature-related data were determined based on results obtained from a germination experiment (Fig. 6) and the average monthly temperatures recorded in Presidente Kubstichek, Minas Gerais, Brazil. Soil moisture parameters were established through optimal model adjustments derived from the literature (SANTNA et al., 2023) and field collections within the species habitat (Fig. 7). In the Climex software, the 'Compare location' function was employed, and the biological parameters were fine-tuned to ensure that all species occurrences were within areas deemed highly suitable according to the model (KRITICOS and BRUNEL, 2016).

2.5. The growth rate for sempre-viva *Syngonanthus nitens*

Ecological niche modeling for *S. nitens* was carried out only in South America, a region where its distribution is restricted. Derived from the S. nitens thermal threshold experiment results, the lower threshold (DV0) was established at 5°C, while the upper threshold (DV3) was set at 40°C. The ideal lower (DV1) and upper (DV2) temperatures, 18°C and 24°C respectively, were determined based on the average of the maximum and minimum temperatures recorded at the species' location of occurrence (Presidente Kubstichek, Minas Gerais, Brazil).

The lower and upper limits, along with the ideal soil humidity incorporated into the model, were determined based on the varying soil humidities observed during different months of the year within the

area where S. *nitens* occurs. These parameters—SM0, SM1, SM2, and SM3—were set at 0.02, 0.2, 2, and 3, respectively to best align with the species' global distribution pattern (refer to Table 1).

The suitability of a species can vary across different seasons, affecting its development either positively or negatively. To assess the growth rate throughout various seasons of the year, we utilized the 'compare location/years' tool. This tool comprises a time series of monthly data, enabling the evaluation of interannual variation effects in a specific location. These values are on a scale from 0 to 1, where the closer the value is to 1, the more suitable the location is considered. The coordinates of the location correspond to the experiment conducted in subtopic 2.1.2. (-18W and − 43W), covering the period from January 1st to December 31st, 2017.

2.6. Stress parameters

The temperature limits for cold stress (TTCS) and heat stress (TTHS) were determined based on DV0 and DV3, respectively, at 5°C and 40°C. Additionally, the rates of accumulation due to cold stress (THCS) and heat were defined as -0.002 and 0.09 week ^{1}. These values exhibit a better adaptation for regions with higher temperatures where the species is found.

The drought stress limit (SMDS) was established using the same value as SM0, which is 0.02, and the stress accumulation rate (HDS) at -0.08 week ^{1}. Moisture stress was not taken into account as *S. nitens* typically thrive in flooded soils, such as clean, moist fields.

Table 1
Values of the settings defined for modeling the sempre-viva *Syngonanthus nitens* using Climex.

Index	Parameter	Unit	Value
Temperature	DV0 = the lower temperature threshold	°C	5
	DV1= the lower optimum temperature	°C	18
	DV2 = the upper optimum temperature	°C	24
	DV3 = the upper temperature threshold	°C	40
Moisture	SM0 = lower soil moisture threshold	–	0.02
	SM1 = lower optimal soil moisture	–	0,2
	SM2 = upper optimal soil moisture	–	2
	SM3 = upper soil moisture threshold	–	3
Cold Stress	TTCS = cold stress temperature threshold	°C	5
	THCS = cold stress temperature rate	$week^{-1}$	-0.002
Heat Stress	TTHS = heat stress temperature threshold	°C	40
	THHS = heat stress temperature rate	$week^{-1}$	0.09
Dry Stress	SMDS = dry stress threshold	°C	0.02
	HDS = dry stress rate	$week^{-1}$	-0.08

2.7. Climate data, models and scenarios

The climate data utilized for the *S. nitens* model were obtained from a Climond 10' grid. These files encompass meteorological data featuring information on average minimum and maximum temperatures, precipitation, and monthly relative humidity. Data from 1961 to 1990, focused on 1975, were employed to represent the historical climate (KRITICOS et al., 2012). Global distributions for 2050 and 2100 were modeled under the A2 emissions scenario using the MIROC-H Global Circulation Model.

3. RESULTS

3.1 Biological data of the sempre-viva *Syngonanthus nitens*

3.1.1 Thermal thresholds for seed germination sempre-viva *Syngonanthus nitens*

Figure 4 displays various patterns observed during the germination process of *S. nitens*: non-germinated seeds (Fig. 5A), germinated seeds distinguished by the protrusion of the embryonic axis (Fig. 5B), and the emergence of the first leaf (Figs. 4C and D).

At 10°C, there was a significantly higher accumulated germination rate of 86%, which differed statistically from the other treatments. Following this, temperatures of 25°C, 20°C, and 30°C exhibited germination rates of 70%, 66%, and 52.5% respectively, with 30°C showing a statistically significant difference from the other treatments ($F_{10, 33} = 65.95$; $p < 0.001$). Intermediate germination rates were observed at temperatures of 15°C (47%), 7°C (44%), and 35°C (39.5%), statistically similar to each other. Similarly, temperatures of 5°C (35%) and 40°C (26%) demonstrated equal germination rates. Notably, seeds subjected to temperatures of 3°C and 45°C did not germinate (Fig. 6).

After eight days post-imbibition, germinated seeds were observed within the 5 to 40°C temperature range, with 76% of the seeds showing root protrusion at 10°C. Post-germination development exhibited a consistent pattern across all treatments. The germination peak occurred twenty-four days after sowing, and stabilization in germination rates persisted until the end of the thirty-one-day evaluation period. Notably, the emergence of the first leaf was observed solely at a temperature of 25°C on the sixteenth day of evaluation, representing 6%.

Based on the findings, we can determine that the optimal upper temperature for *S. nitens* germination is 25°C, while the lower temperature is 10°C. The upper and lower thermal thresholds are identified as 5°C and 40°C, respectively.

3.1.2 Soil moisture and air temperature thresholds in an area where the sempre-viva *Syngonanthus nitens* occurs

It was observed that soil humidity in the species' habitat remains consistently above 50% throughout the year. From May to September, typically considered the dry season, humidity levels ranged between 55% and 111%. However, starting from October with the onset of the rainy season, soil humidity consistently surpassed 106%, reaching its peak in February with levels exceeding 209% (Fig. 7). The highest observed soil moisture within the collection area was 200%, identified as the upper threshold ideal for *S. nitens*. Conversely, the lowest moisture level observed for *S. nitens* occurred in August, with soil moisture recorded at 55%.

From data collection, we obtained an average general, minimum, and maximum temperature for the different months of the year for the Quilombola Raiz Community in the municipality of Presidente Kubistchek, Minas Gerais, Brazil (Fig. 8). The month of July had the lowest average temperature values, with the minimum being 11.3°C and the maximum being 22.6°C. The maximum temperature increases occurred between December and April, obtaining variations of 25.5 and 26.5%. The minimum temperature showed the biggest fluctuations, always remaining below 23°C, which was the temperature observed in February. In the other months, it was between 11.4 and 21.2°C. The average of all months for the

minimum temperature was 17.6°C and for the maximum temperature was 24.3°C, thus being considered the ideal temperature for the development of *S. nitens*.

3.1.3 Survey of the productivity of the sempre-viva *Syngonanthus nitens* in the different months of the year

The quantity of inflorescences recorded each month is depicted in Fig. 8. Between June and August, the count increased from 250 to 1164, subsequently decreasing in the following months: September (987), October (850), November (787), December (697), January (278), February (243), March (184), April (110), and May (102). The flowering of S. nitens begins in June and continues to increase until August, which marks the peak production. From September 2022 to April 2023, the presence of inflorescences was consistently observed but in a declining pattern, representing remnants from the flowering period between June and August. The scapes remained on the plant for months, and during the rainy season, they either broke or rotted.

3.2 Current location of the sempre-viva *Syngonanthus nitens* and its models using Climex

A total of 92 species occurrences were recorded, all situated in South America, with 87 of these records (95%) in Brazil. They are distributed across Jalapão (Tocantins), Distrito Federal, Alto Paraíso (Goiás), within the Espinhaço Range (Minas Gerais and Bahia), as well as in Serra da Mantiqueira and Serra da Canastra in Minas Gerais. The occurrence of *S. nitens* was also documented in Colombia, Bolivia, and Venezuela (Fig. 10a).

The model predicts high climate suitability in tropical regions. However, as it approaches temperate zones, the suitability decreases. The entire Brazilian territory exhibits suitability, with most of its expanse highly suitable for *S. nitens*. The suitability is also notably high in other countries where the species is present. Venezuela's entire territory displays high suitability, while Colombia and Bolivia, as exceptions, have small unsuitable portions. Generally, however, the climatic conditions of these countries align well with the requirements for *S. nitens* according to the model generated in Climex.

Much of Argentina and Chile, alongside the coastal regions of Bolivia and Paraguay, lack distribution potential for *S. nitens*. Notably, all species records are situated in areas of high suitability, thus showcasing a strong correlation between the species' occurrence and the generated model (Fig. 10b).

When observing Fig. 10, one can discern the variation in the spatio-temporal Growth Index (GI) of *S. nitens* throughout the months of 2017. The growth index values ranged between 0.57 and 0.84 between January and May. However, from June onward, a decline in GI initiates, maintaining values between 0.02 and 0.45 from June to August. Following September, the index experienced growth again, reaching 0.77 and sustaining similar values in subsequent months: 0.73 in October, 0.75 in November, and 0.71 in December.

Future scenarios predict a reduction in climatic areas suitable for the survival of *S. nitens* across South America (Fig. 12). This impact is already evident in Brazil's 2050 projection, showing a decrease in highly suitable areas, particularly in the central-west and northeast regions. By the 2100 scenario, this reduction intensifies, with a noticeable lack of suitability in central and northern Brazil, including regions where *S. nitens* currently thrives.

In Colombia, Venezuela, and Bolivia, where species records exist, the projections indicate a transition from highly suitable areas to merely suitable ones by 2050. By 2100, there is a significant increase in areas lacking the necessary climatic conditions for the survival of *S. nitens*. Conversely, the southernmost region of the continent, such as Argentina, is expected to experience an expansion of suitable areas previously deemed unsuitable.

3. DISCUSSION

Temperature plays a crucial role in controlling germination (BASKIN and BASKIN, 1988; BEWLEY and BLACK, 1994; BENECH-ARNOLD and SÁNCHEZ, 1995), as seeds germinate within a specific temperature range unique to each species (BEWLEY and BLACK, 1994). This temperature range for germination can significantly influence the geographic distribution of plants (THOMPSON, 1973; LABOURIAU, 1983; PROBERT, 1992) and is closely tied to the species' adaptation to its environment of occurrence (SCHULTZ and RAVE, 1992).

Syngonanthus nitens seeds exhibit a high germination capacity, comparable to or higher than that observed in other related species (OLIVEIRA and GARCIA, 2005; VALERIANO et al., 2013; OLIVEIRA et al., 2014; OLIVEIRA and GARCIA, 2011). These seeds demonstrate germination across a wide temperature range (5 to 40°C), as noted by Oliveira and Garcia (2011) in their study involving six species within the same genus (*S. anthemidiflorus, S. bisulcatus, S. verticulatus, S. gracilis, S. aciphyllus, S. caulescens* e *S. vernonioides*).

In the same study, a temperature of 10°C resulted in a germination rate exceeding 85% for *S. anthemidiflorus* and *S. bisulcatus*. Similarly, akin to *S. nitens*, species such as *S. aciphyllus* and *S. vernonioides* also displayed germination at higher temperatures of 35 and 40°C.

The high soil humidity to which the seeds of this species are subjected in their natural environment causes a decrease in the amplitude of thermal fluctuations, maintaining lower temperatures, which is reflected in the greater germinability of the seeds at temperatures below 20°C. The optimum temperature for germination also appears to be related to the adaptation of the species to the environment in which it occurs. Seasonally, mesic environments and high altitudes may favor germinating the species' seeds at milder temperatures.

Syngonanthus nitens is widely distributed and has a wide temperature range for germination. Other species of Eriocaulaceae (OLIVEIRA and GARCIA, 2005), Xyridaceae (ABREU and GARCIA, 2005), and Velloziaceae (GARCIA and DINIZ, 2003; SOARES, 2008), which have a wide distribution in the Espinhaço

Range, also germinate in a wider temperature range. Plasticity in germination provides flexibility to environmental variations (VENABLE and BROWN, 1988), allowing the species to survive in adverse situations.

As observed in other studies, the population dynamics of *S. nitens* in rocky fields are directly linked to hydromorphic soils. The species preferably occurs in areas characterized by clean, humid fields and is often associated with paths, forming strips parallel to watercourses. Wet fields are considered collection basins for water absorbed by adjacent plateaus and are essential for maintaining biodiversity and the economy (NARANJO, 1995). These fields consist of herbaceous vegetation and are typically found in the flatter, more waterlogged parts of Alto da Serra. Sediments' deposition forms them from the surrounding higher areas (FÁVERO et al., 2021).

Due to the specific edaphic conditions of the humid, clean fields, especially humidity and organic matter, this environment hosts a distinct flora. These areas correspond to regions where traditional communities engage in economic activities related to subsistence agriculture, extensive livestock farming, and primarily the extraction of natural resources (SCHMIDT, 2011).

An inverse relationship becomes evident when we correlate the number of inflorescences (Fig. 9) with soil moisture (Fig. 7). During the months when *S. nitens* blooms, the soil experiences its lowest moisture percentages. Specifically, June, July, and August exhibited soil humidity levels below the average of the studied area (114%). This observation suggests that the flowering of *S. nitens* is favored during periods of reduced rainfall, which characterize the dry season in the cerrado.

Syngonanthus nitens exhibits seasonal vegetative and reproductive events. It invests in vegetative growth during the rainy season, while reproductive events occur in the dry period. The wetter periods facilitate the germination of seeds that fall alongside the scapes close to the mother plant (SCHMIDT et al., 2007).

Schmidt et al. (2007) observed that the flowering of *S. nitens* in Jalapão, Tocantins, Brazil also takes place during the dry season. They noted that scape growth initiates between April and May, characterized by the presence of young capitula. The flowers bloom in July, following the complete development of the scapes, with seed production commencing in September. Schmidt et al. (2007) also observed remaining inflorescences after anthesis, which, after maturation, stayed on the plant for a few months until they eventually broke or rotted, typically occurring during the rainy season.

To comprehend the impact of climatic conditions on the current and potential distribution of *S. nitens*, records of the species occurrence were gathered, revealing a higher concentration of occurrences in Tocantins, particularly in the Jalapão State Park (PEJ). This prevalence is attributed to an increased number of conducted studies driven by the pressure of extractivism and the species' significant socioeconomic importance in the region. Notably, *S. nitens*, utilized by artisans and extractivists registered with the Tocantins State Environmental Agency, account for approximately 16% of PEJ's total production (SANTNA et al., 2023). Additionally, occurrences have been noted in Goiás and the Federal District.

Other regions where *S. nitens* has been observed include the Espinhaço Range, spanning the states of Minas Gerais and Bahia. In Bahia, its distribution is limited to Chapada Diamantina, while in Minas Gerais, the collected records are more extensive, particularly highlighting the Serra do Espinhaço Meridional. This area is home to the 'Coletoras de sempre-vivas communities, which were awarded the first certificate for an Important System of World Agricultural Heritage in Brazil by the FAO in 2020. Additionally, records of S. nitens have been documented in mountainous regions of Venezuela, Colombia, and Bolivia.

The distribution and climatic suitability model of *S. nitens* has revealed a vast potential distribution area for the species, considering its current restriction to South America. The collected climatic data indicate its tolerance to a wide range of temperatures, potentially contributing to the high suitability observed in Brazil. This ability to endure thermal amplitude is likely associated with the species' habitat at high altitudes. The correlation between altitude and temperature holds particular significance for tropical and subtropical regions, where even a slight variation in altitude can induce substantial climate changes, affect soil composition, and consequently, impact the adaptation of plant species (FRITZSONS et al., 2015).

Based on the model and biological humidity data, it becomes apparent that the soil's water availability is a critical factor affecting the conservation of the species. While the model demonstrates considerable suitability across most of South America, it's noteworthy that the caatinga region, known as the country's most arid biome, exhibits areas with the lowest suitability. Although the species doesn't presently inhabit these areas, nearby records indicate potential vulnerabilities to climate changes in the future.

The seasonal variation results for 2017 reveal significant differences in the monthly growth index values. During spring, summer, and autumn, the model presented growth index values ranging from 0.57 to 0.84, considered ideal for the development of *S. nitens*. However, in winter, these values drop nearly to zero, causing stress for the species as the climatic conditions required for its development become unbalanced.

By comparing the number of inflorescences (Fig. 9) with the growth index (GI) (Fig. 11), it becomes apparent that *S. nitens* flowers during winter, precisely during periods of heightened climatic stress. During these times, the species utilizes physiological mechanisms to trigger flowering—a strategic adaptation to ensure the recruitment of new plants and the colonization of unexplored areas. It is worth noting *S. nitens* capacity for reproduction through vegetative propagation (SANO, 1996). In research conducted by Schmidt (2007), regrowth accounted for 61% of the total number of newly identified plants in the clean, moist fields of PEJ, playing a significantly more substantial role in recruitment than seeds, which accounted for 39%. During months with higher GI values, the species directs its resources toward vegetative growth.

Considering future climate change scenarios allows us to comprehend the direct impact on native species and their distribution. The reduction in highly suitable regions in the 2050 scenario could serve as a map to identify areas at higher risk of *S. nitens* extinction. In the 2100 projection, there is a visible

increase in unsuitable areas, indicating regions where the species, such as Venezuela, Colombia, and Bolivia, may become unsuitable for survival. In Brazil, the transition from highly suitable to suitable and eventually unsuitable areas, as projected, is expected to progress from the central regions towards the peripheries. This shift is influenced by decreased precipitation and an expanding desertification process, contributing to the expansion of unsuitable areas for *S. nitens*.

In light of this, there is growing concern about the potential risk of *S. nitens* facing extinction due to climate change in the upcoming decades. This outlook raises worries not only from a biological standpoint but also in economic terms, as forthcoming climate shifts will directly affect biodiversity levels. The gravity of this situation is further exacerbated by ongoing rates of deforestation and the fragmentation of the Cerrado, leading to an increase in extinction events and a decline in biodiversity (PACHECO et al., 2018).

There is also a possibility that in response to climate change, *S. nitens* will develop adaptation mechanisms. The Cerrado, with an initial diversification dating back approximately 10 million years and most lineages diversifying around 4 million years ago (SIMON et al., 2009), presents adaptations to fire and historical geological attributes that have enriched the region with diverse species. This favors in situ evolution processes (SIMON et al., 2009). Investigations into diversity and genetic structure are crucial in understanding the evolutionary dynamics of species within the Cerrado biome (WERNECK, 2011).

Climate change is projected to cause an increase of up to 4°C by 2100 (MOSS et al., 2010), impacting both anthropogenic influences and intrapopulation genetic diversity levels (WRÓBLEWSKA and MIRSKI, 2018). Ecological predictions derived from niche modeling, coupled with studies on genetic variation, can potentially mitigate extinction rates of local populations, aiding in the formulation of conservation strategies (LIMA et al., 2017a).

The information derived from this study significantly contributes to guiding further research, whether by conducting more comprehensive studies or informing decision-making and management strategies concerning *S. nitens*. Considering the rapid destruction of habitats in the Cerrado, urgent actions are needed to select these areas for conserving and protecting species, particularly the endemic ones.

Syngonanthus nitens holds significant importance in generating income for extractive communities located in Minas Gerais and Tocantins, playing a pivotal role in their cultural identity. Moreover, it inhabits crucial ecosystems that regulate water and sustain biodiversity, emphasizing the direct correlation between its conservation and the preservation of these vital areas. The presented results serve as valuable guidance for decision-making and implementing management measures for *S. nitens*, including monitoring and research across various locations of the species' occurrence, collaboration among stakeholders to establish effective conservation strategies, and zoning of areas for sustainable use.

5. CONCLUSION

The upper and lower temperature thresholds are set at 5°C and 40°C, respectively. The lowest ideal temperature is identified as 18°C, while the highest ideal temperature is at 24°C. The occurrence of *S. nitens* is directly associated with hydromorphic soils. The conducted collection enables the determination of the lowest and highest ideal humidity, set at 55% and 209%, respectively. *Syngonantus nitens* distribution is confined to South America, with 95% of the points recorded in Brazil and the remaining 5% distributed across Venezuela, Colombia, and Bolivia. In future scenarios for 2050 and 2100, a reduction in highly suitable areas is projected, transitioning towards suitable and unsuitable areas by the 2100 projection.

Declarations

Author Contribution

The contributions made by the authors of this work were:data collection - CDbibliographic review - RBediting and correction of the manuscript - ECMpreparation of maps - CMpreparation of figures - PFeach author helped with the following task:Débora Sampaio Mendes - CD, RB, ECM, CM and PFCláudia Eduarda Borges - CD, RB and ECMAdriene Caldeira Batista - CM and PFCrislaine Alves da Conceição - CDTayna Sousa Duque - ECM and PFFausto Henrique Vieira Araujo - ECMVinicius Henrique Moreira - PFRicardo Siqueira da Silva - CD, RB and ECMVanessa Gonçalves do Nascimento - CD Fernanda de Aguiar Coelho - CDPriscila Kelly Farnezi - PF

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Data Availability

Data are provided in the manuscript or in supplementary information files when requested from the authors.

STATEMENT SPECIFYING APPROPRIATE PERMITS AND/OR LICENSES FOR COLLECTING PLANT SPECIMENS

No plant materials were collected in this study. The assessments were carried out in the field, in private property areas and outside the Conservation Unit. The seeds used were donated by evergreen collectors living in the Raiz Community, in the municipality of Presidente Kubitschek, Brazil.

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Figures



Figure 1

Syngonanthus nitens and the confeccion of handicrafts in the Quilombola Raiz Community in the municipality of Presidente Kubistchek, Minas Gerais. Photos: Codecex.



Figure 2

Shows the data collection area situated at coordinates 18°36'47”S and 43°37’18”W, situated within the Quilombola Raiz Community in the municipality of Presidente Kubistchek, Minas Gerais.

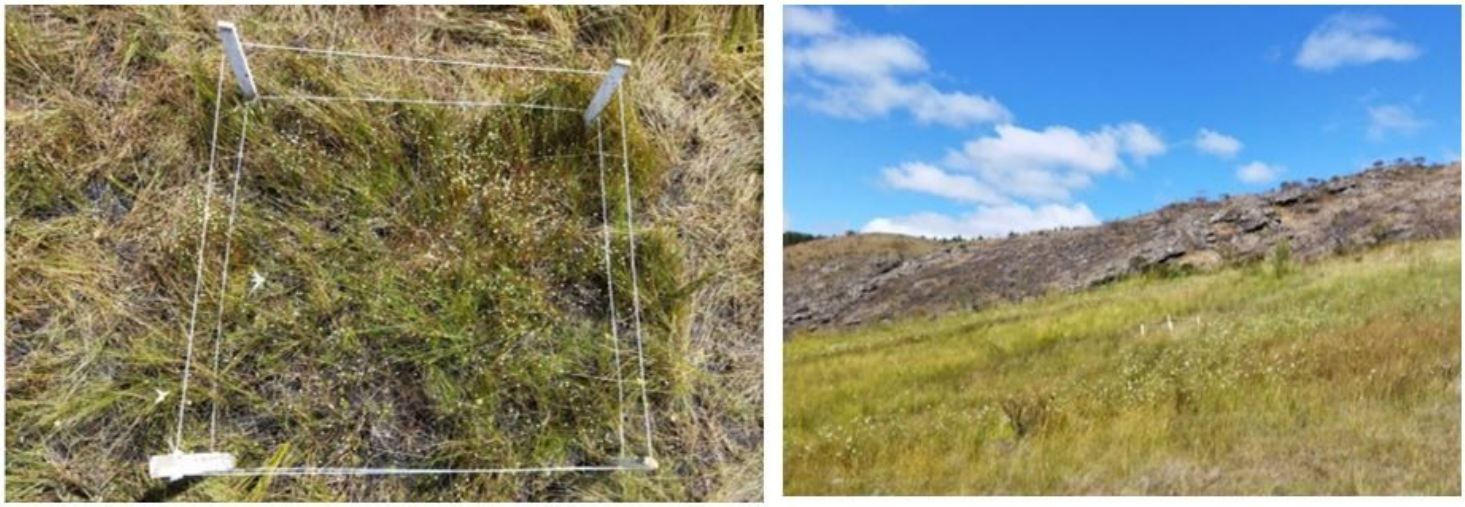


Figure 3

Delimited area to estimate the productivity of *Syngonanthus nitens* in the occurrence field (18°36’47”S and 43°37’18”W) of the Quilombola Raiz Community, Presidente Kubstichek, Minas Gerais, Brazil.

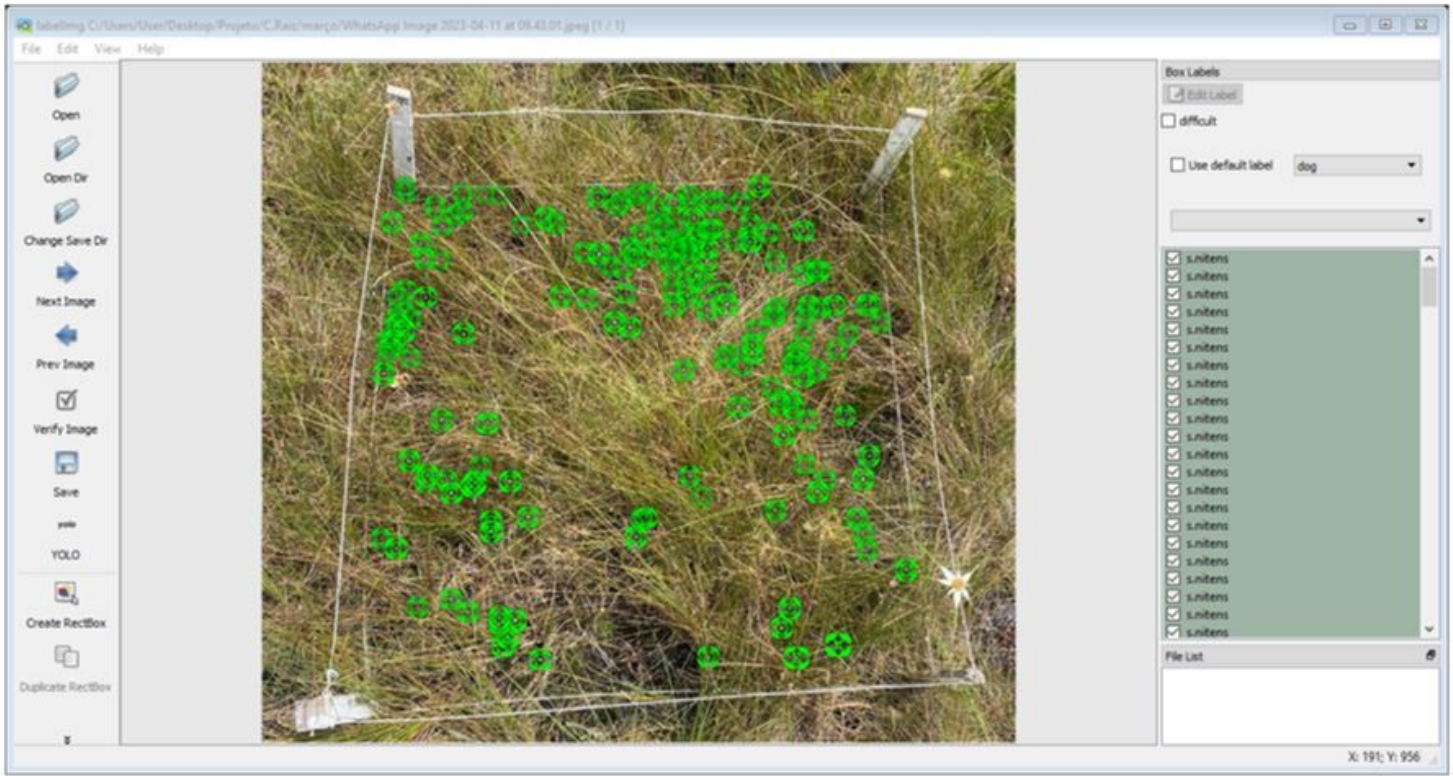


Figure 4

Graphical annotation tool, LabelImg.

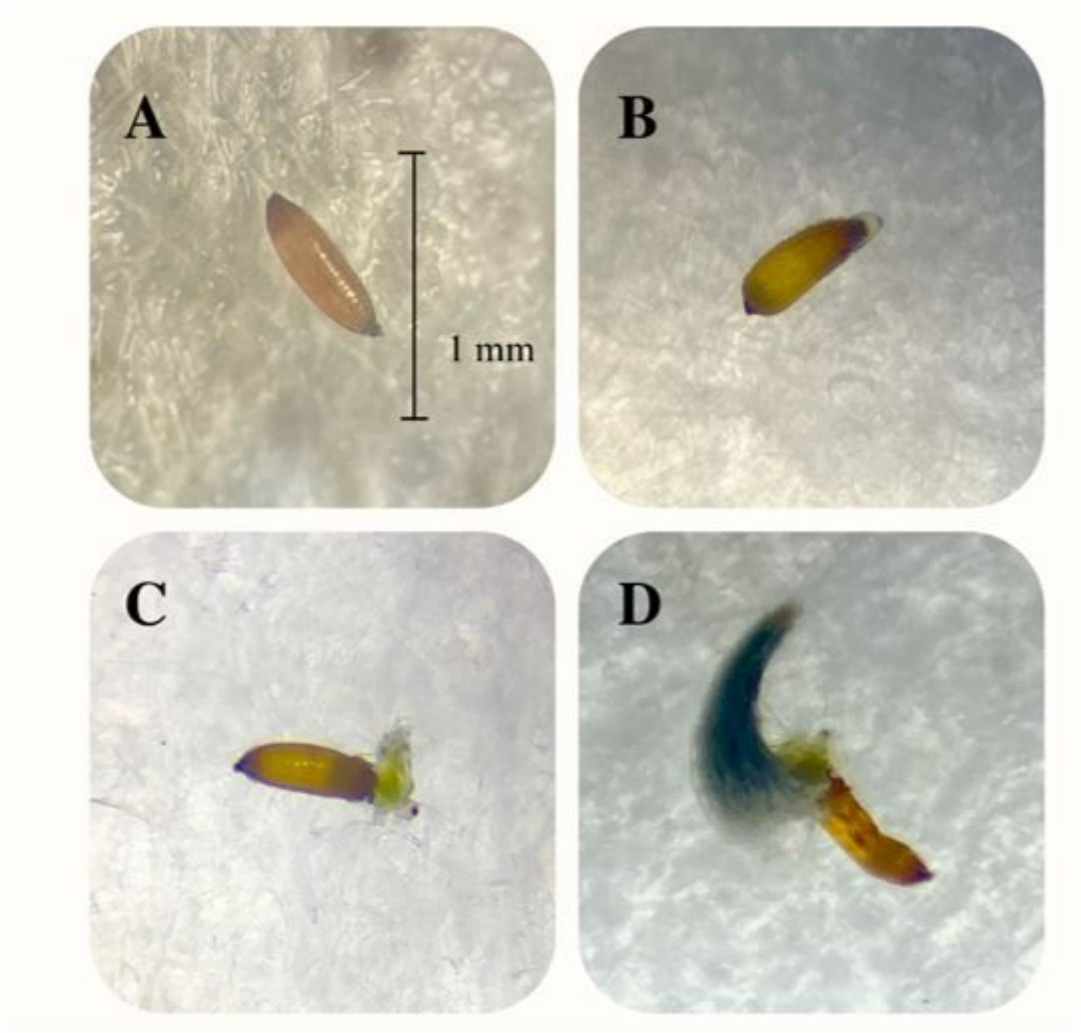


Figure 5

Seeds of the sempre-viva *Syngonanthus nitens* in the germination process: not germinated (A), protrusion of the embryonic axis (B), emergence of the first leaf (C), and first leaf (D).

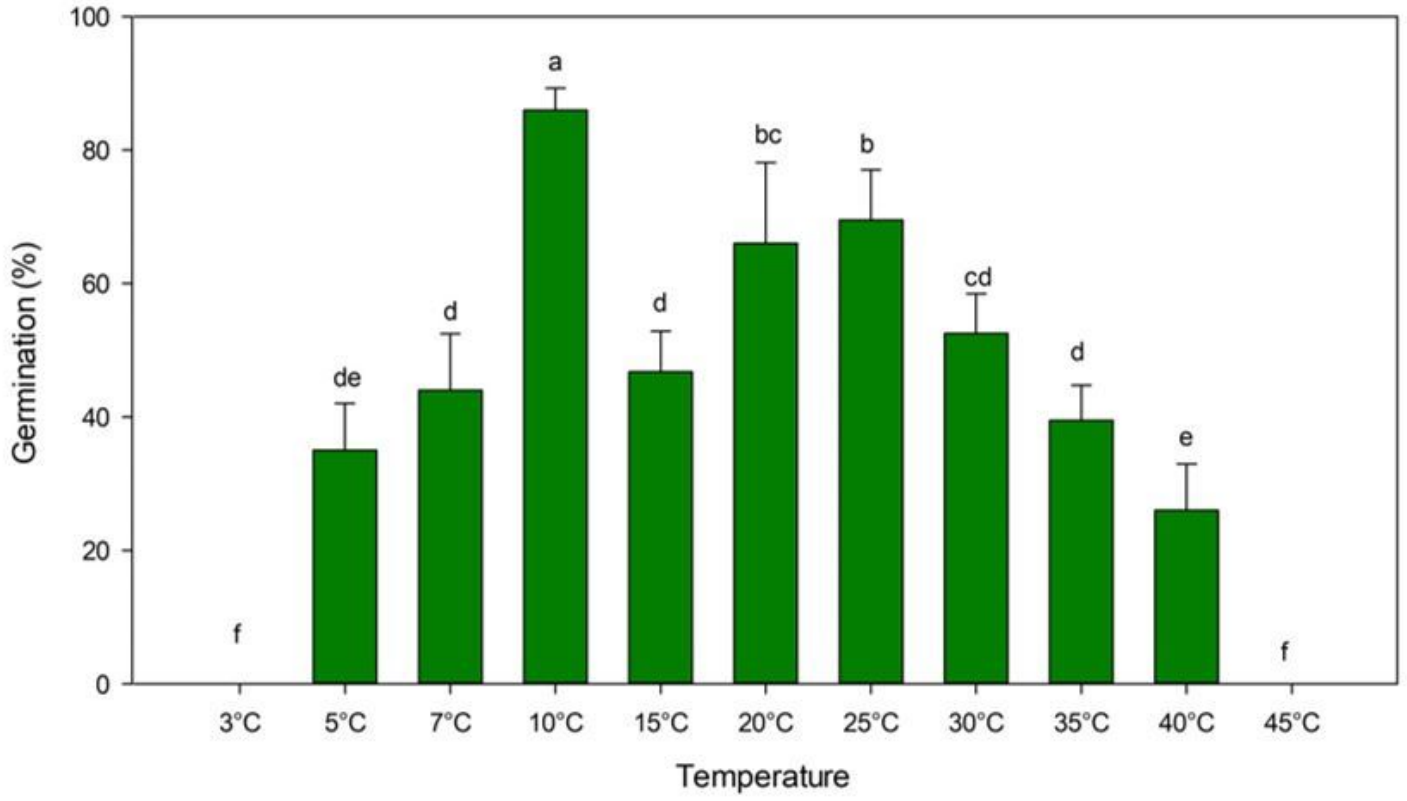


Figure 6

Germination rates (%) of the sempre-viva *Syngonanthus nitens* at different temperatures exposed to absolute light. Bars represent mean ± standard deviation. Equal letters indicate no statistical difference between treatments according to the Tukey test (P<0.05).

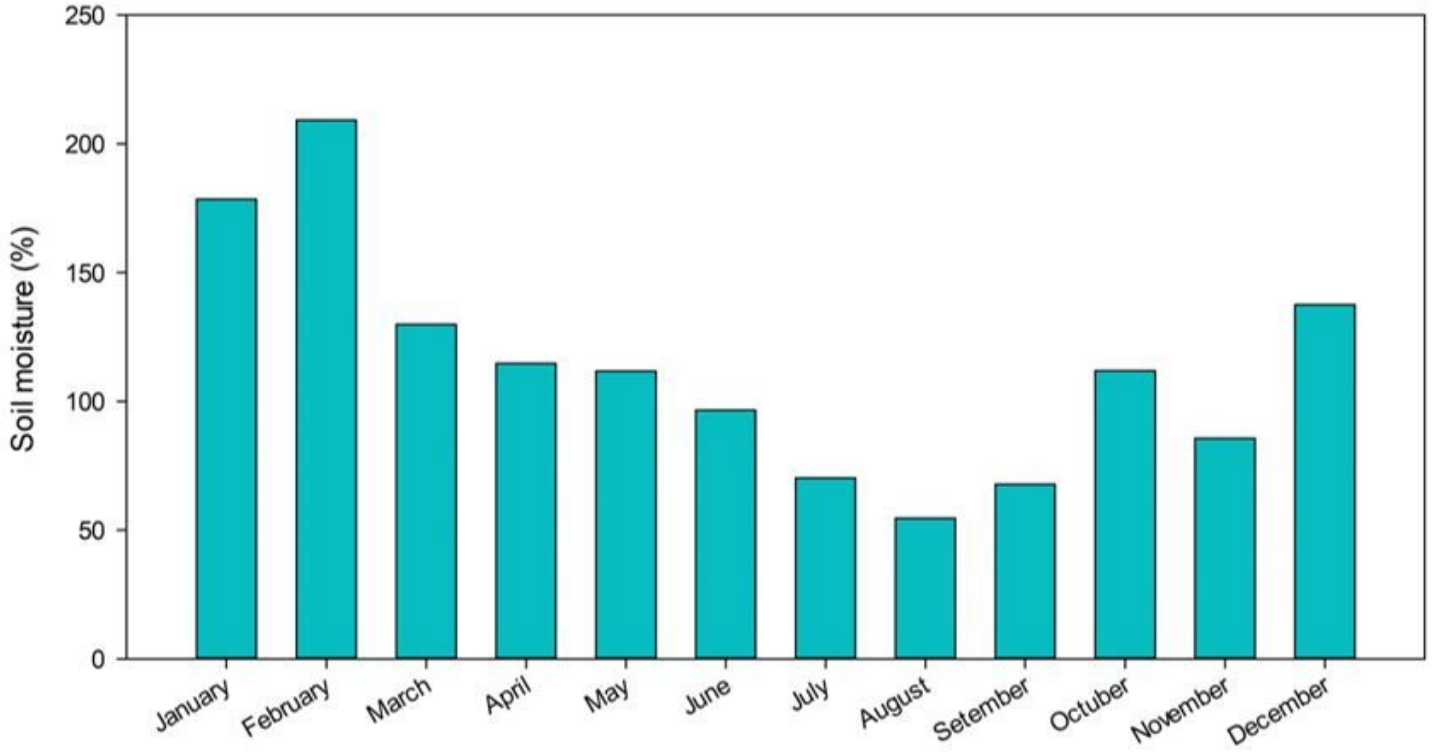


Figure 7

Soil moisture (%) of the area in Presidente Kubistchek, Minas Gerais, Brazil, with the sempre-viva *Syngonanthus nitens* occurrence in different months of the year.

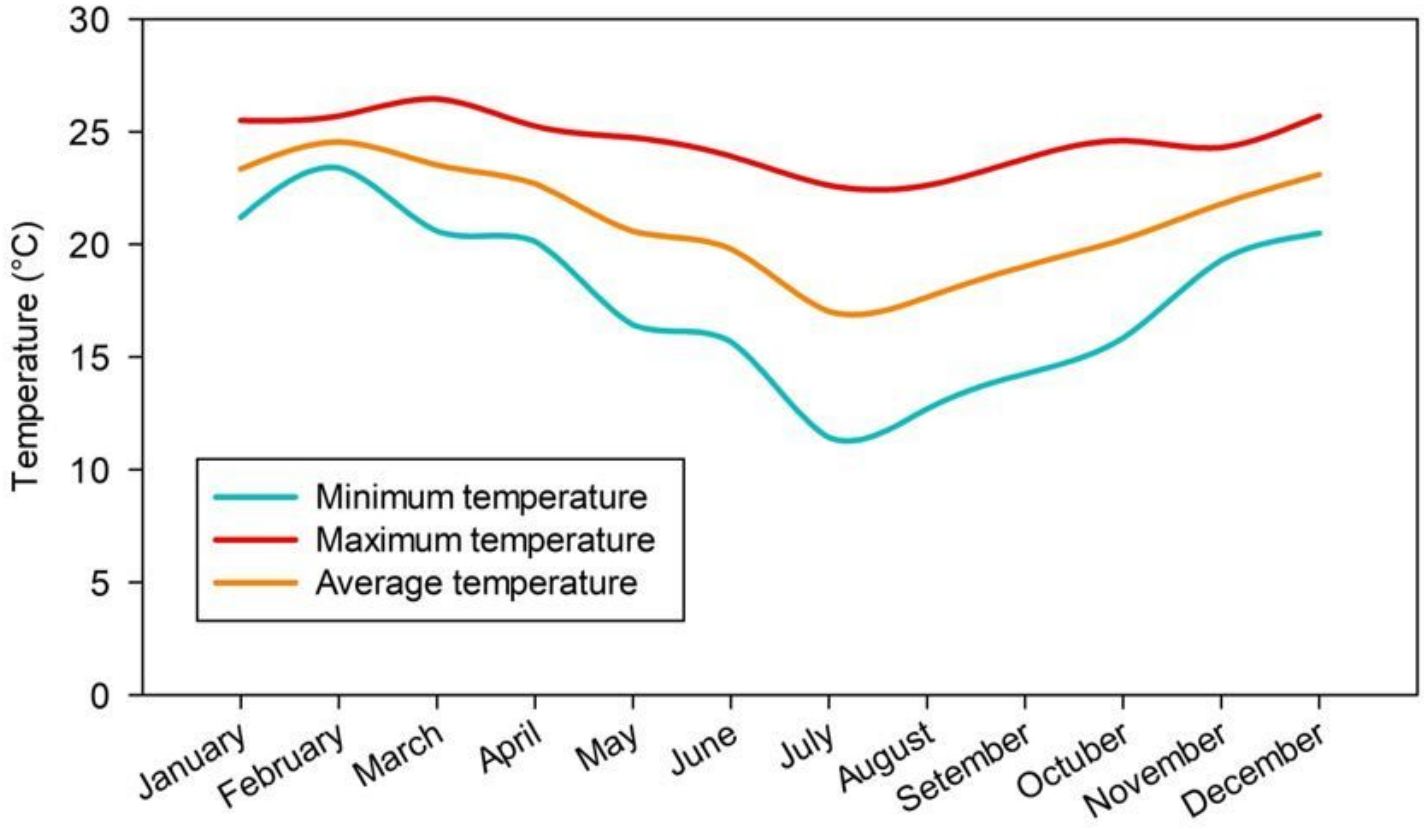


Figure 8

The monthly average of minimum and maximum temperatures was collected in the Quilombola Raiz Community in the municipality of Presidente Kubistchek, Minas Gerais, Brazil.

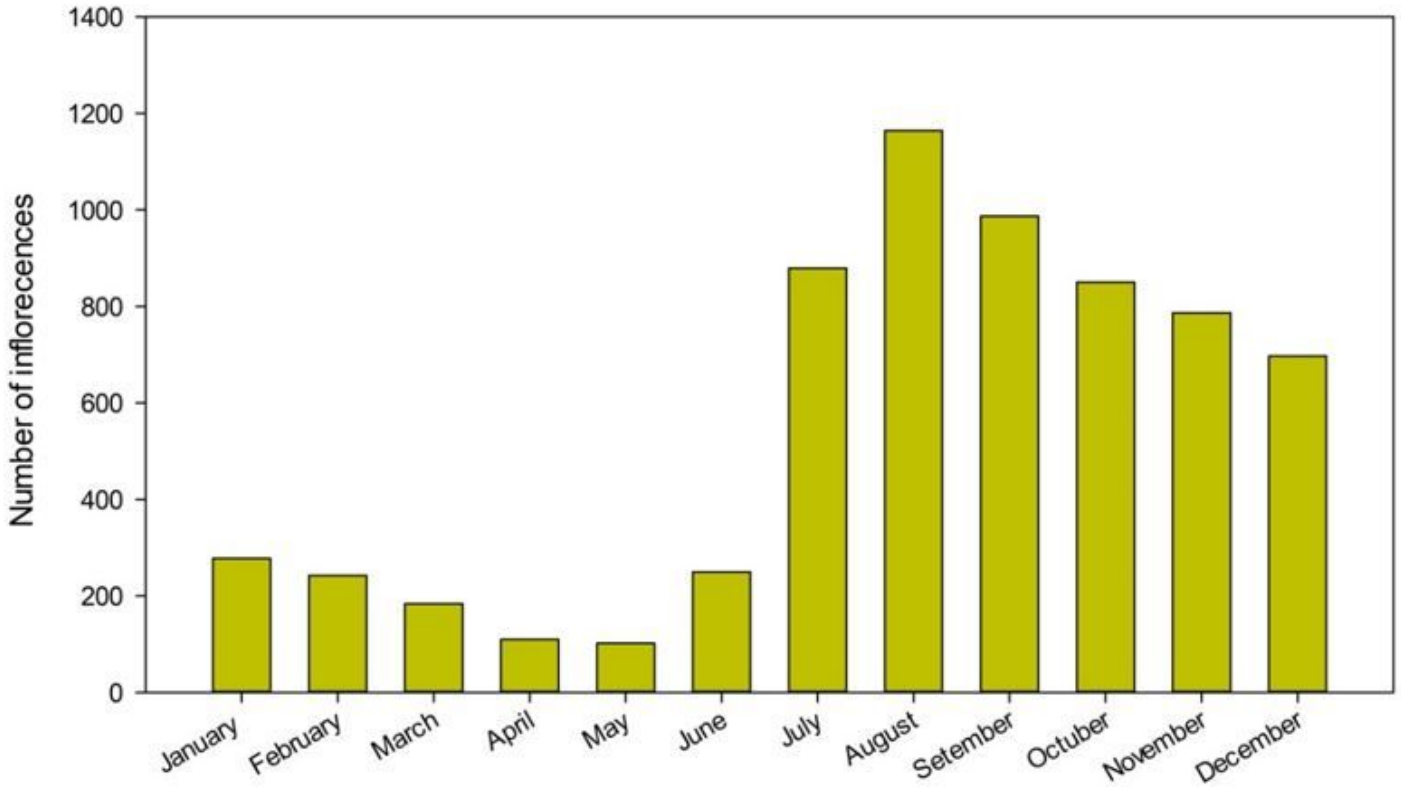


Figure 9

Number of inflorescences of the sempre-viva *Syngonanthus nitens*between July 2022 and June 2023 in the species' area of occurrence (18°36'47”S and 43°37'18”W) in the Quilombola Community of Raiz, municipality President Kubistchek in Minas Gerais, Brazil.

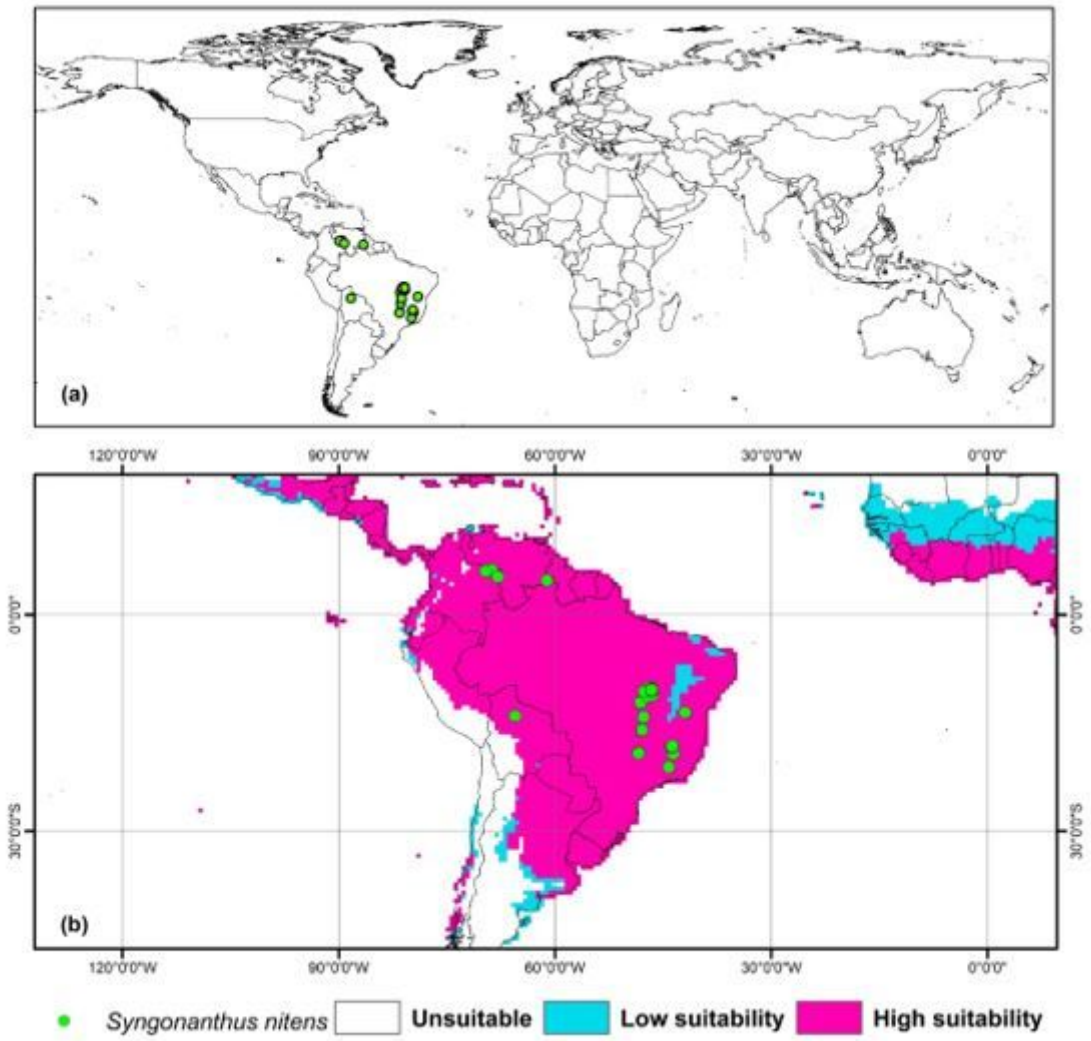


Figure 10

Occurrence records (a) and Ecoclimatic Index (b) for *Syngonanthus nitens* around the world. Model using Climex for the current climate: Unsuitable (EI = 0), Low suitable (0 < EI < 30), High suitable (30 ≤ EI ≤ 100).

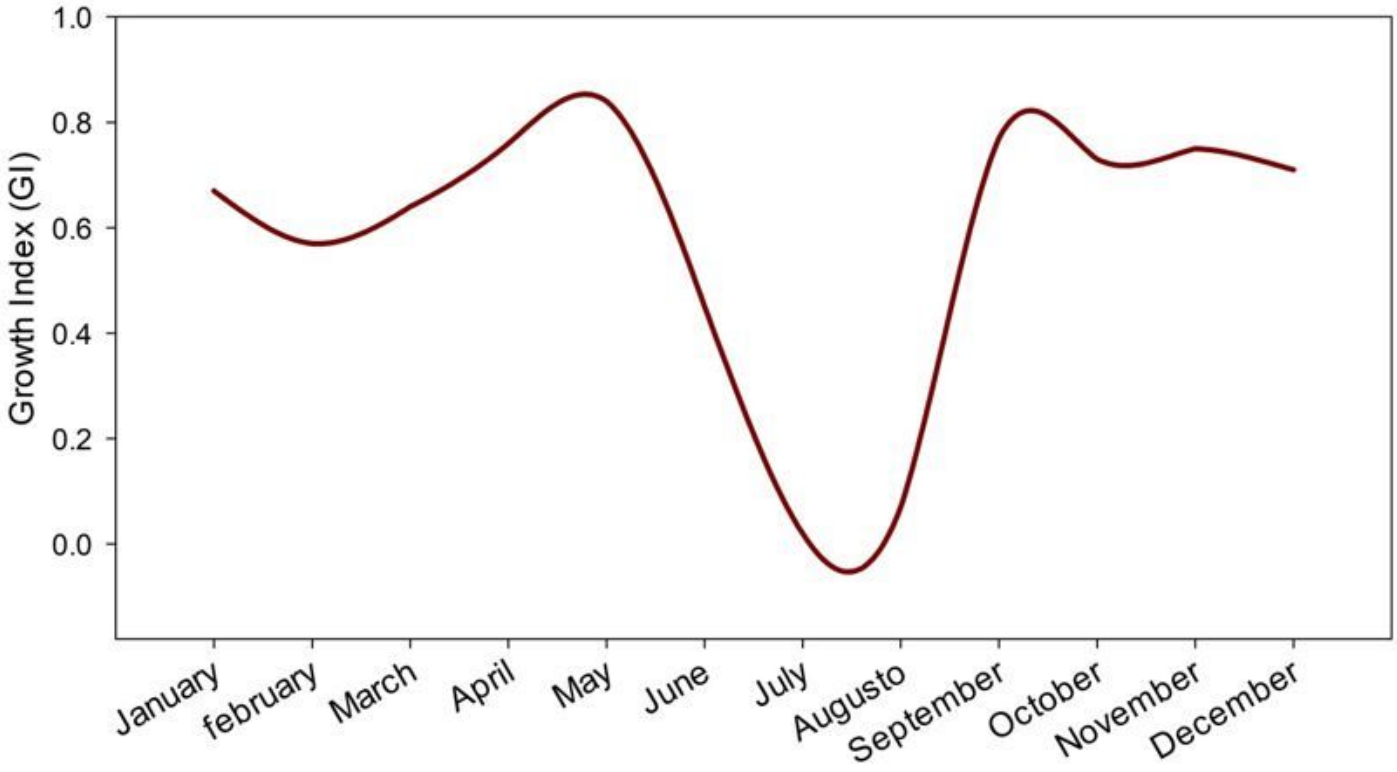


Figure 11

Monthly Growth Index (GI) of the sempre-viva *Syngonanthus nitens* in 2017.

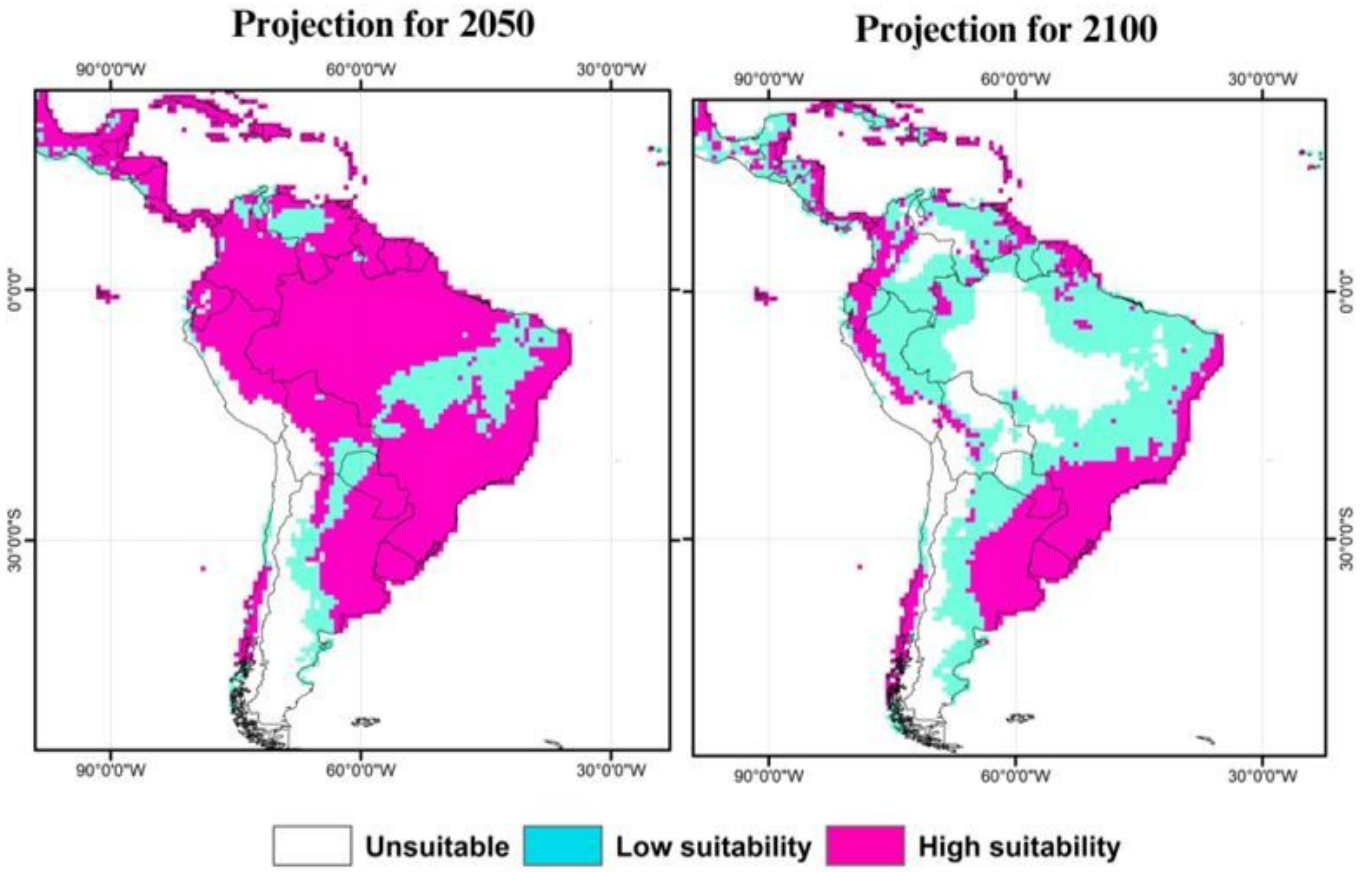


Figure 12

Ecoclimatic Index for the sempre-viva *Syngonanthus nitens* in future climate conditions (2050 and 2100) under the MIROC-H model and SRES A2 scenario.