NEW RECORDS OF *STIGONEMA PANNIFORME* BORNET & FLAHAULT 1887 FOR NORTHEASTERN BRAZIL

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ABSTRACT

The water abundance in the plateaus of the Chapada Diamantina in northern Bahia provides these areas with more favorable temperature, humidity, evapotranspiration, and precipitation conditions compared to areas below these elevations, favoring aquatic and aerophytic species. There is controversy as to whether or not these high regions with a tropical climate surrounded by a semi-arid climate are an alternative manifestation of the Caatinga. In this scenario, this work presents a new record of *Stigonema panniforme*, a true-branched cyanobacterial species of the order Nostocales, in a mountain area in Serra da Fumaça, Chapada Diamantina, Bahia, Brazil. Sampling occurred by sieving submerged roots and filtering water through a plankton net. The analysis used was based on morphology and comparison with other species of the same genus and varieties of the same species. This is the second confirmed record of *S. panniforme* for the Northeast region of Brazil. If we consider the northern areas of Chapada Diamantina as Caatinga, as some authors defend, this is also the first record of *S. panniforme* for the Caatinga. There is the possibility, albeit remote, that this is the first record of *Stigonema panniforme* var. *compactum* for the Americas.
KEYWORDS: cyanobacteria; Nostocales; phytoplankton.

RESUMO

A abundância hídrica nos planaltos da Chapada Diamantina no norte da Bahia propicia à essas áreas condições de temperatura, umidade, evapotranspiração e precipitação mais favoráveis em comparação às áreas abaixo dessas elevações, favorecendo espécies aquáticas e aerofíticas. Há controvérsias se essas regiões altas e de clima tropical circundadas por clima semiárido são ou não uma manifestação alternativa da

Caatinga. Nesse sentido, este trabalho apresenta um novo registro de *Stigonema panniforme*, uma cianobactéria com ramificações verdadeiras da ordem Nostocales, em uma área de montanha na Serra da Fumaça, Chapada Diamantina, Bahia, Brasil. A amostragem ocorreu através de peneiramento de raízes submersas e filtragem em rede de plâncton. A análise empregada foi feita com base morfológica e com comparação com outras espécies do mesmo gênero e variedades da mesma espécie. Trata-se do segundo registro confirmado de *S. panniforme* para a região Nordeste do Brasil. Se considerarmos as áreas do norte da Chapada Diamantina como Caatinga, como defendem alguns autores, este é também o primeiro registro de *S. panniforme* para a Caatinga. Há a possibilidade, embora remota, de que este seja o primeiro registro de *Stigonema panniforme* var. *compactum* para as Américas.
PALAVRAS-CHAVE: cianobactérias; fitoplâncton.; Nostocales..

INTRODUCTION

The Chapada Diamantina plateau is a highland formation in the northeastern Brazilian State of Bahia whose northernmost portion, the “Serras Jacobinas” mountains, form a stretch of about 220 km extending in a north-south direction, constituting a highland enclave within lowland surroundings marked by a predominant semi-arid climate (KAMINO *et al.,* 2008; MENDES; SILVA, 2021; NUNES *et al*., 2023).

As a result of this elevation gradient, nearby higher and lower areas contrast greatly in temperature, rainfall, air humidity, and evapotranspiration. In that regard, the high plateau areas of the Serras Jacobinas, with milder climatic conditions favored by the orographic effect, show vegetation formations that include elements of tropical rainforests, savannas, rupestrian grasslands, and seasonally dry tropical forests and woodlands (BRASIL, 2007; MORO *et al*., 2016; SANTOS NETO *et al*., 2022). On the other hand, the lowland areas at the feet of these mountains belong almost entirely to the Caatinga ecosystem, where low rainfall rates and high temperatures and evapotranspiration prevail (QUEIROZ *et al*., 2017 ; NEGREIROS, 2021).

The high water availability of these high and moist areas surrounded by semi-arid climate favors the development of aquatic and aerophytic organisms, which thrive under such conditions and can expand their distribution by taking advantage of wetter areas, as is the case with many true-branched filamentous cyanobacteria of the Order Nostocales (DVOŘÁK *et al*., 2017). Among these, the genus *Stigonema* C. Agardh ex Bornet & Flahault, 1886, is an interesting example of the aforementioned process.

Stigonema species consist of true-branched filamentous algae, usually attached to the substrate, occurring around the world in various environments, with many growing aerophytically or subaerophytically on barks or wet rocks and some species occurring in pools, swamps, and moors (BICUDO; MENEZES, 2017; GUIRY; GUIRY, 2023). There are a few dozen *Stigonema* species recorded worldwide, with only a few records occurring in Brazil, although always in moist areas with high rainfall rates. However, most studies on the taxonomy of true-branched filamentous cyanobacteria were conducted in temperate regions and are insufficient to elucidate the evolutionary history of this group (FERREIRA *et al.,* 2012).

One *Stigonema* species, *Stigonema panniforme* Bornet & Flahault 1887, was described at the end of the 19th century from samples collected in the Amazon Rainforest (BORNET; FLAHAULT, 1886’1887). However, although the REFLORA

database classifies the species as native to Brazil (REFLORA, 2023), *S. panniforme* shows a worldwide distribution that calls for more studies in order to determine whether this classification is actually valid and supported by phylogenetics and biogeography. The only previous record of *Stigonema panniforme* in the Northeast region of Brazil was made by Magalhães *et al*. (2019) in the metropolitan region of Recife, Pernambuco, in an Atlantic Forest protected remnant, thus once more placing the species in a moist area far from the inner (and drier) areas of Brazil's Northeast region.

There are already records of other *Stigonema* species in the Northeast region of Brazil, as seen in the study of Ramos *et al*. (2018), which recorded four *Stigonema* species in bromeliad phytotelmata in Atlantic Forest areas in the State of Bahia, the study of Szyja *et al.* (2019) in the Caatinga at the Catimbau National Park, in Pernambuco, and other studies conducted in the States of Piauí (POMPÊO *et al*., 1999) and Paraíba (SANTOS, 2014). However, none of these claimed another record of *S. panniforme*.

From this perspective, this study presents a new record of *Stigonema panniforme* for the Northeast region of Brazil and suggests other findings that might indicate new records for the Caatinga and the Americas, bringing insights about the distribution of this taxon and contributing to elucidating its biogeography.

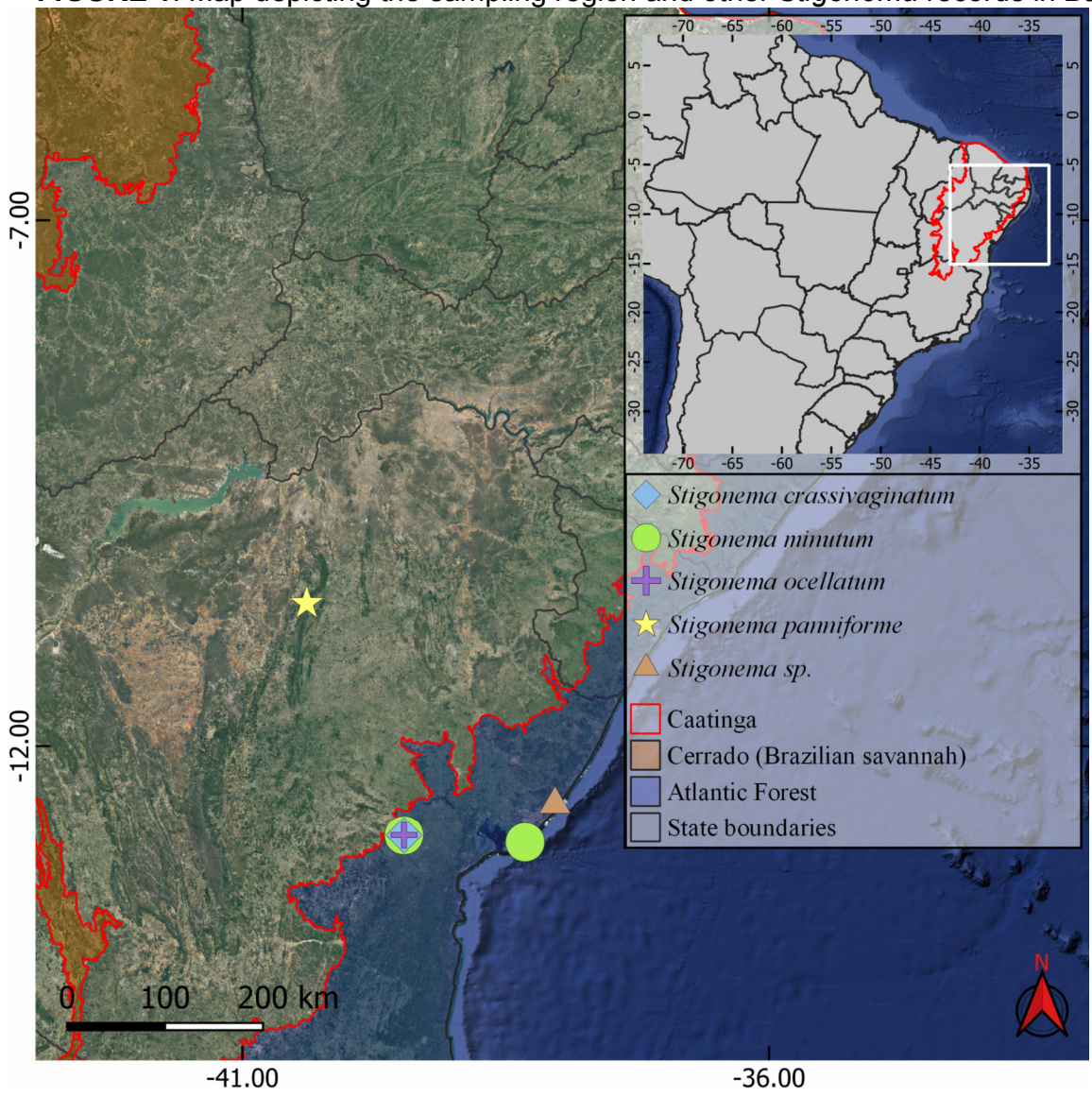
MATERIAL AND METHODS

Sampling occurred in a temporary lake on the Serra da Fumaça mountains, a stretch of the Serras Jacobinas in the Chapada Diamantina plateau, Bahia, Brazil. The area is located within the boundaries of the municipality of Pindobaçu - BA, at the geographic coordinates 10°38'42.42" S and 40°23'23.89" W and at an elevation of 893 m above the sea level.

According to data from the National Institute of Meteorology of Brazil (INMET) for the 10-year period from 2011 to 2020, the mean annual temperature in the area was 24ºC, the mean annual rainfall was 624.5 mm, and the air relative humidity was 67.6% (INMET, 2021). However, it should be noted that these data came from a weather station located in the nearby municipality of Senhor do Bonfim - BA (distant 30 km) since there is no weather station in Pindobaçu according to the INMET database. Furthermore, according to the Köppen-Geiger map, the specific sampling area of this study is classified as *Aw*, corresponding to an equatorial climate with dry winters, whereas the municipality of Senhor do Bonfim is located in a transition area from *Aw* to *BSh* climate (semi-arid with hot summers) (RUBEL *et al*., 2017).

Sampling was performed in 2019 using a 20 µm phytoplankton net. The material poured into the net cone included submerged plant roots that were sieved and washed with water from the lake. Thus, although *S. panniforme* is not a phytoplankton species, this sampling procedure allowed us to collect material attached to the substrate since no visible cyanobacterial growth was identified. The sampling location and the locations of other *Stigonema* records in the State of Bahia can be seen in Figure 1.

FIGURE 1. Map depicting the sampling region and other *Stigonema* records in Bahia.



Source: produced by the authors (2023)

The material was preserved with Lugol's solution and deposited at the herbarium of the Nucleus of Ecology and Environmental Monitoring (NEMA) of the Federal University of Vale do São Francisco (UNIVASF), Petrolina, Pernambuco, Brazil. The samples were analyzed by light microscopy and identification was performed based on morphological features and consulting the specific literature on cyanobacteria (BORNET; FLAHAULT, 1886'1887; HANSGIRG, 1893; BICUDO; MENEZES, 2017; FERREIRA *et al.,* 2012; SANT'ANNA *et al.,* 2013; RAMOS *et al*., 2018). The collected material was compared with other *Stigonema* taxa to confirm the species.

RESULTS AND DISCUSSION

The results of the analyses are presented below and indicate that the material analyzed consists of *Stigonema panniforme* Bornet & Flahault 1887**.**

Material examined: BRASIL. BAHIA: Pindobaçu, Lago da Onça (10°38'42.20" S, 40°23' 23.51" W), 19.VI. 2019, water sample, V.S. Nunes (NEMA/ALG 001).

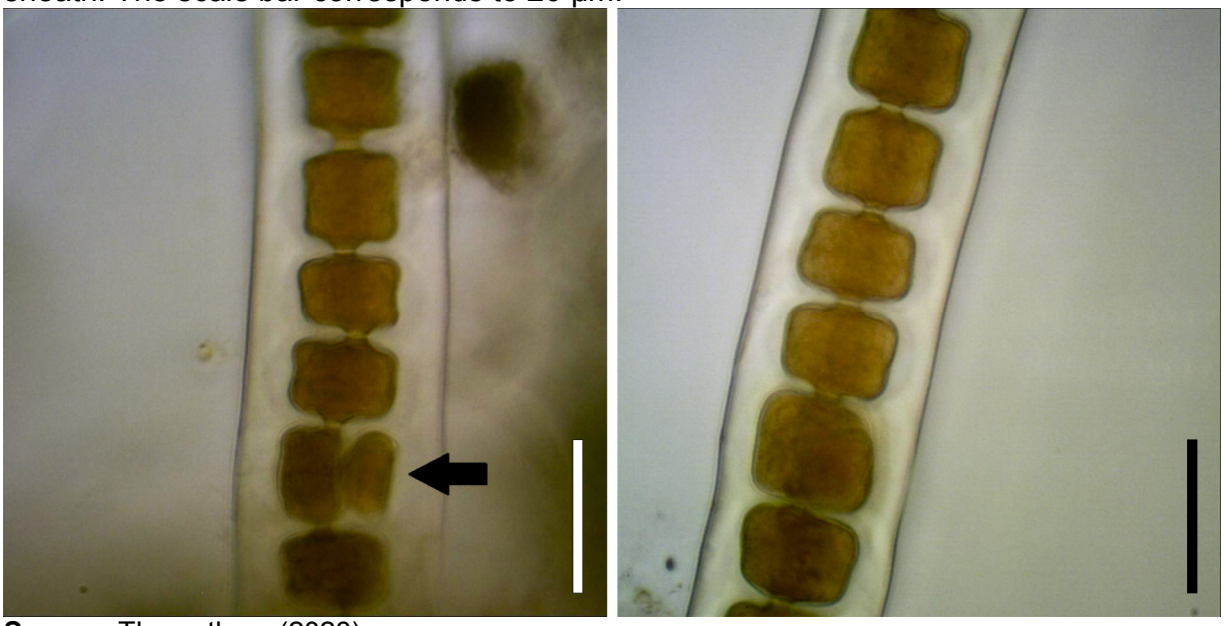
Stigonema panniforme Bornet & Flahault 1887**.** Fig 2.
Filaments forming entangled masses, usually uniseriate, occasionally biseriate or rarely multiseriate, with widths ranging from 22 to 27 µm. Mucilage sheath dense, hyalin, or with colors ranging from brown to greenish. Secondary filaments smaller than the main ones, round at the apex, with smaller and compressed cells in those regions, often perpendicular to the main filaments. Trichomes moniliform in the main filament, with clear intercellular (pit) connections. Cells with shapes ranging from cylindrical to pyramidal, quadratic or compressed, usually wider than longer, with widths ranging from 9 to 16 µm and length ranging from 4 to 15 µm, Heterocysts rare, usually lateral, sometimes intercalated, sometimes similar to the vegetative cells, measuring 8 to 12 µm in length and 6.2 to 6.4 µm in width. No visible hormogonia.

FIGURE 2. Specimens of *S. panniforme* collected and analyzed in the present study. The scale bar corresponds to 20 µm in figures 2A to 2C and to 100 µm in figure 2D.

Source: The authors (2023)

Several important features highlighted in the description can be seen with more detail in Figure 3, which shows a main filament of *S. panniforme* featuring the brown-greenish sheath, the quadratic or cylindrical shape of the cells, the pit connections, and a heterocyst.

FIGURE 3. Magnified visualization (100x) of a main filament of *S. panniforme* highlighting the pit connections, heterocyst (black arrow), cell shape, and mucilage sheath. The scale bar corresponds to 20 µm.



Source: The authors (2023)

In the identification procedure, the specimens were also compared with other *Stigonema* species to rule out taxa with similar morphological features. Table 1 presents this comparison with the holotype of *S. panniforme*, with other *Stigonema* species recorded in northeastern Brazil, and with the two varieties described for the species to assist in the confirmation of the taxonomic conclusions proposed.

BOARD 1. Morphometric comparison between *Stigonema panniforme* (data from the holotype and from the specimens of the present study), *S. panniforme* var. *compactum, S. panniforme* var. *alpinum, S. minutum*, *S. crassivaginatum*, and *S. ocellatum*.

	TW	**CWMF**	**CLMF**
***S. panniforme* (holotype)**[1]	24-26 µm	NI	NI
***S. panniforme* (present study)**	22-27 µm	9-16 µm	4-15 µm
S. panniforme* var. *compactum[2]	14-30 µm	9-15 µm	NI
S. panniforme* var. *alpinum[2]	<18 µm	NI	NI
S. minutum[3]	18-35 µm	NI	6.5 µm
S. crassivaginatum[3]	20-40 µm	12-14 µm	NI
S. ocellatum[1]	35-45 µm	NI	NI

Note: TW: trichome width; CWMF: cell width in the main filament; CLMF: cell length in the main filament. 1: Bornet & Flahault (1886'1887); 2: Hansgirg (1893); 3: Sant'Anna *et al.* (2013).

To the best of our knowledge, this is the second record of *Stigonema panniforme* for the Northeast region of Brazil, and the closest yet to areas of Caatinga *stricto sensu*. This is especially important given the short distance from the sampling area to dry Caatinga areas only 30 km away and considering that this species had only been recorded far from such areas. Also, the specific sampling location was signaled before by Nunes *et al.* (2022) and Nunes (2023) as the diffuse spring of a river that drains down the mountain to lowland Caatinga areas, suggesting that the species may be found downstream as well.

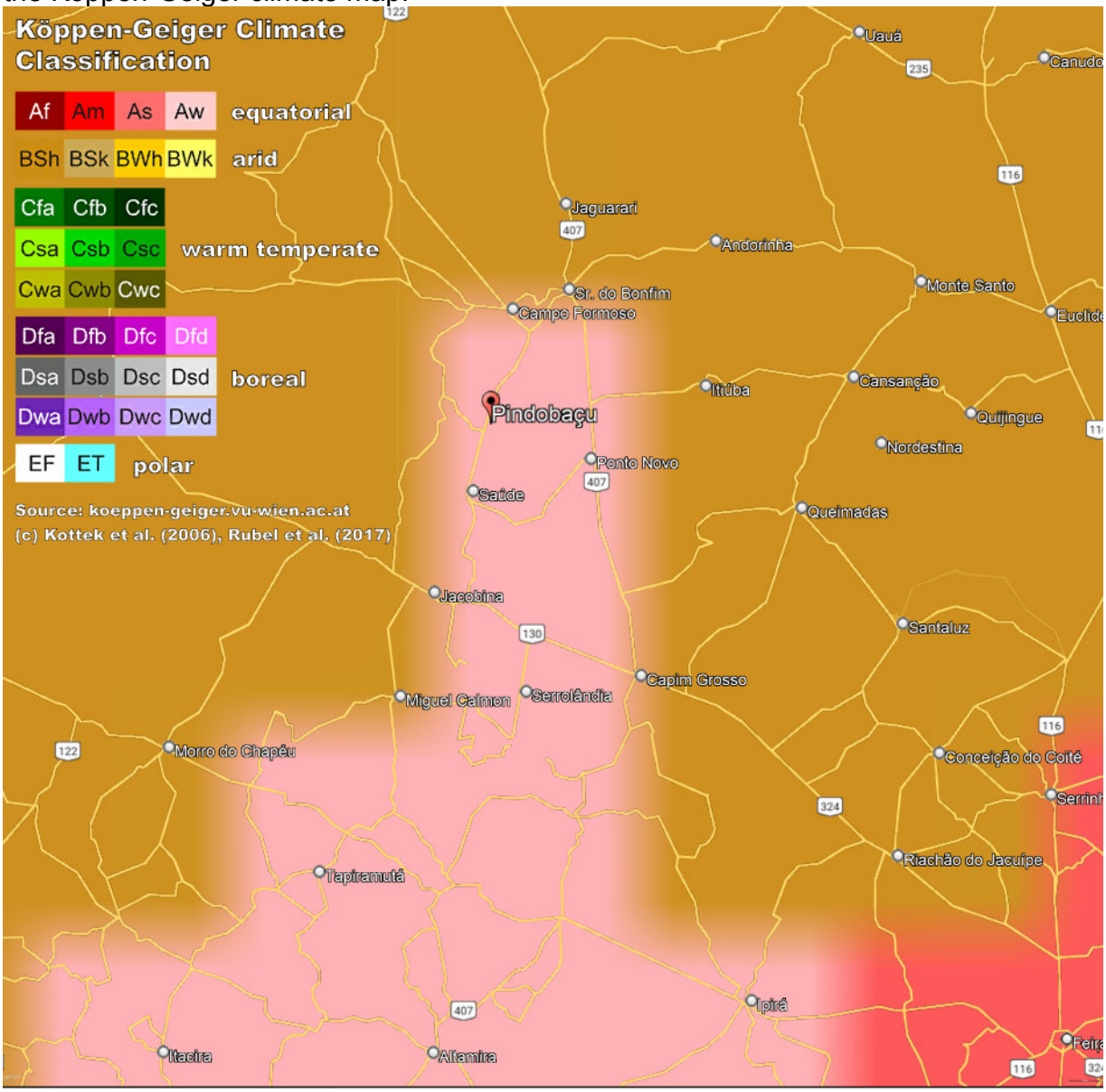
There is some debate as to whether the high areas with evergreen and semi-deciduous tropical rainforests within the Caatinga should be considered part of it. Lima *et al*. (2023) strongly oppose that idea by arguing that a broader classification that includes patches of other biomes enclaved in the Caatinga as such could not be valid since these biomes are nor part of the same evolutionary community and to do so would be to de-characterize the Caatinga as part of the largest continuous expanse of the worldwide Seasonally Dry Tropical Forest and Woodland (SDTFW) biome in the Neotropics (LIMA *et al*., 2023).

On the other hand, Araujo *et al*. (2022) claim that the Caatinga region works as a system instead of an aggregate, and that this region is formed by several landscapes and four primary vegetation types: tropical rainforests, savannas, rupestrian grasslands, and seasonally dry tropical forests and woodlands (SDTFWs) (ARAUJO *et al*., 2022). The authors also argue that the many vegetation types and subtypes are likely due to the large biophysical variation within the Caatinga region.

From this perspective, if the definition of Araujo *et al*. (2022) is considered, this new record of *Stigonema panniforme* is also the first record of this species for the Caatinga, showing that the distribution of this species is even more widespread than thought before and highlighting the ability of this taxon in expanding and occupying new areas.

Another aspect to be considered is that the small lake from where these samples came is temporary, drying up completely during drier months. In that regard, it should also be highlighted that, even though the specific sampling location of the present study is classified as of an equatorial climate with dry winters, the fact that this area is surrounded by the Caatinga *stricto sensu* probably influences its climate and water availability. The climate classification map for the sampling location of the present study and its surroundings can be seen below in Figure 4.

FIGURE 4. Classification of the sampling area and its surrounding region according to the Köppen-Geiger climate map.



Source: Rubel *et al*. (2017).

According to Steli *et al.* (2016), the equatorial climate is characterized by very small annual temperature fluctuations (24°-28°C at sea level) and abundant rainfall rates (1500–5000 mm a year), occurring more or less evenly throughout the year. However, what is seen in the sampling location of the present study (or close to it since the station was 30 km distant) is a much lower annual precipitation (624.5 mm), even though the temperatures agree with the definition of Steli *et al*. (2016). However, due to the orographic effect, which is the cooling of air masses caused by a higher elevation, producing rain, it is very likely that the rainfall rates on the top of the Serra da Fumaça and Serras Jacobinas as a whole are somewhat higher (QUEIROZ *et al*., 2017;

SANTOS NETO *et al*., 2022). On the other hand, the influence of the surrounding Caatinga, or maybe the fact that the area of this study itself might be a form of the Caatinga, probably influences the climate variables observed.

The other possible finding, although less likely, refers to the possibility of the specimens collected to belong to a variety of *S. panniforme* (*Stigonema panniforme* var. *compactum* Hansgirg 1893) since the morphometric measures obtained would allow that classification. However, the solidity of this infraspecific category has been challenged and it may not be sustained. Furthermore, morphometric variations exceeding the minimum and maximum values recorded in the holotype might occur due to phenotypic plasticity. On the other hand, should this category be confirmed and established in the future, this new record would also be the first record of *Stigonema panniforme* var. *compactum* Hansgirg 1893 for the Americas since the only other record was made in the 19th century in what today is the Czech Republic (HANSGIRG, 1893).

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