

A new bluish-leaved *Syagrus* (Arecaceae) from an overlooked OCBIL in the Espinhaço Range (Brazil)

Bruno Francisco Sant'Anna-Santos, Rafael Micheli, Luiz Fernando Lima Carvalho, Patrícia Soffiatti

Departamento de Botânica, Universidade Federal do Paraná, Curitiba, Paraná, Brazil

Corresponding author: Bruno Francisco Sant'Anna-Santos (brunofrancisco@ufpr.br)

Academic editor: Brecht Verstraete ♦ Received 25 January 2023 ♦ Accepted 10 March 2023 ♦ Published 12 April 2023

Abstract

Background and aims – This study is part of ongoing research on the Arecaceae Flora of the Serra do Cabral, an isolated massif in the southwest of the Espinhaço Range in Minas Gerais State. Because of the isolation of the massif, the area has a rich biodiversity and a high level of endemism. While searching for populations of the rare and critically endangered *Syagrus cabraliensis*, a new bluish-leaved palm species was discovered and it is described here.

Material and methods – The new species' morphology is described based on field collections. The pinnae were analysed using SEM and LM cross- and longitudinal sections following default methodology. In addition, we compared the species to *S. cabraliensis* and provided ecological notes and a conservation status assessment.

Key results – *Syagrus carvalhoi* resembles *S. cabraliensis* but they can easily be distinguished by morphoanatomical characters. Both species occur non-sympatrically in the Serra do Cabral, in contrasting microhabitats: *S. carvalhoi* in the southern quartzitic campos rupestres and *S. cabraliensis* in the northern ferruginous campos rupestres. A key to the known grass-like *Syagrus* species from the massif is provided. Based on the restricted area of occurrence and the anthropogenic threats, *Syagrus carvalhoi* is assessed as critically endangered.

Conclusion – *Syagrus carvalhoi* is the second grass-like endemic *Syagrus* species from the Serra do Cabral and presents rare characters within the genus (grass-like aspect, colonial habit, flowers in tetrads, and the stem forking at or below the ground). This discovery corroborates that this isolated OCBIL is a home for endemic and rare palm species. The Serra do Cabral massif has proved a source of morphological and anatomical novelties in Arecaceae, affecting the taxonomy and understanding of the evolution and ecology of palms. Our results reinforce the notion that it is important to conserve this area with rich and rare biodiversity but under alarming and unprecedented threats.

Keywords

campos rupestres, grass-like leaf, Minas Gerais State, new species, Palmae, plant anatomy, Serra do Cabral, taxonomy

INTRODUCTION

Campos rupestres are considered an OCBIL (old, climatically-buffered, infertile landscape), ancient montane habitats with remarkable biodiversity, high degrees of endemism characterised by stable geology and relative modulated climate fluctuation existing across a timespan of millions of years (Hopper 2009; Silveira et al. 2016; Zappi et al. 2017; Morellato and Silveira 2018). These environments are composed of quartzite or ironstone highlands, characterised by shallow and nutrient-poor and toxic soils (Giulietti et al. 1997; Alves et al. 2014; Conceição et al. 2016; Silveira et al. 2016; Zappi

et al. 2017; Neves et al. 2018). Studies demonstrate that especially the attenuated climate and infertile soils are the main drivers of the high biodiversity found in these areas (Silveira et al. 2016).

Most of the campos rupestres occupy the highlands of the Espinhaço Range, forming rocky mountaintop archipelagos holding ca 15% of the Brazilian vascular flora in less than 1% of the territory (Prance 1994; Rapini et al. 2008; Alves et al. 2014; Silveira et al. 2016). The Espinhaço Range, which originated from volcanic events in the Precambrian ca 1750 mya in eastern and central Brazil, extends over a length of 1100 km spanning the states of Bahia and Minas Gerais (Silveira et al. 2016: fig. 3), with

altitudes greater than 800 m (Harley 1995; Giulietti et al. 1997). These ecosystems are composed of a mosaic of vegetation types associated with the Cerrado, Atlantic Forest, and Caatinga (Harley 1995). They are intrinsically delimited by altitude, with depressions in the relief representing potential barriers to gene flow (Lousada et al. 2011), promoting local speciation due to the inherent insular condition (Silveira et al. 2016). Therefore, besides the high number of species, the great concentration of narrow endemics and rare species is remarkable (Rapini et al. 2002, 2008; Costa et al. 2018).

In general, plant communities in campos rupestres possess very restricted distributions, being sometimes known from just a single population (Noblick et al. 2014; Silveira et al. 2016; Noblick 2017a; Sant'Anna-Santos et al. 2023). For example, narrow endemics have recently been found in the Serra do Cabral (hereafter, SC), an isolated massif in the western part of the Espinhaço range in Minas Gerais State (Firmo et al. 2021: fig. 1). The pronounced insular condition of the SC, caused by a 40-km wide depression between it and the main Espinhaço mountain range (Hatschbach et al. 2006), helps to explain the high concentration of endemics, some of them under alarming and unprecedented threats (Hatschbach et al. 2006; Noblick et al. 2014; Noblick 2017a; Costa et al. 2018; Sant'Anna-Santos 2021; Sant'Anna-Santos et al. 2023). The Serra do Cabral State Park is the only conservation unit in the SC and it was established in 2005 due to its diverse biota and archaeological sites with cave paintings (Fidanza et al. 2013). Therefore, any botanical novelty found in the SC contributes to supporting the conservation efforts of these overlooked highlands.

Several endemics and rare species were recently discovered in the SC (Echternacht et al. 2011; Trovó et al. 2012; Noblick et al. 2014; Costa et al. 2018; Guarçoni and Sartori 2020; Firmo et al. 2021; Sant'Anna-Santos 2021). In the last decade, two new endemic species of Arecaceae (*Butia buenopolensis* B.F.Sant'Anna-Santos and *Syagrus cabraliensis* (Noblick & Lorenzi) B.F.Sant'Anna-Santos) were described in this area, both known from a single population severely impacted by anthropogenic threats (Noblick et al. 2014; Sant'Anna-Santos 2021). Narrow endemics represent extremes in evolution, and their uniqueness should be preserved and studied, especially considering the imminent risks of extinction (Sant'Anna-Santos et al. 2023). Furthermore, these new endemic palms notably displayed morphoanatomical novelties with implications for the ecology and systematics of these groups (Firmo et al. 2021; Sant'Anna-Santos 2021; Sant'Anna-Santos et al. 2023).

Syagrus has a high concentration of endemics in the campos rupestres, being commonly occurring dwarf species in these mountainous habitats (Martel et al. 2013; Noblick 2017a; Soares 2022; SpeciesLink Network 2022). In recent years, species numbers have significantly increased due to collection efforts in overlooked campo rupestres, mainly for the genus *Syagrus* (see Noblick 2009, 2010; Noblick and Lorenzi 2010; Noblick et al. 2014).

Syagrus is a Neotropical genus that occurs mostly in South America, largely concentrated in eastern and central Brazil (Glassman 1987; Henderson et al. 1995; Dransfield et al. 2008; Noblick 2017a). As a monophyletic lineage (Meerow et al. 2009), the genus can be recognised by a set of morphological characters such as the pinnate leaves; peduncular bracts longitudinally grooved; inflorescences solitary and interfoliar, protandrous; pistillate flowers slightly smaller to very much larger than the staminate flowers; absence of raphides in the corolla; endocarp with 3 (rarely 4–6) basal or subbasal pores (Henderson et al. 1995; Dransfield et al. 2008; Noblick 2017a; Sant'Anna-Santos et al. 2023). Anatomical characters have proved very useful in confirming the current circumscription of the genus, as well as avoiding misidentification, especially regarding the puzzling dwarf species (Glassman 1987; Tomlinson et al. 2011; Martel et al. 2013; Noblick 2013b, 2017b; Firmo et al. 2021; Sant'Anna-Santos et al. 2023). In the literature, the most relevant information for *Syagrus* can be found in Glassman (1987), Henderson et al. (1995), Dransfield et al. (2008), and Noblick (2010). Noblick (2017a) made the most complete and in-depth morphological revision of the genus, with detailed taxa descriptions, comments about the distribution and ecology, taxonomy, phylogeny, and a key for identification. Since the publication of Noblick (2017a), two new species have been added to the genus (Noblick 2018; Soares and Guimarães 2019), and one dwarf subspecies had its status changed to species level (Sant'Anna-Santos et al. 2023). So, currently, the genus comprises 68 species and one subspecies (Noblick 2017a, 2018; Soares and Guimarães 2019; Sant'Anna-Santos et al. 2023).

One of the rarest and endangered species of the *Syagrus* – the grass-like *Syagrus cabraliensis* (Noblick & Lorenzi) B.F.Sant'Anna-Santos – is only known from a small ferruginous campo rupestre, occurring near the boundaries of the SC State Park, the only conservation unit located in the SC (Noblick et al. 2014; Noblick 2017a; Sant'Anna-Santos et al. 2023). When discovered, the species had already about 60% of its small population buried by a gravel mine and crossed by a large road (Noblick et al. 2014; Sant'Anna-Santos et al. 2023). Therefore, the looming threat of extinction motivated our search for other populations within the protected area's limits.

During the last eight years of unsuccessfully searching for *S. cabraliensis* within the borders of the SC State Park, a hitherto unknown species was discovered. Here, we describe and illustrate this new grass-like palm species and compare it with *S. cabraliensis* as an additional effort to quickly improve measures towards conserving the campos rupestres from the overlooked SC massif. The area under protection by the park is small, and the endemics and rare species are threatened by the proximity of exotic species cultivation, fires, and mining, among other threats (Costa et al. 2018). Therefore, we strongly believe that the discovery of each new taxon and its associated peculiarities has great potential to stimulate

conservation actions (such as the expansion of the park area or fire management for conservation proposes) in protected areas.

MATERIAL AND METHODS

This study is based on field observations across the Serra do Cabral State Park, Minas Gerais, Brazil. The literature review considered all publications on the taxonomy or anatomy of the genus (Glassman 1972, 1987; Henderson et al. 1995; Marcato and Pirani 2001, 2006; Noblick 2004a, 2004b, 2004c, 2009, 2010, 2012, 2013a, 2013b, 2014, 2017a, 2017b, 2018, 2019; Dransfield et al. 2008; Meerow et al. 2009; Noblick and Lorenzi 2010; Genovese-Marcomini et al. 2013; Martel et al. 2013; Soares et al. 2013; Noblick et al. 2014; Silva-Cardoso et al. 2017; Soares and Guimarães 2019; Firmo et al. 2021; Soares 2022; Sant'Anna-Santos et al. 2023). The circumscription adopted here for *Syagrus* is based on Noblick (2017a), Soares (2022), and Sant'Anna-Santos et al. (2023) and the terminology adopted for the morphological and anatomical descriptions followed Dransfield et al. (2008), Noblick (2017a, 2017b), and Sant'Anna-Santos et al. (2023). The term “colonial habit” refers to the occurrence of many clustered individuals in a dense and large arrangement, as shown by Noblick (2017a).

Vegetative and reproductive parts were taken from 30 randomly chosen individuals of the new species. For *S. cabraliensis*, we retrieved information about vegetative and reproductive parts from the literature (Noblick et al. 2014; Noblick 2017a; Sant'Anna-Santos et al. 2023). Specimens of the new species and *S. cabraliensis* were georeferenced and photographed in the field using a digital camera. Flowers of the new species were stored in ethyl alcohol for further stereomicroscope analysis, and the data of *S. cabraliensis* for comparison were retrieved from Sant'Anna-Santos et al. (2023). Flowers were photographed with a stereomicroscope (Bioptika L60T) coupled with a CMOS 12mp PLUS camera.

Distribution data were plotted on a map using QGIS v.3.16.2 (QGIS Development Team 2022) and assembled from the following data sources: states and cities (IBGE 2020); Serra do Cabral State Park (Ministério do Meio Ambiente Brasil 2020); elevation (Miranda 2005); species and sites (data from the current study). The 3D maps were made using QGIS v.3.16.2 (QGIS Development Team 2022); vector data was provided by IBGE (2020); the digital elevation models were sourced from the SRTM (Farr et al. 2007). The models were visualised in 3D, with a vertical exaggeration of 20× using QGIS native plugins and additional add-ins. The conservation status of the new species was evaluated according to the IUCN guidelines and criteria (IUCN 2022) using the GeoCAT tool (Bachman et al. 2011). The localities where *S. carvalhoi* occurs are considered as a single location because they are close together and can be destroyed by one threatening event, following IUCN (2022).

For the anatomical study of the pinnae of the new species, 15 samples were analysed. The samples were collected from the middle of the central pinnae from herbarium specimens of our collections and specimens in the field, following Sant'Anna-Santos (2021) and Firmo et al. (2021). The samples were rehydrated according to Meira and Martins (2003). Freehand sections were directly mounted in water (without staining) or stained with Toluidine Blue pH 4.0 following Ribeiro and Leitão (2020) and observed under a light microscope (Olympus BX51). Photographs were obtained using a digital camera (CMOS 12mp PLUS) coupled to a light microscope (Bioptika B20+). The cross-section of the intermediate region was also recorded using diagrams to illustrate the variation in the arrangement of veins and fibres. The diagrams were made using the software CorelDraw® Graphics Suite 19.0, following Vianna (2017) and Vianna et al. (2017). The terminology adopted here for leaf anatomical descriptions follows Noblick (2013b, 2017b) for margins, Glassman (1972) and Firmo et al. (2021) for midribs and intermediate regions. All anatomical data for *S. cabraliensis* were taken from the literature (see Noblick et al. 2014; Noblick 2017b; Sant'Anna-Santos et al. 2023). For scanning electron microscopy preparations, pinnae samples were fixed in Karnovsky's solution (Karnovsky 1965), dehydrated in ethyl alcohol series, dried by critical point drier (Balzers CPD 030) and sputter-coated with gold (Balzers SCD 050). Samples were observed using a JEOL JSM-6360-LV scanning electron microscope.

TAXONOMIC TREATMENT

***Syagrus carvalhoi* B.F.Sant'Anna-Santos, sp. nov.**

urn:lsid:ipni.org:names:77317187-1

Figs 1–8, Table 1

Diagnosis. *Syagrus carvalhoi* is similar to *Syagrus cabraliensis* (Noblick & Lorenzi) B.F.Sant'Anna-Santos, from which it differs by larger, taller clumps (sometimes with colonial habit); taller plants; leaves bluish and straight (vs dark green and slightly arched); pinnae inserted at various angles near the base but otherwise regularly arranged on the upper part of the leaf towards the tip (vs inserted at various angles throughout the entire rachis); pinnae with symmetric tip (vs asymmetric tip); pinnae glaucous on adaxial surface (vs pinnae glossy on adaxial surface); the presence of inconspicuous rammenta (vs without rammenta); rachillae of different sizes throughout the rachis (vs similar-sized rachillae); staminate flowers briefly pedicellate and filaments briefly connate at the base (vs staminate flowers long pedicellate and stamens with free filaments).

Type. BRAZIL – Minas Gerais • Buenópolis, Parque Estadual da Serra Cabral; 17°57'13.41"S, 44°15'2.46"W; 1044 m; 8 Jan. 2021; fl., fr.; Sant'Anna-Santos 377; holotype: UPCB; isotypes: DIAM, IBGE, MBM, UFG.



Figure 1. *Syagrus carvalhoi*. A. Straight leaves. B. Spicate inflorescences and infructescences. C. Close-up to a symmetrical pinnae tip. D. Branched inflorescence. E. Staminate flowers at anthesis. F. Tetrad. G. Triad. H. Staminate flower. I. Filaments connate. J. Petal. K. Stamens: ventral view. L. Pistillode. M. Stamens: dorsal view. N. Transversal-section: valvate petals. O. Pistillate flower. P. Sepal keeled. Q. Petal obscurely nerved. R. Petal: trichomes. S. Pistil. T. Infructescence. U. Endocarp pores. A, C–U from *Sant’Anna-Santos* 377 (UPCB, holotype), spicate inflorescences and infructescences of B added from habitat photographs. Illustration by Gustavo Surlo.

Description. Small palm, clustering to colonial, 100–140(–160) cm tall. Stem 30–60 × 7–9 cm, subterranean or prostrate, rarely erect, sometimes forking at or below the ground. Leaves pinnate number 6–13; sheathing leaf base ca 6–16 cm long; pseudopetiole 10–21 cm long; petiole 8–15 × 0.4–0.7 cm and 0.2–0.4 cm thick, abaxial side of petiole and rachis with scarce white tomentum; rachis 43–83 cm long; pinnae bluish-green on both surfaces, glaucous on both sides, pinnae narrow, single-folded and almost linear, fold quickly during drying, pinnae numbering 19–26 pairs, in clusters of 2–3, inserted at various angles near the base but otherwise regularly

arranged on the upper part to the leaf towards the tip, inconspicuous rammenta scales along the abaxial midrib; basal pinnae 23–38 × 0.3–0.6 cm, middle pinnae 22–41 × 0.5–1.1 cm, apical pinnae 22.5–29.5 × 0.1–0.3 cm with an asymmetric tip. Inflorescences spicate or spirally branched, with prophyll 6.5–10 × 1.0–1.5 cm; peduncular bract 32–45 cm long, woody, narrow, sulcate, with whitish indument thicker at the base of the bract, inflated portion 19.5–35 × 1.3–2.5 cm, including a 0.8–1.5 cm beak, 1.8–3.1 cm perimeter, 0.8–2 mm thickness; peduncle ca 12.5–18 cm × 3.0–5.0 mm, with white indument; inflorescence axis 12–23 cm long; rachis 0–5.5 cm long; rachillae



Figure 2. Vegetative morphological aspects of *Syagrus carvalhoi*. A. Colonial habit near a rock outcrop (black arrowheads). B. Detail of A: straight and ascending leaves. C. Prostrated stem (white arrowhead). D. Roots (white arrowhead). E. Unbranched stem (white arrowhead). F. Forked stem (white arrowhead). G. Acaulescent specimen: without aerial stem (white arrowhead). Photographs by Bruno F. Sant'Anna-Santos.



Figure 3. Reproductive morphological aspects of *Syagrus carvalhoi*. A. Dried inflorescence: inflorescence peduncle (pe) surrounded by prophyll (pr) and peduncular bract (pb). B. Bifurcate prophyll (white arrowhead). C. Base of a peduncle (pe) and peduncular bract (pb), tomentose (white arrowhead). D. Dorsal surface of the peduncular bract, deeply grooved (white arrowhead). E. Ventral surface of the peduncular bract, deeply grooved (white arrowhead). F. Tetrad after the fall of the staminate flower, bracteoles (br). G. Fruits (fr) with persistent perianth (pp), mostly covered by a brown lepidote indumentum (in) contrasting the green glabrous tip (gt). Photographs by Bruno F. Sant’Anna-Santos.

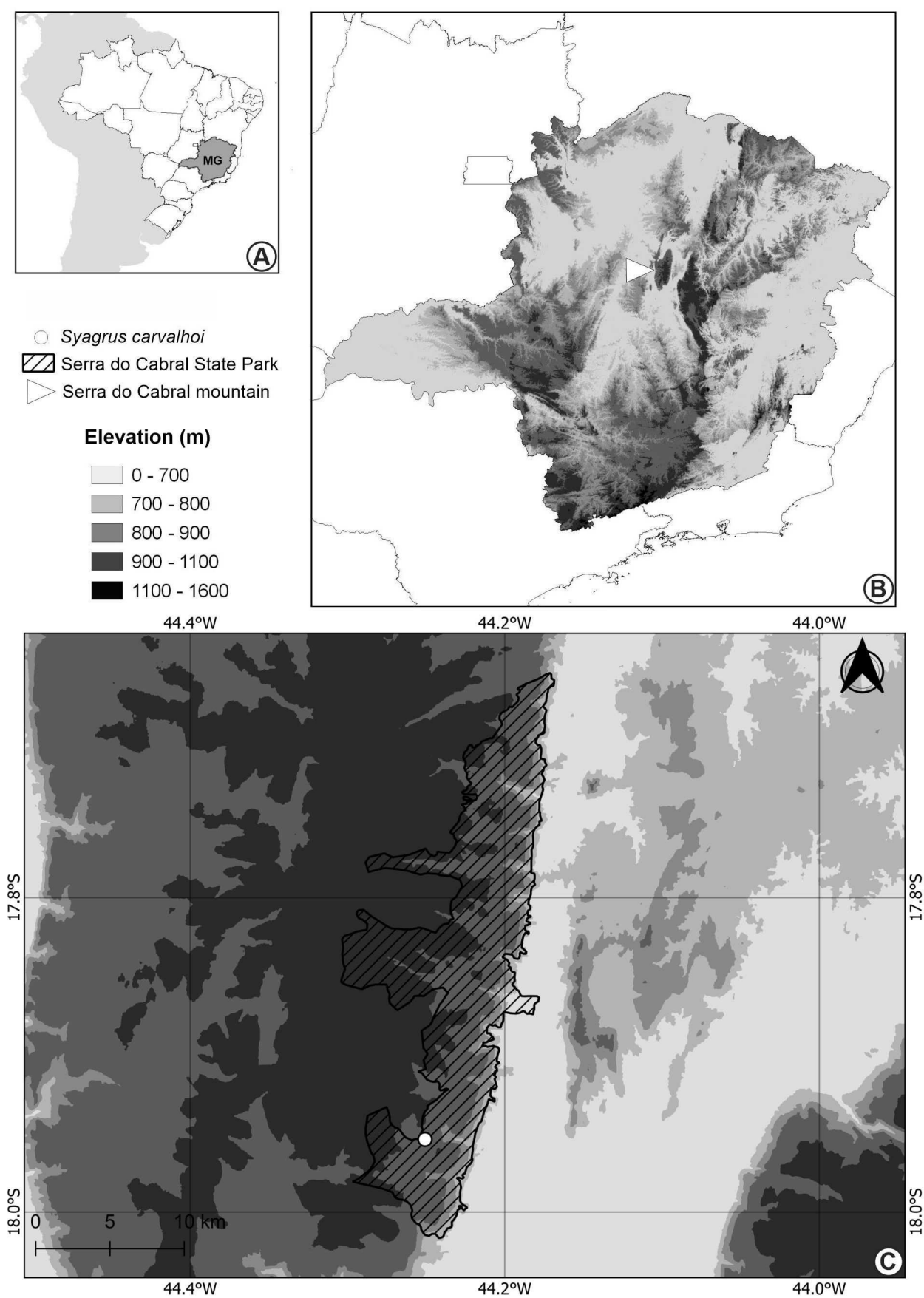


Figure 4. Distribution maps of *Syagrus carvalhoi*. **A.** Minas Gerais State (MG) in Brazil. **B.** Location of the Serra do Cabral massif (white arrowhead) in Minas Gerais State. **C.** Location of *S. carvalhoi* (white dot) in the southern part of the Serra do Cabral State Park.

1–4(–6), glabrous, 6–15 cm long at the apex, 9.5–18 cm long at the base; flowers arranged in triads or tetrads with two central pistillate flowers, each flanked by a staminate flower, both staminate and pistillate flowers with three sepals and three petals. Staminate flowers 6.4–10.8 × 2.5–4.1 mm at the apex, 8.3–16.8 × 2.6–4.3 mm at the base, those at the apex sessile, those at the base frequently pedicellate, pedicels ca 1 mm long, green to yellow, sepals 0.8–2.0 × 0.5–0.6 mm, glabrous, triangular, no visible nerves, briefly connate at the base, petals 5.5–7.2 × 2.0–2.8 mm at the apex, 8.2–10.2 × 1.5–2.8 mm at the base, with acute tips, nerves indistinct; ovate-triangular, valvate, stamens 3.9–9.5 mm long; anthers 2.7–3.5 mm long; filaments 2.1–6.8 mm long, very briefly connate at the base; pistillode trifold, ca 1.0–1.5 mm. Pistillate flowers elongate-pyramidal, 9.9–10.8 × 4.0–5.8 mm at the apex, 11.8–16.4 × 3.6–7.5 mm at the base, glabrous; sepals 9.9–12.9 × 2.3–2.6 mm, yellow, without visible venation, triangular, imbricate, with scarce hairs at the margin; petals 9.6–10.1 × 1.8–2.4 mm, obscurely nerved and slightly raised on the lower third of the petal, the lower third of margins with multiseriate hairs, imbricate at the base but valvate at the tips, triangular; pistil 5.4–10 × 2.5–4.0 mm, with lepidote indument from the base of the pistil to nearly the base of the stigmas, stigmas 2.7–3.7 mm long, glabrous; staminodial ring ca 0.4–1.2 mm in height, 6-dentate. Fruits ellipsoid, 1.8–2.7 × 1.0–1.6 cm, green tip when mature, tip glabrous, rest of the fruit brown, scaly lepidote tomentum, epicarp less than 0.5 mm thick, mesocarp less than 0.5 mm thick, succulent, and fibrous; endocarp 1.4–1.8 × 1.0–1.3 cm and ca 1 mm thick, trivittate interior. Seeds ellipsoid to nearly globose, endosperm homogeneous. Germination remote tubular.

Distribution. *Syagrus carvalhoi* is endemic to the southern part of the Serra do Cabral State Park, municipality of Buenópolis, north-central Minas Gerais state, Brazil (Fig. 4).

Habitat and ecology. The Serra do Cabral is characterised by two well-defined seasons: rainy, with hot and humid summers and mean precipitation of 750 mm, from November to April, and a dry season, with winters occurring from May to October (Hatschbach et al. 2006). The mean annual temperature is 22°C, but the relief has a significant influence on the temperatures, with higher areas having mild and more humid summers, with mean annual precipitation of 1500 mm and mean temperatures of 20°C (Hatschbach et al. 2006). The new species grows on quartzitic campos rupestres, on sandy soils of low fertility near rocky outcrops. Among the distinct relief types that compose the Serra do Cabral massif described by Hatschbach et al. (2006), *S. carvalhoi* occurs in the “plateau” with altitudes between 1000 and 1206 m. These habitats are well represented by species of Poaceae (Fig. 5A), Velloziaceae (Fig. 5A), Cyperaceae (Fig. 5B), Eriocaulaceae (Fig. 5C), Melastomataceae and Xyridaceae (Hatschbach et al. 2006; Echternacht et al. 2011; Conceição et al. 2016; Costa et al. 2018). However, the graminoid species dominate in these high landscapes

(Conceição et al. 2016) and the new species goes almost unnoticed due to its grass-like appearance during the rainy season (Fig. 5A), when most species have fresh greenish or bluish leaves. On the other hand, *Syagrus carvalhoi* is more easily noticed in the dry season (Fig. 5D) because it is one of the few species whose leaves do not dry out (and do not lose the bluish colour). Instead, the leaves of *S. carvalhoi* have a thick epicuticular wax layer covering the lamina and were frequently folded during the dry season – probably by the action of expansion cells on the abaxial surface of the midrib (Fig. 5D–G). Despite the role of expansion tissue in the unfolding and expansion of the mature lamina (Tomlinson et al. 2011), the folding of the lamina in palms has been associated with the action of expansion tissue cells combined with the water lost from the hypodermis (Defaveri et al. 2015; Barbosa et al. 2022). Closing movements of the lamina under dry conditions were also observed for other palms in semi-arid regions and could reduce the loss of water and the incidence of sunlight on the leaf surface (Oliveira et al. 2016). Regarding the local fauna, the constant presence of snakes under the *S. carvalhoi* (Fig. 5H), as well as the signs of rodent predation on its fruits (Fig. 5I), reinforces the ecological relevance of this palm as a shelter for reptiles and a food source for small mammals in the SC highlands. Different insect species also visit the new species (Fig. 5J–L). However, the most frequent interaction observed was the remarkable presence of beetle larvae feeding on the seeds (Fig. 5L). Palm fruits experience greater predation than dispersion (Henderson 2002; Guimarães and Silva 2012), which, coupled with intense fires and the physical barriers imposed by the relief, probably affects the dispersibility of *S. carvalhoi*.

Phenology. The phenology was monitored between December 2019 and November 2022, and the species flowers and bears fruits throughout the year.

Etymology. The specific epithet *carvalhoi* is named in honour of Wellington Geraldo Oliveira Carvalho Júnior, a palm enthusiast who discovered this species. Mr Carvalho and his family have provided financial and logistical support to our research in recent years. So, our team's discoveries were only possible thanks to his support and motivation.

IUCN conservation assessment. *Syagrus carvalhoi* is known only within the boundaries of the Serra do Cabral State Park. Near the park, there are small farms where livestock is raised, roads, *Pinus* sp. and *Eucalyptus* sp. plantations, and mining gravel extraction (Hatschbach et al. 2006; Noblick et al. 2014; Costa et al. 2018; Sant'Anna-Santos 2021; Sant'Anna-Santos et al. 2023). Furthermore, according to Hatschbach et al. (2006), the extraction of “sempre-vivas” (Eriocaulaceae) also constitutes a severe threat to the native vegetation of the area. Additionally, the Serra do Cabral State Park has been severely affected by fire, and the ever-closer presence of humans. Therefore, due to its restricted area of occupancy (AOO = 12 km²) and the extent of occurrence (EOO = 1.922 km²), and according to the IUCN (2022) categories and criteria, *S.*



Figure 5. Habitat and morphoanatomical aspects of *Syagrus carvalhoi* with ecological implications. **A.** Specimens of Poaceae (3 black arrowheads) and Velloziaceae (2 white arrowheads) near *S. carvalhoi* (sc). **B.** *Cyperus* sp. **C.** *Paepalanthus* sp. **D.** Pinnae frequently folded during the dry season. **E.** Pinna (pi) manually unfolded exposing the adaxial surface; the red dotted circle shows a diagram of the expansion tissue (et) on a midrib cross-section. **F.** Pinna densely covered by epicuticular wax (ew) compared to an area where the wax was manually removed (re). **G.** Epicuticular wax, SEM. **H.** The white circle shows a snake (sn) revealed after removing old leaves. **I.** Hole (ho) caused by predation of fruits (fr) by rodents. **J.** Insect (in) on an old pseudopetiole. **K.** Ant (an) walking on a pinna. **L.** Larva of a beetle (la) feeding on the endocarp (en). Photographs by Bruno F. Sant'Anna-Santos.

Table 1. Differences between *Syagrus carvalhoi* and *S. cabraliensis*.

| Characters | <i>S. carvalhoi</i> | <i>S. cabraliensis</i> |
|---|----------------------------------|------------------------------------|
| Site of occurrence | Southern part of Serra do Cabral | Northern part of Serra do Cabral |
| Habitat | Quartzitic campo rupestre | Ferruginous campo rupestre |
| Size (cm) | 100–140(–160) | 37–80(–95) |
| Pinnae colour | Bluish | Dark green |
| Pinnae number | 19–26 | 9–19 |
| Pinnae tip | Symmetrical | Asymmetrical |
| Ramenta scales | Present | Absent |
| Leaves | Straight | Slightly arched |
| Pinnae arrangement on the upper part of the rachis | Regular | Various angles |
| Leaf rachis length (cm) | 43–83 | 25–39 |
| Peduncular bract length (cm) | 32–45 | 12.2–31 |
| Length of the inflated portion of the peduncular bract (cm) | 19.5–35 | 8.5–19 |
| Rachis length (cm) | 0–5.5 | 0–2.0 |
| Size of the rachillae throughout the rachis | Different size | Similar size |
| Pedicle length of the basal staminate flowers (mm) | ca 1 | 1–4.5(–5.0) |
| Filaments | Very briefly connate at the base | Distinct |
| Length of the basal pistillate flowers (mm) | 11.8–16.4 | 10.0–11.8 |
| Indumentum of the petals of pistillate flowers | Margins with hairs | Glabrous |
| Number of endocarp pores | 3 | 3 or 6 |
| Endocarp pore position | Only subbasal | Subbasal or subbasal and subapical |

carvalhoi should be considered Critically Endangered (CR): B2ab(ii,iii).

Additional specimens examined (paratypes). BRAZIL – Minas Gerais • Buenópolis, Parque Estadual da Serra do Cabral; 17°56'08.85"S, 44°16'28.21"W; 1206 m; 6 Jan. 2020; fl.; *Sant'Anna-Santos & Firmo* 236; MBM • Buenópolis, Parque Estadual da Serra do Cabral; 17°56'08.85"S, 44°16'28.21"W; 1206 m; 6 Jan. 2020; fr.; *Sant'Anna-Santos & Firmo* 237; MBM • Buenópolis, Parque Estadual da Serra do Cabral; 17°56'08.85"S, 44°16'28.21"W; 1206 m; 6 Jan. 2020; fr.; *Sant'Anna-Santos & Firmo* 238; MBM • Buenópolis, Parque Estadual da Serra do Cabral; 17°56'20.50"S, 44°15'11.29"W; 1100 m; 7 Jan. 2020; fl.; *Sant'Anna-Santos & Firmo* 242; MBM • Buenópolis, Parque Estadual da Serra do Cabral; 17°56'20.50"S, 44°15'11.29"W; 1100 m; 7 Jan. 2020; fl., fr.; *Sant'Anna-Santos & Firmo* 244; MBM.

Pinnae anatomy. Both adaxial and abaxial surfaces of the pinnae are coated by epicuticular wax in the form of hook-shaped filaments (Figs 5G, 6A). Stomata occur on both surfaces, with guard cells located at the same level as normal epidermal cells (Fig. 6B–C). The lateral subsidiary cells of the stomata are deeper than the epidermis, with its distal portion reaching the pinnae surface (Fig. 6B, G). In the cross-section, the hypodermis forms one layer of cells longitudinally elongated to quadrangular shaped on both

surfaces (Fig. 6B–E). The hypodermis below the stomata is interrupted by substomatal chambers (Fig. 6B, G). The lamina symmetry is isolateral, composed only of palisade parenchyma cells throughout the mesophyll (Fig. 6C–F). The adaxial tertiary vascular bundles are connected to the hypodermis, while the abaxial tertiary vascular bundles are connected or not to the hypodermis (Fig. 6C, F, H). The tertiary bundles have no distinguishable protoxylem and metaxylem and are always partially surrounded by a sclerenchymatic sheath (Fig. 6C, F, H). Secondary and primary vascular bundles are connected to the hypodermis on both surfaces, and the hypodermis is sometimes biseriate above or below these veins (Fig. 6D–E). The secondary and primary vascular bundles are fully surrounded by a sclerenchymatic sheath (Fig. 6D–E). The primary vascular bundles have a larger diameter, three to four phloem poles, noticeable protoxylem and metaxylem elements, and a sclerenchymatic sheath extension (Fig. 6E). Secondary vascular bundles are similar to the primary bundles but with smaller sizes and indistinguishable protoxylem and metaxylem elements (Fig. 6D). Stegmata with conical to round silica bodies that are somewhat spinulose are frequently associated with the fibres of the vascular bundles (Fig. 6G). At the margin, tertiary vascular bundles are attached to both surfaces (Fig. 6H). The raphide-containing idioblasts are commonly found

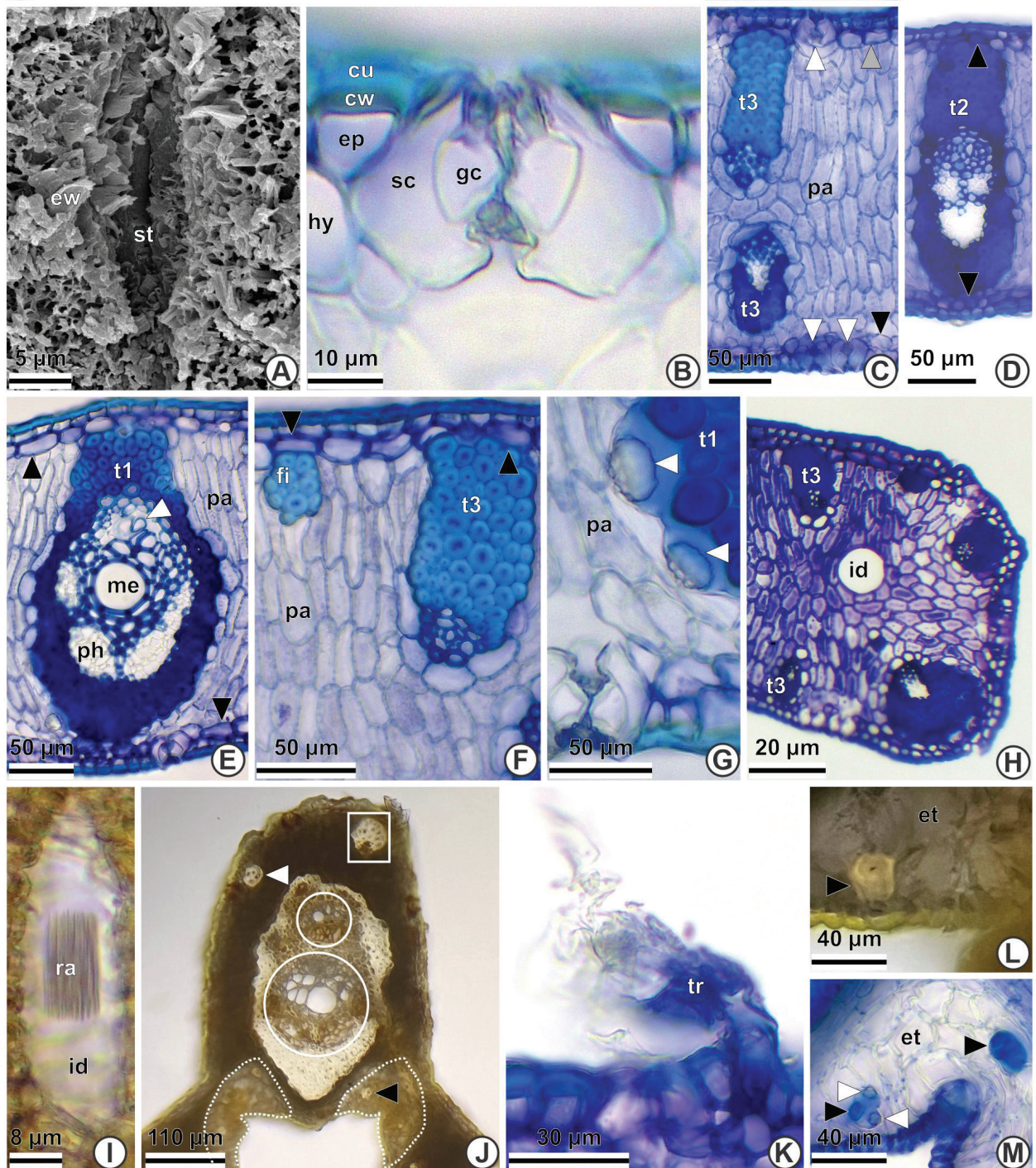


Figure 6. Pinnae anatomy of *Syagrus carvalhoi* using SEM (A) and LM with cross- (B–H, J–M) and longitudinal (I) sections. **A.** Adaxial surface: epicuticular waxes (ew) and stomata (st). **B.** Adaxial surface: guard cells (gc) at the same level of the epidermis (ep); subsidiary cells (sc) at the same level of hypodermis (hy). Cell wall (cw), cuticle (cu). **C.** Stomata on both surfaces (white arrowheads); palisade parenchyma (pa) throughout the mesophyll; tertiary vascular bundles (t3) connected to the adaxial hypodermis (grey arrowhead) and not connected to the abaxial hypodermis (black arrowhead). **D.** Secondary vascular bundles (t2) connected to hypodermis (black arrowheads) on both surfaces. **E.** Primary vascular bundles (t1) connected to the hypodermis (black arrowheads), conspicuous metaxylem (me), protoxylem (white arrowhead) and phloem (ph). **F.** Adaxial surface: non-vascular fibre bundle (fi) and tertiary vascular bundle (t3) connected to the adaxial hypodermis (black arrowheads). Palisade parenchyma (pa). **G.** Silica bodies (white arrowheads) associated with primary vascular bundle (t1). Palisade parenchyma (pa). **H.** Tertiary vascular bundles (t3) and a raphide-containing idioblast (id). **I.** Idioblast (id) containing raphides (ra). **J.** Expansion tissue interrupted (surrounded by the dotted white line); fibres in the expansion tissue (white arrowhead); two collateral bundles (white circles); group of fibres (black arrowhead) and accessory bundle (white rectangle). **K.** Trichome (tr). **L.** Fibre (black arrowhead) in the expansion tissue (et). **M.** Silica bodies (white arrowheads) associated with the fibres (black arrowheads) in the expansion tissue (et).

in the centremost layers of the mesophyll (Fig. 6H–I). The idioblasts are generally empty in thinner and stained sections (Fig. 6H), but raphides can be noted in thicker and unstained sections (Fig. 6I). The main vascular system of the midrib consists of two collateral bundles; the larger with more conspicuous xylem vessel elements and phloem (Fig. 6J). It is surrounded by a fibrous ring and 1–2 accessory bundles on the adaxial surface (Fig. 6J). Trichomes were observed on the adaxial surface of the midrib (Fig. 6K). The number of small groups of fibres around the main vascular system might be absent or, when present, in groups of 1 to 3 (Fig. 6J). The expansion tissue is interrupted and has fibres associated with stegmata (Fig. 6L–M). Four patterns of vein and fibre arrangement were observed in the leaves of *S. carvalhoi*. Pattern 1 (Fig. 7A): on the adaxial surface, there are four nonvascular fibre bundles of various sizes and one tertiary vascular bundle. On the abaxial surface, there are three tertiary vascular bundles (the median one slightly larger) between two primary (or between one primary and one secondary) vascular bundles. Pattern 2 (Fig. 7B): on the

adaxial surface, there are five to six nonvascular fibre bundles of various sizes and one tertiary vascular bundle. On the abaxial surface, there are five tertiary vascular bundles (three large - the median one slightly larger, plus two small) between two primary (or one primary and one secondary) vascular bundles. Pattern 3 (Fig. 7C): on the adaxial surface, there are three nonvascular fibre bundles of similar size and two tertiary vascular bundles. On the abaxial surface, there are four tertiary vascular bundles (three large - the median is slightly larger, plus one small) between two primary (or between one primary and one secondary) vascular bundles. Pattern 4 (Fig. 7D): on the adaxial surface, there are two tertiary vascular bundles. On the abaxial surface, there are three tertiary vascular bundles (the median slightly larger) between two primary (or one primary and one secondary) vascular bundles. Pattern 4 did not repeat the arrangement of veins and fibres along the section. So, the number of veins and fibres varies, as shown in Fig. 7C. Table 2 compares the pinnae anatomy of *S. carvalhoi* and *S. cabraliensis*.

Key to distinguish between *Syagrus carvalhoi* and *Syagrus cabraliensis*

- 1 Plants with straight leaves; pinnae glaucous on adaxial surface; pinnae with symmetrical tips; 19–26 pairs of pinnae along the rachis; pinnae regularly inserted on the upper part of the rachis; peduncular bract 32–45 cm long; basal and apical rachillae of different length.....*S. carvalhoi*
- Plants with slightly arched leaves; pinnae glossy on adaxial surface; pinnae with asymmetrical tips; 9–19 pairs of pinnae along the rachis; pinnae inserted at various angles on the upper part of the rachis; peduncular bract 12.2–31 cm long; basal and apical rachillae of similar length..... *S. cabraliensis*

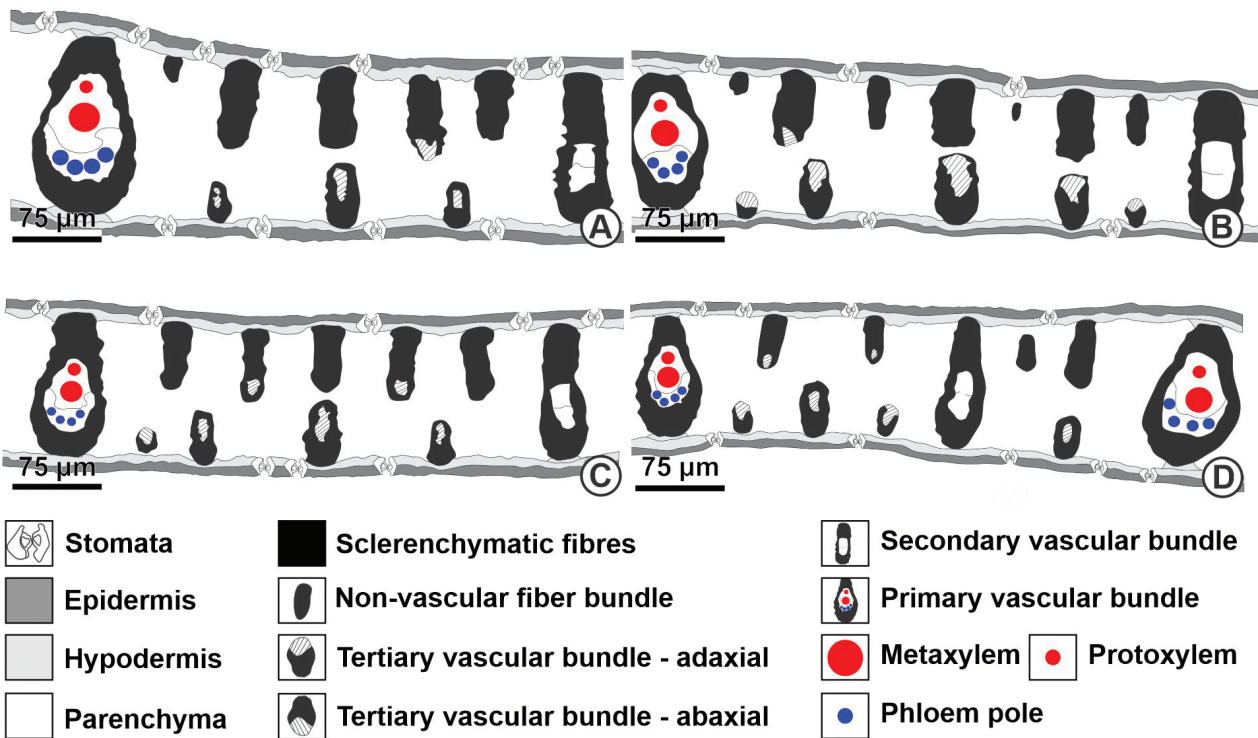


Figure 7. Diagrams of the pinnae variation of *Syagrus carvalhoi* (cross-section of the intermediate region). A. Type 1. B. Type 2. C. Type 3. D. Type 4.

Table 2. Differences in leaf anatomy between *Syagrus carvalhoi* and *S. cabraliensis*.

| Characters | <i>S. carvalhoi</i> | <i>S. cabraliensis</i> |
|--|------------------------------------|-------------------------------------|
| Adaxial veins | Present | Sometimes |
| Expansion tissue | Interrupted | Continuous |
| Number of small groups of fibres around the main vascular bundle | 0–3 | 5–12 |
| Trichomes | Present | Absent |
| Mesophyll symmetry | Isolateral | Dorsiventral |
| Guard cells level | At the same level of the epidermis | At the same level of the hypodermis |

Notes. *Syagrus carvalhoi* has a grass-like aspect – typically attributed to dwarf palms with narrow pinnae and slender inflorescences according to Noblick (2017a). Within the genus, a few other dwarf species fit (or nearly fit) the grass-like aspect: *Syagrus angustifolia* Noblick & Lorenzi, *Syagrus campylospatha* Becc., *Syagrus graminifolia* Becc., and *Syagrus cabraliensis* (Noblick & Lorenzi) B.F.Sant'Anna-Santos (Noblick 2017a; Sant'Anna-Santos et al. 2023). In addition to its isolation in the Serra do Cabral, *S. carvalhoi* is easily distinguished from *S. angustifolia* and *S. graminifolia* by spirally branched inflorescences – versus unilaterally branched inflorescences in *S. angustifolia* and *S. graminifolia*, among other notable morphoanatomical differences (Noblick 2013b, 2017a, 2017b). *Syagrus carvalhoi* still resembles *S. campylospatha* by the spirally branched inflorescences, the colonial habit and the narrow, straight and ascending leaves. However, several morphological characters easily differentiate the two species, for instance, the almost glabrous fruits and the spine-tipped pinnae of *S. campylospatha* (Noblick 2017a). Furthermore, the pinnae anatomy of *S. campylospatha* is unique within the genus (Noblick 2017a). Finally, *S. campylospatha* is endemic to Paraguay and Mato Grosso do Sul state in Brazil (Noblick 2017a), very distant from the distribution of *S. carvalhoi*. The other grass-like species, *S. cabraliensis*, shares some rare characters with *S. carvalhoi*, such as the flowers arranged in tetrads and the stems forking at or below the ground. Thus, based on the rare morphological similarities and the co-occurrence in the SC massif, *S. carvalhoi* is conceivably closely related to *S. cabraliensis*. Despite the ca 30 km distance between the populations of *S. carvalhoi* and *S. cabraliensis* (Fig. 8A), the two species are not sympatric. Due to some peculiarities of the relief (Fig. 8A), the campos rupestres form an archipelago-like system of mountains (Alves et al. 2014), which promotes isolation favouring speciation. Furthermore, while *S. carvalhoi* grows in quartzitic campos rupestres in the southern SC (Fig. 8B), *S. cabraliensis* occurs on a small ferruginous campo rupestre (Fig. 8C) on the northern SC (Noblick et al. 2014; Noblick 2017a; Sant'Anna-Santos et al. 2023). It is not the first case of a species that occurs only in the northern or the southern part of the SC, an area recognised by the presence of narrow endemics (Noblick et al. 2014; Costa et al. 2018; Guarçoni and Sartori 2020; Sant'Anna-

Santos 2021). These endemic dwarf palms of the campos rupestres of the Espinhaço Range revealed a set of rare characters (Noblick 2009, 2017a; Noblick and Lorenzi 2010; Noblick et al. 2014; Firmo et al. 2021; Sant'Anna-Santos 2021; Sant'Anna-Santos et al. 2023). Regarding the newly discovered dwarf palms for the SC, these endemics possess morphological and anatomical characters that offer new insights for taxonomic, ecological, and evolutionary studies in Arecaceae. For instance, the small group of fibres in the mesophyll of *Butia buenopolensis* made this species unique within its genus (Sant'Anna-Santos 2021). From an ecological point of view, the well-developed subterranean stems of these dwarf Arecaceae from the SC may increase their ability to survive intense fires, dry conditions and nutrient-poor soils, as previously stated in the literature (Glassman 1987; Henderson et al. 1995; Noblick 2017a; Sant'Anna-Santos et al. 2023). Additionally, we showed that the pinnae of *S. carvalhoi* are covered by a thick epicuticular wax and are frequently folded during the dry season. These characteristics might reduce leaf exposure to sunlight and water loss by transpiration (Oliveira et al. 2016). The expansion tissue in the midrib of *S. carvalhoi* is likely linked to the inward folding when subjected to dry conditions, as previously suggested for *Allagoptera arenaria* (Gomes) Kuntze (Defaveri et al. 2015) and *Allagoptera campestris* (Mart.) Kuntze (Barbosa et al. 2022). The morphological and anatomical differences between these species are shown in Fig. 8, Tables 1 and 2, and the key. Morphologically, it is easy to differentiate *S. carvalhoi* from *S. cabraliensis*: the former is represented by taller plants, larger and taller clumps (sometimes with colonial habit); bluish leaves that are straight and ascending, pinnae with symmetrical tips; staminate flowers with brief pedicels (Fig. 8B–G). Anatomically, the pinnae of *S. carvalhoi* were very useful in differentiating it from *S. cabraliensis*. For instance, the midrib is a source of characters that did not show variation between the specimens evaluated (Table 2). The patterns of veins and the arrangement of fibre bundles were also helpful in differentiating *S. carvalhoi* from *S. cabraliensis* (Table 2), despite the variation observed along the intermediate region (Fig. 7A–C) of the former. Noblick (2017b) first cited the variation in pinnae anatomy in the *Syagrus* genus using the pinnae margin anatomy. For some taxa, Noblick (2017b) carefully used more than one image

to represent the pinnae anatomy, as we did here for *S. carvalhoi* (Fig. 7). Thus, a broad and standardised sampling is essential to guarantee the correct characterisation of the studied species (Noblick 2017b; Noblick and Sant’Anna-Santos 2021). Including *S. carvalhoi*, 11 species of *Syagrus* possess variation in pinnae anatomy (Noblick et al. 2014;

Noblick 2017b; Sant’Anna-Santos et al. 2023). However, *Syagrus glazioviana* Becc. stands out as an extreme regarding such variation, requiring six different images of the same pinnae region (margin) to illustrate the pinnae anatomy of this taxon (Noblick 2017b). Considering the large area of occurrence of *S. glazioviana*, it could either

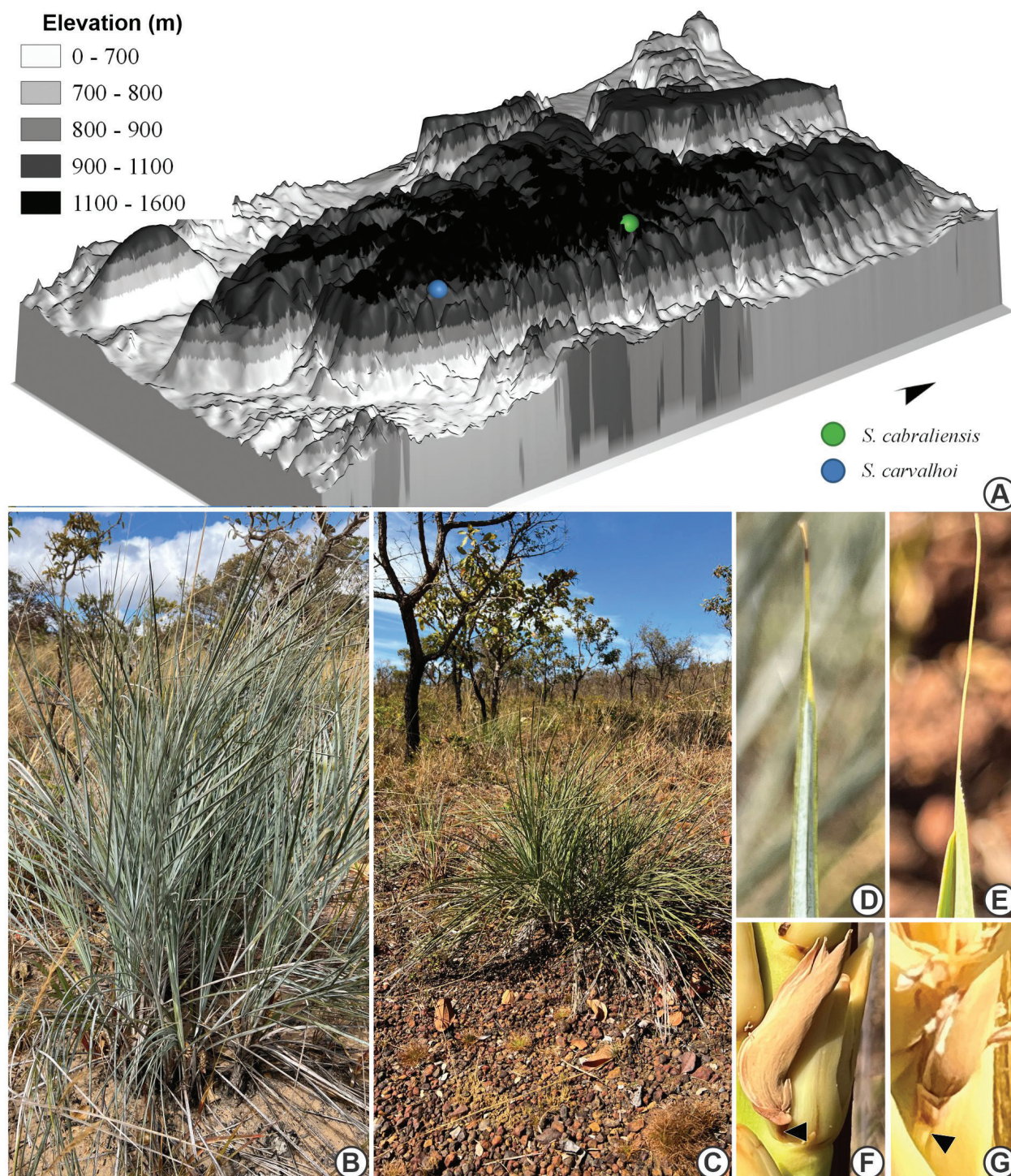


Figure 8. 3D map of the Serra do Cabral massif (A) and some morphological differences between the grass-like *Syagrus carvalhoi* (B, D, F) and *Syagrus cabraliensis* (C, E, G). A. Relief of the SC and the location of *S. carvalhoi* and *S. cabraliensis*. B. Bluish, straight and ascending leaves. C. Dark green and slightly arched leaves. D. Symmetrical pinna tip. E. Asymmetrical pinna tip. F. Staminate flower with short pedicel (black arrowhead). G. Staminate flower with long pedicel (black arrowhead). Photographs B–G by Bruno F. Sant’Anna-Santos.

indicate a true case of intra-specific variation within a single species or a complex of several closely related unresolved species (Noblick 2017b). Nevertheless, it is important to emphasise that variation in pinnae anatomy could be expected in narrow endemic species, as shown by Sant'Anna-Santos et al. (2023) for *S. cabraliensis* and here for *S. carvalhoi*. However, although such variation is possible, it should not be considered a rule for all taxa. For example, no variation was observed in the pinnae anatomy of *Butia buenopolensis*, another micro-endemic palm from the southern part of the SC (Sant'Anna-Santos 2021). Thus, even for narrow endemics, several samples should be collected, and the anatomical data correlated with morphological data, field observations and species distribution before a taxonomic decision. This hitherto unknown species from Serra do Cabral State Park is from the southern part of the Serra do Cabral massif, an area where the Arecaceae flora still needs field efforts in comparison to the northern part of the SC as well as other areas of the Espinhaço Range (Hatschbach et al. 2006; Reflora 2022; SpeciesLink Network 2022). In the last few years, field efforts of our team have resulted in important advances in the knowledge of Arecaceae from Serra do Cabral, such as the discovery of *Butia buenopolensis* (Sant'Anna-Santos 2021), the reassessment of the morphology and anatomy of *S. cabraliensis* (Sant'Anna-Santos et al. 2023) and at least one new *Syagrus* species not yet described (Firmo et al. 2021). These findings highlight the endemism of the Arecaceae family in the SC with species with rare characters as well as the need for more collection efforts. The restricted distribution of *S. carvalhoi* suggests that the taxon only grows in that specific habitat and is dependent on its preservation for survival. So, there is an urgent need for additional research to help develop conservation strategies that are more comprehensive and might effectively protect the biodiversity of this overlooked OCBIL.

ACKNOWLEDGEMENTS

We thank Jarbas J. de Alcantara, and the staff of the Serra do Cabral State Park (licence 091/2018 IEF-MG), Ricardo A. dos Santos, and Deivison Henrique Teixeira Firmo for the assistance during part of the fieldwork activities; the CME/UFPR for the scanning electron microscopy analyses; and Dr Elaine Lopes Pereira Nunes for the valuable suggestions and language corrections. We thank Dr Brecht Verstraete, one anonymous editor, and two reviewers for the valuable comments and corrections made to the manuscript. Bruno Francisco Sant'Anna-Santos received financial support from Pró-Reitoria de Pesquisa da Universidade Federal do Paraná (Edital 04/2019).

REFERENCES

- Alves RJV, Silva NG, Oliveira JA, Medeiros D (2014) Circumscribing campo rupestre – megadiverse Brazilian rocky montane savanas. *Brazilian Journal of Biology* 74(2): 355–362. <https://doi.org/10.1590/1519-6984.23212>
- Bachman S, Moat J, Hill AW, de la Torre J, Scott B (2011) Supporting red list threat assessments with GeoCAT: geospatial conservation assessment tool. *ZooKeys* 150: 117–126. <https://doi.org/10.3897/zookeys.150.2109>
- Barbosa LHS, Silva GS, Júnior AFN, Appezzato-da-Glória B (2022) Leaf phenotypic variation of *Allagoptera campestris* (Mart.) Kuntze (Arecaceae) in response to unnatural disturbances in the Cerrado. *Flora* 287(1): 151993. <https://doi.org/10.1016/j.flora.2021.151993>
- Conceição AA, Rapini A, Carmo FF, Brito JC, Silva GA, Neves SPS, Jacobi CM (2016) Rupestrian grassland vegetation, diversity, and origin. In: Fernandes G (Ed.) *Ecology and Conservation of Mountaintop Grasslands in Brazil*. Springer, Chamony, 105–128. https://doi.org/10.1007/978-3-319-29808-5_6
- Costa FN, Andrino CO, Sano PT, Trovó M, Echternacht L (2018) *Paepalanthus* (Eriocaulaceae) in the central Espinhaço range in Minas Gerais, Brazil: checklist, endemism, and nomenclatural changes. *Phytotaxa* 367(2): 133–144. <https://doi.org/10.11646/phytotaxa.367.2.3>
- Defaveri ACA, Barros CF, Arruda RCO, Simas NK, Sato A (2015) *Allagoptera arenaria* (Arecaceae): leaf anatomy of a palm from the Brazilian shore. *Brittonia* 67(4): 336–349. <https://doi.org/10.1007/s12228-015-9384-2>
- Dransfield J, Uhl NW, Asmussen CB, Baker WJ, Harley MM, Lewis CE (2008) *Genera Palmarum, the Evolution and Classification of Palms*. Kew Publishing, Kew, 1–732.
- Echternacht L, Trovó M, Oliveira CT, Pirani JR (2011) Areas of endemism in the Espinhaço Range in Minas Gerais, Brazil. *Flora* 206(9): 782–791. <https://doi.org/10.1016/j.flora.2011.04.003>
- Farr TG, Rosen PA, Caro E, Crippen R, Duren R, Hensley S, Kobrick M, Paller M, Rodriguez E, Roth L, Seal D, Shaffer S, Shimada J, Umland J, Werner M, Oskin M, Burbank D, Alsdorf D (2007) The shuttle radar topography mission. *Reviews of Geophysics* 45(2): 1–33. <https://doi.org/10.1029/2005RG000183>
- Fidanza K, Martins AB, Almeda F (2013) Four new species of *Trembleya* (Melastomataceae: Microlicieae) from Serra do Cabral, Minas Gerais, Brazil. *Brittonia* 65(3): 280–291. <https://doi.org/10.1007/s12228-012-9281-x>
- Firmo DHT, Santos SA, Perez MEMP, Soffiatti P, Sant'Anna-Santos BF (2021) Reassessing species boundaries in the *Syagrus glaucescens* complex (Arecaceae) using leaf anatomy. *Botany* 99(7): 379–387. <https://doi.org/10.1139/cjb-2020-0165>
- Genovese-Marcomini PR, Mendonça MS, Carmello-Guerreiro SM (2013) Morphoanatomy of the flower of *Syagrus inajai* (Spruce) Becc. (Arecaceae-Arecoideae-Attaleinae), Amazon. *Brazilian Journal of Biology* 73(3): 649–661. <https://doi.org/10.1590/S1519-69842013000300025>

- Giulietti AM, Pirani JR, Harley RM (1997) Espinhaço range region, eastern Brazil. In: Davis SD, Heywood VH, Herrera-Macbride O, Villa-Lobos J, Hamilton AC (Eds) Centres of Plant Diversity: a Guide and Strategy for their Conservation. IUCN Publication Unity, Cambridge, 397–404.
- Glassman SF (1972) Systematic studies in the leaf anatomy of palm genus *Syagrus*. American Journal of Botany 59(8): 775–788. <https://doi.org/10.2307/2441082>
- Glassman SF (1987) Revisions of the palm genus *Syagrus* Mart. and other selected genera in the *Cocos* alliance. University of Illinois Press, Champaign, 1–230.
- Guarçoni EAE, Sartori MA (2020) Checklist of the Bromeliaceae of the Serra do Cabral, Minas Gerais, Brazil, with a description of a new species. Phytotaxa 443(1): 38–50. <https://doi.org/10.11646/phytotaxa.443.1.4>
- Guimarães CAL, Silva LAM (2012) Piaçava da Bahia (*Attalea funifera* Martius): do Extrativismo à Cultura Agrícola. Editus, Ilhéus, 1–262.
- Harley RM (1995) Introduction. In: Stannard BL (Ed.) Flora of the Pico das Almas, Chapada Diamantina, Bahia. Royal Botanic Gardens, Kew, 1–40.
- Hatschbach G, Guarçoni EAE, Sartori MA, Ribas O (2006) Aspectos fisionômicos da vegetação da Serra do Cabral - Minas Gerais, Brasil. Boletim Do Museu Botânico Municipal 67(1): 1–33.
- Henderson A (2002) Evolution and Ecology of Palms. The New York Botanical Garden Press, New York, 1–259.
- Henderson H, Galeano G, Bernal R (1995) Field Guide to the Palms of the Americas. Princeton University Press, New Jersey, 1–502.
- Hopper SD (2009) OCBIL theory: towards an integrated understanding of the evolution, ecology and conservation of biodiversity on old, climatically buffered, infertile landscapes. Plant and Soil 322(1): 49–86. <https://doi.org/10.1007/s11104-009-0068-0>
- IBGE (2020) Instituto de Geografia e Estatística. Portal de mapas. <https://portaldemapas.ibge.gov.br> [accessed 09.05.2022]
- IUCN (2022) Guidelines for Using the IUCN Red List Categories and Criteria. Version 15. <https://www.iucnredlist.org/resources/redlistguidelines> [accessed 15.12.2022]
- Karnovsky MJ (1965) A formaldehyde-glutaraldehyde fixative of high osmolality for use in electron microscopy. Journal of Cell Biology 27(2): 1A–149A.
- Lousada JM, Borba EL, Ribeiro KT, Ribeiro LC, Lovato MB (2011) Genetic structure and variability of the endemic and vulnerable *Vellozia gigantea* (Velloziaceae) associated with the landscape in the Espinhaço Range, in southeastern Brazil: Implications for conservation. Genetica 139(4): 431–440. <https://doi.org/10.1007/s10709-011-9561-5>
- Marcato AC, Pirani JR (2001) Flora da Serra do Cipó, Minas Gerais, Palmae (Arecaceae). Boletim de Botânica 19: 45–54. <https://doi.org/10.11606/issn.2316-9052.v19i0p45-54>
- Marcato AC, Pirani JR (2006) Flora de Grão-Mogol, Minas Gerais: Palmae (Arecaceae). Boletim de Botânica 24(1): 1–8. <https://doi.org/10.11606/issn.2316-9052.v24i1p1-8>
- Martel C, Noblick L, Stauffer FW (2013) An anatomical character to support the cohesive unit of *Butia* species. Palms 57(1): 30–35. https://palms.org/wp-content/uploads/2016/05/vol57n1p30_37.pdf [accessed 15.03.2023]
- Meerow AW, Noblick L, Borrone JW, Couvreur TLP, Mauro-Herrera M, Hahn WJ, Kuhn DN, Nakamura K, Oleas NH, Schnell RJ (2009) Phylogenetic analysis of seven WRKY genes across the palm subtribe Attaleinae (Arecaceae) identifies *Syagrus* as sister group of the Coconut. PLoS ONE 4(10): e7353. <https://doi.org/10.1371/journal.pone.0007353>
- Meira RMSA, Martins FM (2003) The inclusion of herbalized material using methacrylate for plant anatomy studies. Revista Árvore 27(1): 109–112. <https://doi.org/10.1590/S0100-67622003000100015>
- Ministério do Meio Ambiente Brasil (2020) Ministério do Meio Ambiente. Mapa - Unidades de Conservação. <https://antigo.mma.gov.br/areas-protetidas/cadastro-nacional-de-ucs.html> [accessed 16.03.2023]
- Miranda EE (2005) Brasil em Relevô. Campinas: Embrapa Monitoramento por Satélite. <https://www.cnpem.embrapa.br/projetos/relevobr/> [accessed 10.09.2022]
- Morellato LPC, Silveira FAO (2018) Plant life in campo rupestre: new lessons from an ancient biodiversity hotspot. Flora 238: 1–10. <https://doi.org/10.1016/j.flora.2017.12.001>
- Neves DM, Dexter KG, Pennington RT, Bueno ML, Miranda PLS, Oliveira-Filho AT (2018) Lack of floristic identity in campos rupestres—A hyperdiverse mosaic of rocky montane savannas in South America. Flora 238: 24–31. <https://doi.org/10.1016/j.flora.2017.03.011>
- Noblick L (2004a) *Syagrus vermicularis*, a fascinating new palm from northern Brazil. Palms 48(3): 109–116.
- Noblick LR (2004b) *Syagrus cearensis*, a twin-stemmed new palm from Brazil. Palms 48(2): 70–76.
- Noblick LR (2004c) Transfer of *Syagrus campicola* to *Butia*. Palms 48(1): 42.
- Noblick LR (2009) *Syagrus evansiana*, a new palm from Minas Gerais, Brazil. Palms 53(3): 113–118. <https://palms.org/wp-content/uploads/2016/05/v53n3p113-118.pdf> [accessed 15.03.2023]
- Noblick LR (2010) *Syagrus*. In: Lorenzi H, Noblick L, Kahn F, Ferreira E (Eds) Flora Brasileira: Arecaceae (palmeiras). Instituto Plantarum, Nova Odessa, 304–360.
- Noblick LR (2012) *Syagrus* × *mirandana*, a naturally occurring hybrid of *S. coronata* and *S. microphylla*. Palms 56(2): 57–60. <https://palms.org/wp-content/uploads/2016/05/vol56n2p57-60.pdf> [accessed 15.03.2023]
- Noblick LR (2013a) *Syagrus stenopetala*: a good species. Palms 57(3): 147–149. <https://palms.org/wp-content/uploads/2016/05/vol57n3p147-149.pdf> [accessed 15.03.2023]
- Noblick LR (2013b) Leaflet anatomy verifies relationships within *Syagrus* (Arecaceae) and aids in identification. PhytoKeys 26: 75–99. <https://doi.org/10.3897/phytokeys.26.5436>
- Noblick LR (2014) *Syagrus*: an overview. The Palm Journal 205: 3–31.
- Noblick LR (2017a) A revision of the genus *Syagrus* (Arecaceae). Phytotaxa 294(1): 001–262. <https://doi.org/10.11646/phytotaxa.294.1.1>
- Noblick LR (2017b) Key to *Syagrus* identification using leaflet margin anatomy: Supplement to “A revision of *Syagrus*

- (Arecaceae)". *PhytoKeys* 81: 19–46. <https://doi.org/10.3897/phytokeys.81.12909>
- Noblick LR (2018) *Syagrus guaratingensis*: a new species from Bahia, Brazil. *Palms* 62(2): 77–86.
- Noblick LR (2019) Guide to the Palms of Northeastern Brazil. UEFS Editora, Feira de Santana, 1–87.
- Noblick LR, Lorenzi H (2010) New *Syagrus* species from Brazil. *Palms* 54(1): 18–42.
- Noblick LR, Lorenzi H, Souza VC (2014) Four new taxa of acaulescent *Syagrus* (Arecaceae) from Brazil. *Phytotaxa* 188(1): 1–13. <https://doi.org/10.11646/phytotaxa.188.1.1>
- Noblick LR, Sant'Anna-Santos BF (2021) Diversity of leaf anatomy within a single leaflet and between leaflets of four *Butia* (Arecaceae, Arecoideae) species. *PhytoKeys* 180: 31–52. <https://doi.org/10.3897/phytokeys.180.66018>
- Oliveira D, Medeiros M, Pereira S, Oliveira M, Frosi G, Arruda E, Santos M (2016) Ecophysiological leaf traits of native and exotic palm tree species under semi-arid conditions. *Bragantia* 75(2): 128–134. <https://doi.org/10.1590/1678-4499.364>
- Prance GT (1994) A comparison of the efficacy of higher taxa and species numbers in the assessment of biodiversity in the neotropics. *Philosophical Transactions of the Royal Society B* 345(1): 89–99. <https://doi.org/10.1098/rstb.1994.0090>
- QGIS Development Team (2022) QGIS Geographic Information System. Open Source Geospatial Foundation Project. <https://qgis.org/> [accessed 10.10.2022]
- Rapini A, Mello-Silva R, Kawasaki ML (2002) Richness and endemism in Asclepiadoideae (Apocynaceae) from the Espinhaço Range of Minas Gerais, Brazil - a conservationist view. *Biodiversity and Conservation* 11: 1733–1746. <https://doi.org/10.1023/A:1020346616185>
- Rapini A, Ribeiro PL, Lambert S, Pirani JR (2008) A flora dos campos rupestres da Cadeia do Espinhaço. *Megadiversidade* 4(1–2): 16–24.
- Reflora (2022) Reflora. Herbário Virtual. <https://reflora.jbrj.gov.br/reflora/herbarioVirtual/> [accessed 15.01.2023]
- Ribeiro VC, Leitão CAE (2020) Utilisation of Toluidine blue O pH 4.0 and histochemical inferences in plant sections obtained by free-hand. *Protoplasma* 257(3): 993–1008. <https://doi.org/10.1007/s00709-019-01473-0>
- Sant'Anna-Santos BF (2021) A new endemic and critically endangered species of *Butia* (Arecaceae) with comments on morpho-anatomical novelties in the genus. *Plant Systematics and Evolution* 307(1): 4. <https://doi.org/10.1007/s00606-020-01729-w>
- Sant'Anna-Santos BF, Azevedo IFP, Micheli R, Soffiatti P (2023) Morpho-anatomical novelties of a dwarf *Syagrus* (Arecaceae) of canga: implications for ecology, conservation, and taxonomy. *Plant Systematics and Evolution* 309: 8. <https://doi.org/10.1007/s00606-023-01843-5>
- Silva-Cardoso IMA, Souza AM, Scherwinski-Pereira JE (2017) The palm tree *Syagrus oleracea* Mart. (Becc.): a review. *Scientia Horticulturae* 225: 65–73. <https://doi.org/10.1016/j.scienta.2017.06.054>
- Silveira FAO, Negreiros D, Barbosa NPU, Buisson E, Carmo FF, Carstensen DW, Conceição AA, Cornelissen TG, Echternacht L, Fernandes GW, Garcia QS, Guerra TJ, Jacobi CM, Lemos-Filho JP, Le Stradic S, Morellato LPC, Neves FS, Oliveira RS, Schaefer CE, Viana PL, Lambers H (2016) Ecology and evolution of plant diversity in the endangered campo rupestre: a neglected conservation priority. *Plant and Soil* 403(1): 129–152. <https://doi.org/10.1007/s11104-015-2637-8>
- Soares KP (2022) *Syagrus* in Flora e Funga do Brasil. Jardim Botânico do Rio de Janeiro. <http://reflora.jbrj.gov.br/reflora/floradobrasil/FB15732> [accessed 10.12.2022]
- Soares KP, Guimarães CAL (2019) *Syagrus amicum*, a new Arecaceae from Bahia, Brazil. *Phytotaxa* 387(2): 158–164. <https://doi.org/10.11646/phytotaxa.387.2.8>
- Soares KP, Pimenta RS, Guimarães CA (2013) Duas novas espécies de *Syagrus* Mart. (Arecaceae) para o Brasil. *Ciência Florestal* 23(3): 417–426. <https://doi.org/10.5902/1980509810553>
- SpeciesLink Network (2022) Sistema de informação distribuído para coleções biológicas: a integração do Species Analyst e do SinBiota (FAPESP). <https://specieslink.net/search/> [accessed 07.12.2022]
- Tomlinson PB, Horn JW, Fisher JB (2011) The Anatomy of Palms. Oxford University Press Inc., New York, 1–251.
- Trovó M, Costa FN, Echternacht L (2012) *Actinocephalus pachyphyllus*: re-establishment, redefinition, and a new combination in Eriocaulaceae from Brazil. *Kew Bulletin* 67(1): 25–31. <https://doi.org/10.1007/s12225-012-9334-z>
- Vianna SA (2017) A new species of *Acrocomia* (Arecaceae) from Central Brazil. *Phytotaxa* 314(1): 45–54. <https://doi.org/10.11646/phytotaxa.314.1.2>
- Vianna SA, Carmelo-Guerreiro SM, Noblick LR, Colombo CA (2017) Leaf anatomy of *Acrocomia* (Arecaceae): an additional contribution to the taxonomic resolution of a genus with great economic potential. *Plant Systematics and Evolution* 303(2): 233–248. <https://doi.org/10.1007/s00606-016-1369-4>
- Zappi DC, Moro MF, Meagher TR, Lughadha EN (2017) Plant biodiversity drivers in Brazilian campos rupestres: Insights from phylogenetic structure. *Frontiers in Plant Science* 8: 1–15. <https://doi.org/10.3389/fpls.2017.02141>