



Two new species of *Nolina* (Nolinoideae: Asparagaceae) endemic to Western Mexico

EDUARDO RUIZ-SANCHEZ^{1,2}, PABLO CARRILLO-REYES^{1,2}, LUIS HERNÁNDEZ-SANDOVAL^{3,4} & CHELSEA D. SPECHT⁵

¹Departamento de Botánica y Zoología, Centro Universitario de Ciencias Biológicas y Agropecuarias, Universidad de Guadalajara, Camino Ing. Ramón Padilla Sánchez 2100, Nextipac, Zapopan, Jalisco 45200, Mexico. E-mail: pcarreyes@gmail.com

²Laboratorio Nacional de Identificación y Caracterización Vegetal (LaniVeg), Camino Ing. Ramón Padilla Sánchez 2100, Nextipac, Zapopan, Jalisco 45200, Mexico.

³Universidad Autónoma de Querétaro, Escuela de Biología, Av. de las Ciencias s/n. Campus Juriquilla. Querétaro, Querétaro, Mexico.

⁴Laboratorio Nacional de Identificación y Caracterización Vegetal (LaniVeg), Av. de las Ciencias s/n. Campus Juriquilla. Querétaro, Querétaro, Mexico.

⁵School of Integrative Plant Sciences, Section of Plant Biology and the L.H. Bailey Hortorium, Cornell University, 502 Mann Library, Ithaca, NY 14853, US.

Abstract

Nolina in Mexico is represented by 26 described species, 18 of them are endemic. Previous molecular and ecological studies indicated that populations of *Nolina parviflora* from Jalisco and Zacatecas may be genetically and ecologically distinct from the described *N. parviflora* and therefore merit delimitation as a separate species. A detailed morphological study of samples from Jalisco and Zacatecas and a review of existing herbarium collections confirmed the existence of two new *Nolina* species, which are here described and illustrated as *Nolina caxcana* and *Nolina rodriguezii*. Both species are endemic to Mexico.

Keywords: endemic, Jalisco, Sierra Madre Occidental, Trans-Mexican Volcanic Belt, Zacatecas

Introduction

Nolina Michaux (1803: 207–208) is a North American genus comprising approximately 32 described species (Trelease 1911, Hochstätter & Donati 2010, Donati 2011, García-Mendoza *et al.* 2012, Hernández-Sandoval 2019). The geographical distribution of the genus includes western and eastern ranges. The western range extends from Utah (United States of America) in the north, through Baja California, the Sierra Madre Occidental, the Trans-Mexican Volcanic Belt and to the Sierra Madre del Sur (Oaxaca, Mexico) in the south. The eastern range of *Nolina* extends from Florida (United States of America) in the north, through the Sierra Madre Oriental, and to the Sierra Norte de Oaxaca (Mexico) in the south. From the described 32 *Nolina* species, Espejo-Serna & López-Ferrari (1996) recognized 20 species and two varieties in their checklist of Monocots of Mexico. In a subsequent checklist of plants native to Mexico, Villaseñor (2016) recognized 22 *Nolina* species, 14 of them endemic. Finally, Hernández-Sandoval (2018) considered 22 *Nolina* species for Mexico (16 endemic) in a nomenclatural revision, but characterized a different set of names than those used by the former authors.

Morphologically, *Nolina* species are dioecious plants with an acaulescent, shortly caulescent or arborescent habit (Trelease, 1911). They have linear or strap-like leaves crowded into terminal rosettes. Minimal information is available on phenology, but recent field data suggest that flowering cycle periods are up to three years (Ruiz-Sanchez & Specht 2013).

Based on phylogenetic analyses including molecular and morphological data, *Nolina* was found to be closely related to *Beaucarnea* Lemaire (1861: 59) and *Dasyllirion* Zuccarini (1838: 258) within the Asparagaceae (Kim *et al.* 2010, Seberg *et al.* 2012, Rojas-Piña *et al.*, 2014). In a previous phylogeographic study of *N. parviflora* (Kunth (1816: 269)) Hemsley (1884: 372) using chloroplast and nuclear markers, Ruiz-Sanchez & Specht (2013) found two well-supported clades. One clade comprises populations from Jalisco and Zacatecas, and the second clade comprises the

rest of the populations, mainly distributed along of the Trans-Mexican Volcanic Belt. A subsequent ecological study of *N. parviflora* populations distributed along the Trans-Mexican Volcanic Belt using species distribution models, climatic analysis, spatial connectivity and morphological comparison, found significant differences in climatic and genetic variables between *N. parviflora* populations from the Central and Eastern Trans-Mexican Volcanic Belt, and those of the Western Trans-Mexican Volcanic Belt, Sierra Madre Occidental, Sierra Madre Oriental and Sierra Madre del Sur (Ruiz-Sanchez & Specht 2014). This evidence supports the recognition of *N. parviflora* in its original circumscription (Trelease 1911, 1920). In contrast, populations from peripheral areas are genetically isolated from remaining *N. parviflora*. Taxonomic status of some populations has been reviewed by the reanalysis of morphological evidence, leading to its recognition as distinct species; such is the case of *N. hibernica* F. Hochstätter & D. Donati (2010: 74) from Tamaulipas in the Sierra Madre Oriental; *N. azureogladiata* D. Donati (2011: 54) from Oaxaca in the Sierra Madre del Sur; *N. excelsa* García-Mendoza *et al.* (2012: 22); from the Tehuacán-Cuicatlán valley; *N. orbicularis* L. Hernández (2019: 1) from San Luis Potosí, Guanajuato and Querétaro in the Sierra Madre Oriental; and *N. robusta* L. Hernández (2019: 5) from San Luis Potosí and Querétaro, also in the Sierra Madre Oriental.

In this context, some *Nolina* populations from Western Mexico were evaluated. Based on previous genetic evidence (Ruiz-Sanchez & Specht 2013, 2014), geographical distribution and morphological differences compiled through an exhaustive herbarium review and field work, we here describe two new species of *Nolina* endemic to Western Mexico and morphologically similar to *N. parviflora*. We include photos comparing and contrasting the two new species, a distribution map, as well as a morphological comparative table for delimiting the two new *Nolina* species from each other and from *N. parviflora*.

Taxonomy

Nolina caxcana Ruiz-Sanchez, P. Carrillo & L. Hern. sp. nov. (Figs. 1–2)

TYPE:—MEXICO. Zacatecas: Municipio Teúl de González Ortega, cerca del puente sobre el río Patitos, camino El Conejo-Milpillas de Allende, 21°21' 06"N, 103°33' 59"W, 1700 m, 8 April 2015 (fl), *P. Carrillo-Reyes et al.* 7749 (holotype: IBUG!; isotypes: CIIDIR!, IEB!, MEXU!, QMEX!, UAMIZ!, XAL!).

Nolina caxcana differs from congeneric species in having shorter trunks with branches emerging from the base, shorter and narrower leaves, inflorescences with few and short primary branches, and quantitatively smaller fruits (4.5–6 × 6–8 mm vs. 8–10 × 9–14 mm).

Shrubby, perennial plants, dioecious, 1.5–2 m tall, 5–7 (–10) cm in basal diameter, base slightly widened, outer bark fissured, grayish with rectangular ornamentation; trunks cespitose. One or two branches emerge from the base. Leaves bright green, reflexed at maturity, alternate, spirally arranged, marcescent throughout the length of the trunk; base 2–3 cm long, 1.5–2.5 cm wide, deltoid, thickened, whitish, 80–108 cm long, 0.8–1.1 cm wide, linear, chartaceous, apex dry, erect and slightly pungent, margin denticulate with single teeth, upper and lower surface with grooves, dry old leaves reflexed and persisting. Inflorescence paniculate, erect, narrow up to 2.15 m long, 2 cm in basal diameter, basal bracts 64–71 cm long, 5 cm wide, lanceolate, appressed, papery, decreasing in length towards the apex, short denticulate, light green to cream at the base; primary branches approximately 9–12 cm long, branches aperture at 45°, secondary branches 1.3–2.3 cm long with 3 flowers per node; bracteole 2.5–4.2 mm de long, 1.5–2 mm wide, ovate to deltoid, margin fimbriate, papery, whitish. Flowers unisexual. Staminate flowers (2–) 3 per node; campanulate; pistilodiums reduced; pedicels 1.5–2 mm long, articulating in the basal third; tepals 6, lanceolate, arranged in 2 series of 3, 3–3.8 mm long, 1.2–1.6 mm wide, free, almost equal, elliptical to obovate, apex apiculate, reflexed, whitish, with a green midvein, margin hyaline; stamens 6, free, filaments 1–1.2 mm long, shorter than the tepals, anthers ca. 1 mm long; ovary superior. Pistillate flowers 2–3 per node, campanulate on pedicels 5–7 mm long, long articulated near the base; tepals lanceolate, 2.2–2.5 mm long, 1 mm wide, cream; ovary not seen; stigmas not seen; staminodes not seen. Fruit a 3-lobed capsule, 4.5–6 mm long, 6–8 mm wide in cross section, ellipsoidal sect, rounded distally, inflated, pericarp thin, pedicels 5–7 mm long, the locules with one or three seeds, rarely 4. Seeds 3.8–4 mm long, 2–2.4 mm wide, subglobose to reniform when dry, muriculate, light brown.

Habitat and distribution:—*Nolina caxcana* grows in the crevices of rocks and boulders, inhabiting oak forest along with *Juniperus blancoi* Martínez (1946: 73), *Agave maximiliana* Baker (1877: 201), *Dasyilirion* sp. Zuccarini (1838: 258), *Bursera fagaroides* (Kunth in Humboldt *et al.* 1824: 611) Engler (1880: 44), *B. multijuga* Engler (1883: 42), *Quercus castanea* Née (1801: 276), *Q. eduardi* Trelease (1924: 121), *Q. laeta* Liebmman (1854: 179), *Q.*

magnoliifolia Née (1801: 268), and *Rhus pachyrrhachis* Hemsley (1879: 218). The only known population is located in the Patitos river canyon, along the Zacatecas-Jalisco border, at 1680–1710 m elevation. Apparently, *N. caxcana* is a narrow endemic species in the southernmost portion of the Sierra Madre Occidental (Fig. 5).

TABLE 1. A comparison of the morphology of *Nolina caxcana*, *N. rodriguezii* and *N. parviflora*.

Character/Taxon	<i>N. caxcana</i>	<i>N. rodriguezii</i>	<i>N. parviflora</i>
Plant size (m)	1.5–2	2–2.5	4–5
Trunk	shrubby	arborescent	arborescent
Branch type	branched at base	branched above	branched above
Marcescent	along the branches to the base trunk	along the branches, but not at the base trunk	close to the rosettes
Leaves			
Length (cm)	80–108	90–145	100–150
Width (cm)	0.8–1.1	0.9–1.5	1–2
Apex	entire, dehydrated	entire, dehydrated	disintegrate, erect to helical with fibers
Margin color	green	green-yellow	green-yellow, brown with the age
Orientation of teeth	to the apex	to the apex	to both sides
Cusps of teeth	1–3	1–2	1–2
Teeth size (mm)	0.1–0.2	0.1–0.2	0.1–0.2
Inflorescence length (m)	2.14	1.5	2.5
Bracts form	Linear	Triangular to linear	Triangular to linear
Inflorescence branches aperture	45°	60–90°	>45°
Staminate flowers per node	2–3	2	2
Pedicels of staminate flowers (mm)	1.5–2	1.5–2	3–4
Fruit			
Fruit pedicels (mm)	5–7	7–12	7–12
Length (cm)	4.5–6	8–8.5	8–10
Diameter (cm)	6–8	9–10	10–14
Fruit scission (mm)	4	2–4	2
Color seed	Light brown	Dark brown	Brown-reddish
Flowering			
Period	March–June	August–November	April
Fructification			
Period	May–October	December–April	May–July

Comparison:—On the basis of morphology, *Nolina caxcana* resembles *N. parviflora* and *N. rodriguezii* (Table 1). However, *N. caxcana* has smaller trunks of 1.5–2 m arising from the base, vs. trunks branching above in *N. rodriguezii* (branches of 1–2.5 m) and *N. parviflora* (branches of 2–4 m). Leaves in *N. caxcana* are shorter and narrower than in *N. rodriguezii* (published here) and *N. parviflora*, leaves are deciduous in some populations of *N. parviflora* but marcescent in *N. caxcana* and *N. rodriguezii*. Fruits are smaller (length/width) in *N. caxcana* than those in *N. rodriguezii* and *N. parviflora*. *Nolina caxcana* is smaller than *N. rodriguezii* and *N. parviflora* in all aspects (Table 1).

Due to the small size fruits and panicles with ascending branches, *Nolina caxcana* is located in the section *Microcarpae* (Trelease (1911: 420)) Hochstätter (2010: 23).

Etymology:—The specific epithet honors the Caxcan ethnic group that inhabited southern Zacatecas, where the plants were collected.

Phenology:—Collections of this species with fruits were made in 2003, 2010 and 2017; with flowers in 2015. Taking into account this information, it is possible that the plants flower from April to May and develop fruit during July through October.

Additional specimens examined:—MEXICO. Zacatecas: Municipio Teúl de González Ortega, Cerca de El Infiernito, 8.2 km al SO de El Conejo por el camino a Huitzila, 21°20'49"N, 103°33'31"W, 1810 m, 1 March 2019 (sterile), *P. Carrillo-Reyes & E. Ruiz-Sánchez 9272* (IBUG); cerca del puente sobre el río Patitos, camino El Conejo-Milpillas de Allende, 21°21'N, 103°33'W, 1680 m, 20 June 2003 (fr), *P. Carrillo-Reyes 4061* (IBUG, IEB, MEXU); por la cañada al S del puente Patitos, 21°21' 04.5" N, 103°34' 00.2" W, 1708 m, 22 July 2010 (fr), *E. Ruiz-Sánchez et al. 308* (IEB); 0.2–0.5 km al SSE del Puente sobre el Río Patitos, carretera El Conejo-Milpillas Allende, 21°21'04"N, 103°33'59"W, 1700 m, 14 April 2013 (sterile), *P. Carrillo-Reyes & E. Ruiz-Sánchez 6948* (IBUG); 0.5 km al SSE del Puente sobre el Río Patitos, carretera El Conejo-Milpillas de Allende, 21°20' 52.76"N, 103°33'55.41"W, 1684 m, 31 May 2018 (fl), *E. Ruiz-Sánchez & D. Sánchez 595* (IBUG). Jalisco, Municipio Tequila, 0.4 km al NO del Puente sobre el río Patitos (5.2 km en línea recta al NE de Milpillas de Allende). 21°21' 17"N, 103°34' 12"W, 1710 m, 2 May 2017 (fr), *P. Carrillo-Reyes et al. 8575* (IBUG); 0.2 km al NNO del Puente sobre el Río Patitos, carretera El Conejo-Milpillas de Allende, 21°21'9.55"N, 103°34'7.75"W, 1711 m, 31 May 2018 (fl), *E. Ruiz-Sánchez & D. Sánchez 594* (IBUG).

IUCN Conservation assessment:—*Nolina caxcana* is currently known from few collections made very close to one another. Localities are separated by no more than 2 km distance and are outside of any local protected areas. Plants grow on steep rocky hillsides that are inappropriate either for agriculture or for raising cattle. However, low levels of perturbation by cattle have been observed. No other threats were detected. Using GeoCAT (Bachman *et al.*, 2011) and based on the limited number of localities, the Extent of Occurrence (EOO) is 0.245 km², meanwhile the size of the Area of Occupancy is 8 km², based on cells of 2 km. A preliminary category of Critically Endangered (CR (B2 bii)) is proposed following the IUCN (2012) criteria.

***Nolina rodriguezii* Ruiz-Sanchez, P. Carrillo & L. Hern. sp. nov. (Fig. 3–4)**

TYPE:—MEXICO. Jalisco: Municipio Tizapán el Alto, Los Arcos, ± 10 km al E de Tizapán, cerca de límite con el Edo. de Michoacán, [20°09'58"N, 102°57'07"W], 1650–1750 m, 3 February 1979 (fr), *R. Guzmán & R. McVaugh 1324* (holotype: IBUG!; isotype: MEXU).

Nolina rodriguezii differs from *N. caxcana* in being taller with branching stems, and from *N. parviflora* in being smaller; leaves are similar in size to *N. parviflora* but narrower, and both longer and wider than *N. caxcana*; inflorescences have fewer branches than *N. parviflora* and are smaller; fruit size is in between *N. caxcana* and *N. parviflora*.

Arborescent, perennial plants, dioecious, 2–2.5 m tall, (10–) 28–30 cm in basal diameter, base widened, outer bark fissured, brown with rectangular ornamentation; branches 5 to 10. Branched above (not at) the base. Leaves green, reflexed at maturity, alternate, spirally arranged, marcescent along the branches; base 5.5–6 cm long, 4.5 cm wide, deltoid, thickened, whitish, 90–145 cm long, 0.9–1.5 cm wide, linear, chartaceous, apex long attenuated, margin denticulate, upper and lower surface with grooves; dry old leaves reflexed and persistent. Inflorescence terminal, appearing axillary due to displacement by the rapid growth of a new rosette, paniculate, erect to apically arched, lax up to 1.5 m long, 1–2 cm in basal diameter, basal bracts 46–56 cm long, 2 cm wide, lanceolate, adpressed, papery, decreasing in length towards the apex, margin entire or denticulate, light green to cream; primary branches approximately 14–21 (–29) cm long, branches aperture at 60–90°, secondary branches 3.5–5 cm long; bracteole 3–6 mm de long, 1.5–2 mm de wide, ovate to deltoid, margin fimbriate, membranaceous, whitish. Flowers unisexual. Staminate flowers 2 per node; campanulate; pistilodiums reduced; pedicels 1.5–2 mm long, articulating in the basal third; tepals 6, lanceolate, arranged in 2 series of 3, 2.5–3 mm long, 1.2–1.8 mm wide, free, almost equal, elliptical to obovate, apex short mucronate, whitish, with a pale green central strip, hyaline margin; stamens 6, free, filaments 1–1.5 mm long, shorter than the tepals, anthers 0.8–1 mm long; ovary superior. Pistillate flowers 2 per node, campanulate on pedicels 5–7 mm long, long articulated near the base; tepals lanceolate 2–3 mm long, 1 mm wide, cream with a dark midvein; ovary 3-lobed; stigmas 3-lobed; staminodes ca. 0.3 mm long. Fruit a 3-lobed capsule, 8–8.5 mm long, 9–10 mm wide in cross section, ellipsoidal sect, rounded distally, inflated, thin pericarp, the locules with one or two seeds. Seeds 3.4–3.8 mm long, 2.2–2.4 mm wide, subglobose, muriculate, dark brown.

Habitat and distribution:—*Nolina rodriguezii* inhabits tropical dry forest, oak forest and oak-pine forest, as well as the ecotone between tropical dry and oak forest. At the type locality it grows along with *Agonandra racemosa* (Candolle (1825: 41)) Standley (1920: 506), *Heliocarpus* Linnaeus (1753: 448), *Opuntia fuliginosa* Griffiths (1908: 262–263), *Zanthoxylum* Linnaeus (1753: 270), *Celtis caudata* Planchon (1848: 294), *Pouzolzia nivea* Watson (1887: 453), *Pittocaulon velatum* (Greenman 1914: 280–281) H. Robinson & Brettell (1972: 451), *Iresine* P. Browne (1756: 358–359) at 1650–2500 m.

Most of its populations are distributed in the state of Jalisco and a few individuals are found in Michoacán near the type locality (Fig. 5).

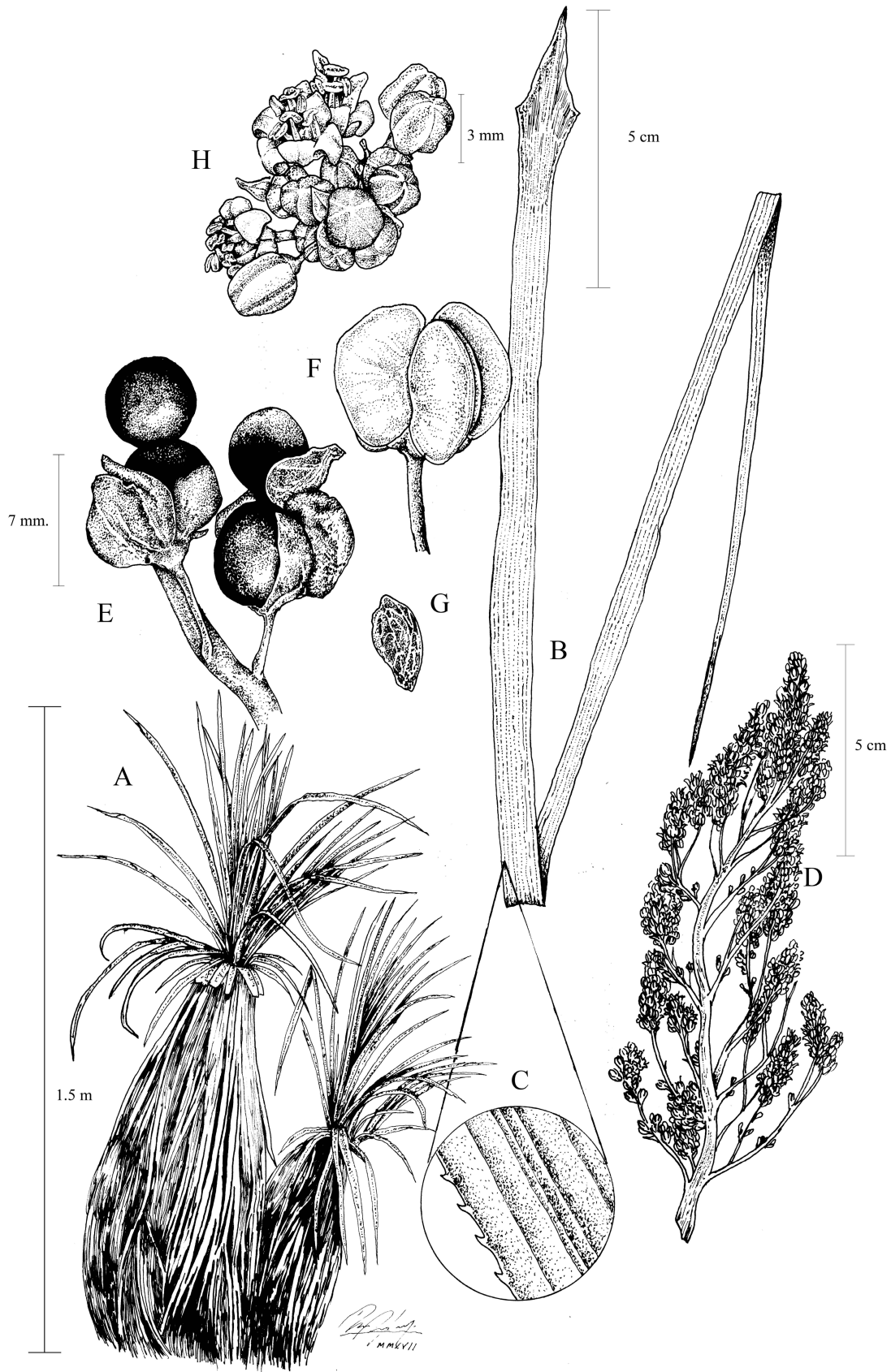


FIGURE 1. *Nolina caxcana*. A. Habit. B. Leaf. C. Leaf margin detail. D. Inflorescence fragment. E. Fragment, showing fruits with seeds. F. Fruit. G. Immature dry fruit. H. Staminate flowers. Drawing by Daniel Barba based on *P. Carrillo-Reyes et al.* 7749 (B–D, H) and *E. Ruiz-Sanchez et al.* 308 (E–G).



FIGURE 2. *Nolina caxcana*. A. Inflorescence fragment with fruits. B. Leaves and inflorescence with flowers. C. Typical habit growth. D. Staminate flowers. E Fruits with seeds. Photos by E. Ruiz-Sanchez (A, C, E) and P. Carrillo-Reyes (B, D).

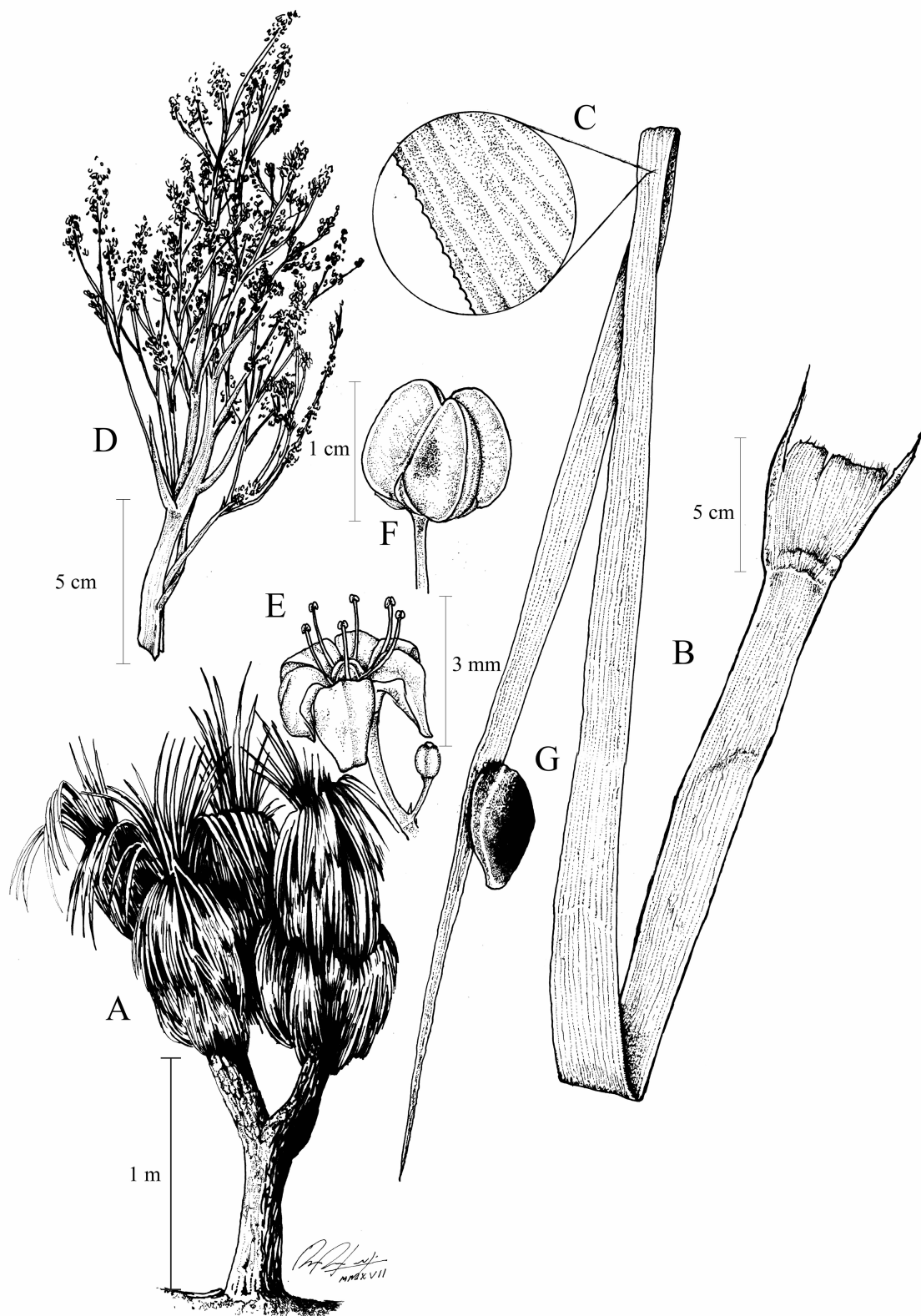


FIGURE 3. *Nolina rodriguezii*. A. Habit. B. Leaf. C. Margin leaf detail. D. Inflorescence fragment. E. Staminate flowers. F. Fruit. G. Immature dry seed. Drawing by Daniel Barba based on R. Guzmán & R. McVaugh 1324 (B–D, F–G) and L. Torres & P. Silva-Sáenz 103 (E).

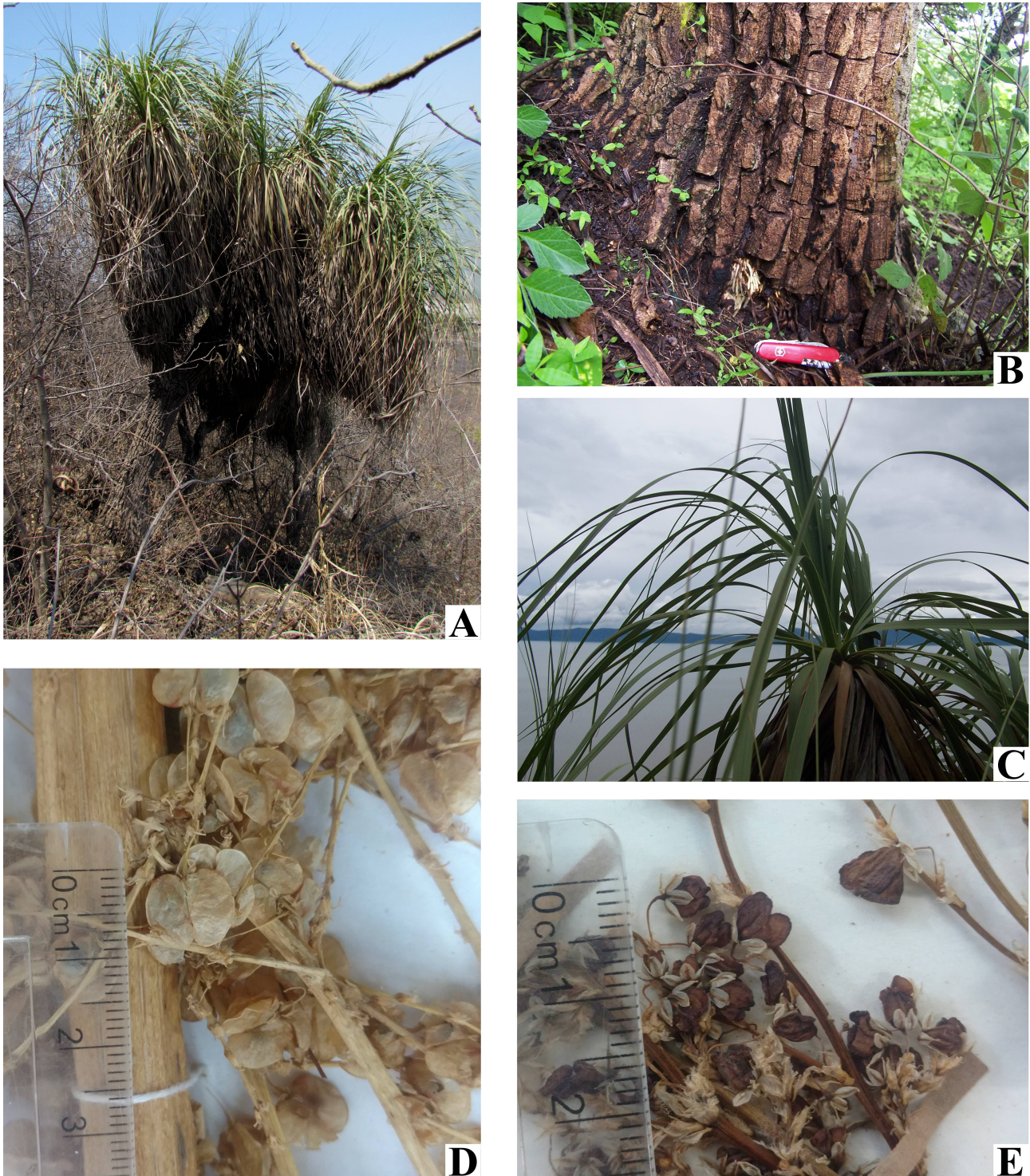


FIGURE 4. *Nolina rodriguezii*. A. Typical growth habit. B. Basal portion showing fissured outer bark. C. Leaves. D. Fruits (R. Guzmán & R. McVaugh 1324). E. Pistillate flowers with immature fruits (L. Torres & P. Silva-Sáenz 103). Photos by E. Ruiz-Sanchez (A–C).

Comparison:—On the basis of morphology, *Nolina rodriguezii* resembles *N. parviflora* and *N. caxcana* (Table 1). However, *N. rodriguezii* is in between *N. caxcana* and *N. parviflora* with respect to plant size. Leaves in *N. rodriguezii* are more similar in size to *N. parviflora* than *N. caxcana*. Fruit size (length/width; 8–8.5 × 9–10 mm) is also in between *N. caxcana* (4.5–6 × 6–8 mm) and *N. parviflora* (8–10 × 10–14 mm) (Table 1).

Due to its arborescent habit, narrow leaves up to 15 mm wide, inflorescence with open branches and large fruits, *Nolina rodriguezii* is located in the section *Arborescentes* (Trelease 1911: 422; Hochstätter 2010: 29).

Etymology:—The specific epithet honors Dr. Aarón Rodríguez from the Institute of Botany of the University of Guadalajara, in recognition for his achievements in studying the botanical diversity of Western Mexico, and his dedicated work as a teacher of young botanists.

Phenology:—Taking into account examined herbarium specimens, it is possible that the plants flower from August to November, and are in fruit from December to April.

Additional specimens examined:—MEXICO. Jalisco: Municipio Chapala, sierra de Ajijic, sendero El Chupinaya, en el parteaguas del cerro, 20°19'34" N, 103°16'29" W, 2400 m, 4 March 2017 (fr), *J. P. Ortiz-Brunel 103* (IBUG); Municipio Jilotlán de los Dolores, 7 km al NE de Huapala, camino a Jilotlán de los Dolores, [19°23'14"N, 103°06'13"W], 1100 m, 4 April 1988 (fr), *A. García Mendoza et al., 3684* (MEXU, QMEX); Municipio Jocotepec, barranca del Agua (La Tetita) ladera enfrente de Zapotitán de Hidalgo, [20°21'41"N, 103°26'31"W], 2500 m, 5 November 1988 (fl, fr), *J.A. Machuca 6025* (IBUG, IEB); Municipio Tapalpa, La Estancia 2800 m. al NNE de Tapalpa, [19°57'49"N, 103°45'17"W], 2220 m, 4 November 1993 (fl), *L. Torres & P. Silva-Sáenz 103* (IBUG); brecha Tapalpa-Venustiano Carranza, aprox. 24 km al S de Tapalpa, delante de la desviación a la Yerbabuena, [19°49'42"N, 103°47'52"W], 2000 m, 12 March 1989 (sterile), *A. Flores et al., 1514* (IBUG); Municipio Tequila, volcán de Tequila, [20°49'11"N, 103°51'10"W], 1980 m, 10 August 1969 (fl), *X. Madrigal 2314* (MEXU); Municipio Tequila, volcán de Tequila, [20°51'36"N, 103°49'12"W], 1980 m, 13 October 2005 (sterile), *L. Hernández, 5659* (QMEX); Municipio Tizapán el Alto, Los Arcos, límite de Jalisco y Michoacán por la carretera a Tizapán, [20°09'58"N, 102°57'07"W], 1300 m, 13 August 1988 (fl), *O. Reyna et al. 664* (IBUG, MEXU); Municipio Tlajomulco de Zúñiga, camino a la barranca El Caballito, al SE de San Miguel Cuyutlán, [20°21'12"N, 103°23'08"W], 2100 m, 12, January 1992 (fr), *R. Ramírez-Delgado & A. Rodríguez 2465* (IBUG, IEB, MEXU); Municipio Tuxcueca, Cerro Alto, al S de San Nicolás [20°10'15"N, 103°16'08"W], 2240 m, 12 December 1991 (fl), *J.A. Machuca 6025* (IEB).

IUCN Conservation assessment:—*Nolina rodriguezii* is known only from a few collections mainly restricted to the state of Jalisco. Using GeoCAT (Bachman *et al.*, 2011) the Extent of Occurrence (EOO) is 8,527.6 km², meanwhile the size of the Area of Occupancy is 32 km², based on cells of 2 km. A preliminary category of Vulnerable (VU (B2 bii)) is proposed following the IUCN (2012) criteria.

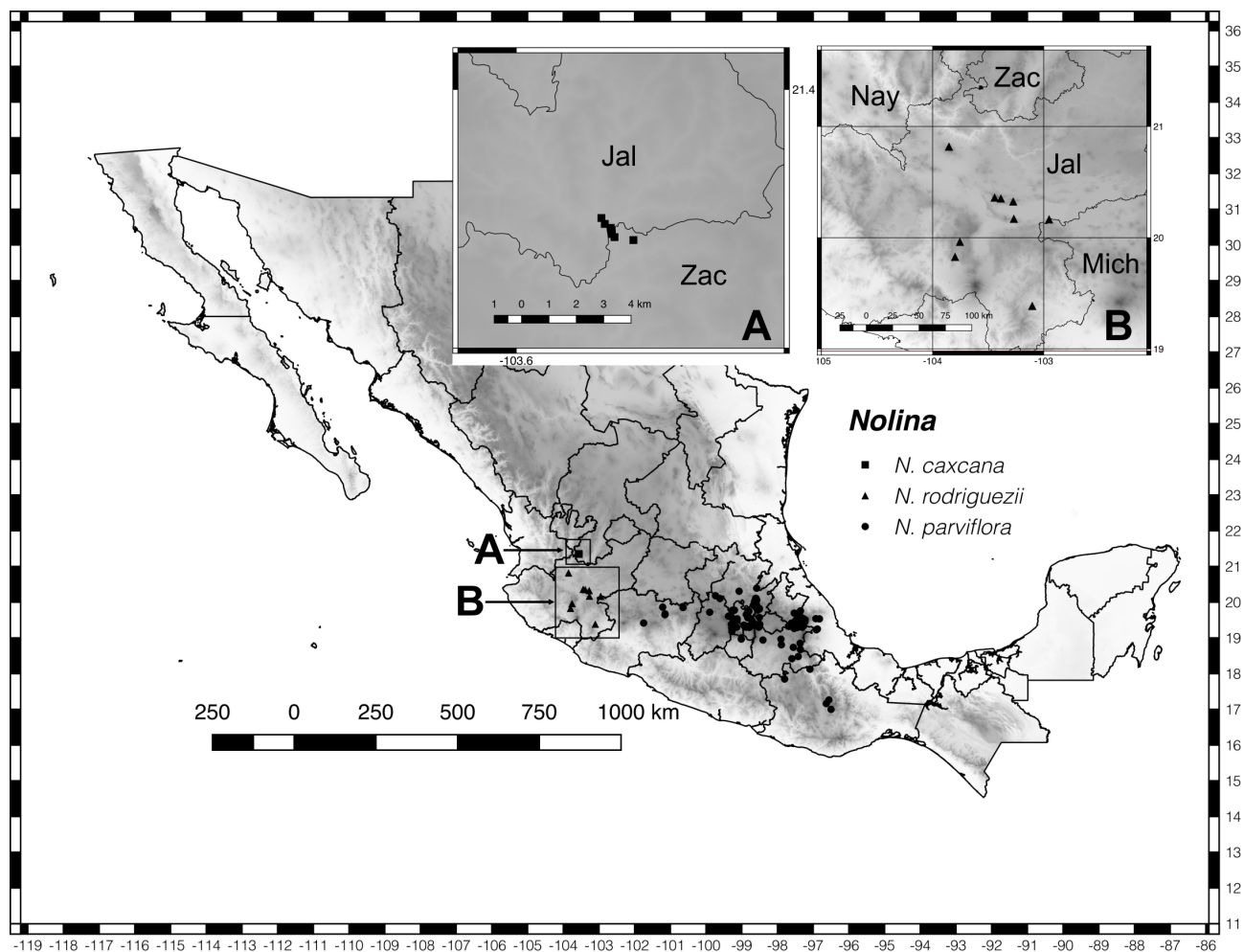


FIGURE 5. Geographical distribution of *Nolina caxcana* (black squares), *N. parviflora* (black circles), and *N. rodriguezii* (black triangles). Records are based on herbarium specimens.

Discussion

Nolina caxcana and *N. rodriguezii* are two new species segregated from, but morphologically resembling *N. parviflora*. In the treatment of Liliaceae for the Flora Novo-Galiciana, McVaugh (1989) recorded two *Nolina* species: *N. juncea* (Zuccarini (1845: 19)) Macbride (1918: 16) and *N. parviflora*, both now considered *N. parviflora* from McVaugh's treatment. Specimens of *N. rodriguezii* and *N. caxcana* were not included in McVaugh's treatment, as the first collection of *N. caxcana* was made in 2003 only.

There is molecular evidence from chloroplast and nuclear markers that *N. parviflora* populations are divided into two well-supported clades, one corresponding to *N. parviflora* s.s. and the second comprising populations from Jalisco and Zacatecas (Ruiz-Sanchez & Specht, 2013). These are here described as *N. caxcana* and *N. rodriguezii*, respectively. There is additional evidence of ecological divergence among populations from these taxa based on climatic variables (Ruiz-Sanchez & Specht, 2014). Ruiz-Sanchez & Specht (2014) found no evidence of spatial or genetic connectivity among populations of *N. parviflora* with the populations of Jalisco (*N. rodriguezii*) and Zacatecas (*N. caxcana*), and here we corroborate those molecular and ecological findings with morphological comparisons, describing the two new *Nolina* species.

Recently, two *Nolina* species endemic to Mexico have been described based on morphological comparisons (*N. excelsa* and *N. hibernica*), both related to *N. parviflora* or *N. nelsonii* (Hochstätter and Donati, 2010; García-Mendoza et al. 2012). With the description here of *N. caxcana* and *N. rodriguezii*, the number of *Nolina* species endemic to Mexico increases to eighteen. However, the number of endemic species could increase even more in the next years with additional botanical fieldwork and the collection of vegetative and reproductive material of *Nolina* populations.

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References

- Bachman, S., Moat, J., Hill, A.W., de la Torre, J. & Scott, B. (2011) Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool, Version BETA. E-Infrastructures for data publishing in biodiversity science. *ZooKeys* 150: 117–126. <https://doi.org/10.3897/zookeys.150.2109>
- Baker, J.G. (1877) *The gardeners' chronicle & agricultural gazette*. Gardeners Chronicle, London, 201 pp.
- Browne, P. (1756) *The Civil and Natural History of Jamaica in Three Parts*. Printed for the author, London, pp. 1–503. <https://doi.org/10.5962/bhl.title.10826>
- Candolle, A. de. (1825) *Prodromus Systematis Naturalis Regni Vegetabilis*. Sumptibus Sociorum Treuttel et Würtz, Paris, 644 pp.
- Donati, D. (2011) Una nuova specie appartenente al genere *Nolina* Michx: *Nolina azureogladiata* D. Donati sp. nov. *Piante Grasse* 31: 52–58.
- Engler, H.G.A. (1880) Diagnosen neuer Burseraceae un Anacardiaceae. *Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzengeographie* 1 (1): 41–47.
- Engler, H.G.A. (1883) Burseraceae. *Monographiae Phanerogamarum* 4: 1–169.
- Espejo-Serna, A. & López-Ferrari, A.R. (1996) *Las Monocotiledóneas Mexicanas. Una Sinopsis Florística. 1. Lista de Referencia*. Parte VI. Dioscoreaceae a Nolinaceae. Consejo Nacional de la Flora de México-Universidad Nacional Autónoma Metropolitana Iztapalapa-Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México, D.F.
- García-Mendoza, A., Solano, E. & Rivera-Lugo, M. (2012) *Nolina excelsa* (Nolinaceae) una especie nueva del estado de Oaxaca, México.

Botanical Sciences 90: 21–25.

<https://doi.org/10.17129/botsci.382>

- Greenman, J.M. (1914) Descriptions of North American Senecioneae. *Annals of the Missouri Botanical Garden* 1: 263–290.
<https://doi.org/10.2307/2990077>
- Griffiths, D. (1908) Illustrated studies in the genus *Opuntia*. *Annual Report of the Missouri Botanical Garden* 19: 259–272.
<https://doi.org/10.5962/bhl.title.818>
- Hemsley, W.B. (1879) *Biologia Centrali-Americana; or, contributions to the knowledge of the fauna and flora of Mexico and Central America*. Vol. I. Porter, Dulau, London, 576 pp.
- Hemsley, W.B. (1884) *Biologia Centrali-Americana; or, contributions to the knowledge of the fauna and flora of Mexico and Central America*. Vol. III. Porter, Dulau, London, 711 pp.
- Hernández-Sandoval, L. (2018) *Catálogo nomenclatural de la familia Nolinaceae Nakai en México*. Universidad Autónoma de Querétaro. Facultad de Ciencias Naturales. Bases de datos SNIB-CONABIO Proyecto No. KT011. México, Ciudad de México.
- Hernández-Sandoval, L. (2019) Dos especies nuevas de *Nolina* (Asparagaceae) del centro de México. *Phytoneron* 12: 1–9.
- Hochstätter, F. & Donati, D. (2010) Una nuova specie appartenente al genere *Nolina*: *Nolina hibernica* Hochstätter & Donati. *Piante Grasse* 30: 72–77.
- Hochstätter, F. (2010) *Il Genere/The genus Nolina (Nolinaceae)*. Gli Speciali di Piante Grasse. Associazione Italiana Amatori delle Piante Succulente, Bologna.
- Humboldt, A., Bonpland, A. & Kunth, K.S. (1825) Burseraceae. *Nova genera et species plantarum* 7: 27.
- IUCN Standards and Petitions Subcommittee (2012) Guidelines for using the IUCN Red List categories and criteria. Version 12. Prepared by the Standards and Petitions Subcommittee in February 2012. Available from: <http://jr.iucnredlist.org/documents/RedListGuidelines.pdf> (accessed 1 June 2016)
- Kim, J.-H., Kim, D.-K., Forest, F., Fay, M.F. & Chase, M.W. (2010) Molecular phylogenetics of Ruscaceae sensu lato and related families (Asparagales) based on plastid and nuclear DNA sequences. *Annals of Botany* 106: 775–790.
<https://doi.org/10.1093/aob/mcq167>
- Kunth, C.S. (1816) *Voyage de Humboldt et Bonpland. Sixième Partie. Botanique. Nova Genera et Species Plantarum*. (quarto ed.) 1. Ed. Folio. Maze, Paris.
- Lemaire, C. (1861) Genre nouveau de la famille des Asparagacées: *Beaucarnea* (Dasyliiriaceae nob.) *L'Illustration horticole* 8 (Misc.): 57–62.
- Liebmann, F.M. (1854) Oversigt over det kongelige danske videnskabernes selskabs forhandling og dets medlemmers arbejder. *Bulletin de l'Académie royale des sciences et des lettres de Danemark*: 179.
- Linnaeus, C. (1753) *Species plantarum* (Vol. 1). Impensis GC Nauk.
<https://doi.org/10.5962/bhl.title.669>
- Macbride, J.F. (1918) Further new or otherwise interesting Liliaceae. *Contributions from the Gray Herbarium of Harvard University* 56: 1–20.
- Martínez, M. (1946) Los *Juniperus* mexicanos. *Anales del Instituto de Biología, Universidad Nacional Autónoma de México* 17: 3–128.
- McVaugh, R. (1989) *Liliaceae. Flora Novo-Galiciana. A descriptive account of the vascular plants of western Mexico*. Vol.15. The University of Michigan Herbarium, Ann Arbor, pp. 20–293.
- Michaux, A. (1803) *Genre nouveae de la famille des Asparagacées: Beaucarnea. Flora Boreali-Americana: sistens? caracteres plantarum quas in America septentrionali collegit et detexit*. Vol. 1. Bibliopola Jouanaux junior.
- Née, L. (1801) Descripción de varias especies nuevas de Encina (*Quercus* de Lineo) *Anales de Ciencias Naturales* 3: 260–278.
- Planchon, J.E. (1848) Sur les Ulmacées. *Annales des Sciences Naturelles. Botanique, sér. 3* 10: 244–296.
- Robinson, H.E. & Brettell, R.D. (1973) Studies in the Senecioneae (Asteraceae) I a new genus *Pittocaulon*. *Phytologia* 26 (6): 451–454.
- Rojas-Piña, V., Olson, M.E., Alvarado-Cárdenas, L.O. & Eguiarte, L.E. (2014) Molecular phylogenetics and morphology of *Beaucarnea* (Ruscaceae) as distinct from *Nolina*, and the submersion of *Calibanus* into *Beaucarnea*. *Taxon* 63: 1193–1211.
<https://doi.org/10.12705/636.31>
- Ruiz-Sanchez, E. & Specht, C.D. (2013) Influence of the geological history of the Trans-Mexican Volcanic Belt on the diversification of *Nolina parviflora* (Asparagaceae: Nolinoideae). *Journal of Biogeography* 40: 1336–1347.
<https://doi.org/10.1111/jbi.12073>
- Ruiz-Sanchez, E. & Specht, C.D. (2014) Ecological Speciation in *Nolina parviflora* (Asparagaceae): Lacking Spatial Connectivity along of the Trans-Mexican Volcanic Belt. *Plos One* 9: e98754.
<https://doi.org/10.1371/journal.pone.0098754>
- Seberg, O., Petersen, G., Davis, J.I., Pires, C.P., Stevenson, D.W., Chase, M.W., Fay, M.F., Devey, D.S., Jørgensen, T., Sytsma, K.J. & Pillon, Y. (2012) Phylogeny of the Asparagales based on three plastid and two mitochondrial genes. *American Journal of Botany* 99: 875–889.

<https://doi.org/10.3732/ajb.1100468>

- Standley, P. (1920) The North American species of *Agonandra*. *Journal of the Washington Academy of Sciences* 10: 505–509.
- Trelease W. (1911) The desert group Nolineae. *Proceedings of the American Philosophical Society* 50: 404–443.
- Trelease W. (1920) Liliaceae. In: Standley, P. Trees and shrubs of Mexico. *Contributions from the United States National Herbarium* 23 (1): 87–101.
- Trelease W. (1922) *Quercus*. In: Standley, P. Trees and shrubs of Mexico. *Contributions from the United States National Herbarium* 23 (2): 171–198.
- Villaseñor, J.L. (2016) Checklist of the native vascular plants of Mexico. *Revista Mexicana de Biodiversidad* 87: 559–902.
<https://doi.org/10.1016/j.rmb.2016.06.017>
- Walter, T. (1788) *Flora caroliniana: secundum systema vegetabilium perillustris Linnaei digesta; characteres essentielles naturalesve et differentias veras exhibens; cum emendationibus numerosis: descriptionum antea evulgatarum: adumbrationes stirpium plus mille continens: necnon, generibus novis non paucis, speciebus plurimis novisq. ornate*. Sumptibus J. Fraser Prostant venales apud J. Wenman, in Vico vulgo dicto Fleet-street, Londini, 263 pp.
<https://doi.org/10.5962/bhl.title.9458>
- Watson, S. (1887) Contributions to American Botany. *Proceedings of the American Academy of Arts and Sciences* 22: 396–481.
<https://doi.org/10.2307/20021520>
- Zuccarini, J.G. (1838) Über einige merifanifche Agaven. *Allgemeine Gartenzeitung* 6: 257–259.
- Zuccarini, J.G. (1845) *Plantarum novarum vel minus cognitarum, quae in horto botanico herbarioque regio Monacensi servantur, Fasc. V. Abhandlungen der Mathematisch-Physikalischen Classe der Königlich Bayerischen Akademie der Wissenschaften* 4. Bayerische Akademie der Wissenschaften, pp. 3–36.