Revista peruana de biología 31(3): e27800 (octubre 2024)
doi: https://dx.doi.org/10.15381/rpb.v31i3.27800
ISSN-L 1561-0837; eISSN: 1727-9933
Universidad Nacional Mayor de San Marcos

Trabajos originales

Revisiting *Loxanthocereus riomajensis*, lectotypification, biogeography and conservation status of an endemic species from Arequipa, Peru

Revisando a *Loxanthocereus riomajensis*, lectotipificación, biogeografía y estado de conservación de una especie endémica de Arequipa, Perú

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Citación

Pauca-Tanco GA, Hoxey P. 2024. Revisiting Loxanthocereus riomajensis, lectotypification, biogeography and conservation status of an endemic species from Arequipa, Peru. Revista peruana de biología 31(3): ***e27800*** 001- 016 (octubre 2024). doi: https://dx.doi.org/10.15381/rpb.v31i3.27800

Presentado: **05/04/2024**
Aceptado: **22/09/2024**
Publicado online: **14/10/2024**

Editor: **Leonardo Romero**

Abstract

This study aims to clarify the taxonomy of *Loxanthocereus riomajensis*, as well as to understand its actual and potential geographic distribution, and to present its conservation status. Specialized literature was reviewed, and field visits were conducted. The collected data, including herbarium samples, presence records, and additional information, were used to describe the species in detail, create a geographical distribution map, generate potential distribution models using the MaxEnt algorithm, and assess its conservation status using IUCN considerations. The results demonstrate that morphologically, *L. riomajensis* is an independent species endemic to the departament of Arequipa, found in the provinces of Condesuyos and Caylloma, spanning an altitudinal range from 1600 to 2100 m asl. The potential distribution covers an area of 1135.3 km², in the provinces of Condesuyos, Castilla, La Unión, Caravelí, Caylloma, and Arequipa. Regarding its conservation status, it is classified as endangered (EN). Finally, a lectotype is designated.

Keywords:
Biogeography, conservation, MaxEnt, taxonomy, potential distribution.

Resumen

Este estudio tiene como objetivo aclarar la taxonomía de *Loxanthocereus riomajensis*, así como comprender su distribución geográfica real y potencial, presentado también su estado de conservación. Se revisó literatura especializada y se realizaron visitas de campo. Los datos recolectados, que incluyen muestras de herbario, registros de presencia e información adicional, se utilizaron para describir la especie en detalle, crear un mapa de distribución geográfica, generar modelos de distribución potencial mediante el algoritmo MaxEnt, y evaluar su estado de conservación utilizando las consideraciones de la IUCN. Los resultados demuestran que morfológicamente, *L. riomajensis* es una especie independiente y endémica del departamento de Arequipa, encontrándose en las provincias de Condesuyos y Caylloma, abarcando un rango altitudinal desde los 1600 hasta los 2100 m snm. La distribución potencial cubre un área de 1135.3 km², en las provincias de Condesuyos, Castilla, La Unión, Caravelí, Caylloma y Arequipa. En cuanto a su estado de conservación, se clasifica como en peligro (EN). Por último, se designa un lectotipo.

Palabras clave:
Biogeografía, conservación, MaxEnt, taxonomía, distribución potencial.

Introduction

The Cactaceae is a botanical family of predominantly American distribution, with 124 – 236 genera and up to 1900 species (Hunt et al. 2006, Anderson 2001). They inhabit environments ranging from deserts to Amazonian jungles (Anderson, 2001). Several centers of diversity have been identified, with the deserts of Peru being one of them (Trabuco et al. 2022). Currently, Peru hosts a total of 42 genera and 270 species of cacti (Ostolaza 2019), with 7 genera being endemic, among which *Loxanthocereus* Backeb. stands out as one of the most species-rich, with 18 species (Ostolaza 2019, Arakaki et al. 2006).

Loxanthocereus (from the Greek "*loxo*": oblique and the Latin "*xantho*": flower) is a genus distributed on the western slopes of the Peruvian Andes, ranging from of La Libertad Department in the north to the Tacna Department in the south (Ostolaza 2019, Hoxey 2020). It thrives in desert ecosystems such as coastal hillsides (*lomas*), arid valleys, and xerophilic shrublands in the Andean foothills (Ostolaza 2019, Pauca & Quipuscoa 2017). These cacti can be found at elevations ranging from 200 to approximately 3500 m above sea level (Arakaki et al. 2006, Brako & Zarucchi 1993). Taxonomically, the status of *Loxanthocereus* has been a subject of debate. Some authors consider it part of *Cleistocactus* Lem. (Hunt et al. 2006, Anderson 2001) or *Borzicactus* Riccob. (Hunt 2016), while others argue that it is an independent genus (Ostolaza 2019, Lodé 2015, Ritter 1981). The genus *Loxanthocereus* has flowers adapted for hummingbird pollination with unique floral characteristics, such as the absence of hairs at the base of the stamens, a long nectar chamber, and a rudimentary diaphragm. Unlike *Cleistocactus*, the flowers always open wide at anthesis, and in comparison, to *Borzicactus*, the floral tubes of *Loxanthocereus* are thinner (Ostolaza 2019). Furthermore, molecular studies by Arakaki (2002) suggest that *Loxanthocereus* should be recognized as independent from *Cleistocactus* and *Borzicactus*.

In terms of species richness, *Loxanthocereus* is best represented in the Departments of Lima and Arequipa, with ten and six species, respectively (Ostolaza 2019, Pauca & Quipuscoa 2017). In the case of Arequipa, out of the six recorded species, *L. gracilis* (Akers & Buining) Backeb*., L. riomajensis* Rauh & Backeb., and *L. jajoianus* (Backeb.) Backeb. are endemic to the department, distributed in the coastal zone, arid valleys, and foothills, respectively (Ostolaza 2019, Pauca & Quipuscoa 2017). There has not been a consensus on the status of *L. riomajensis.* Some authors consider it synonymous with *L. sextonianus* (Backeb.) Backeb. (Anderson 2011, Hunt et al. 2006, Hunt 1999, Brako & Zarucchi 1993) or a synonym of *Borzicactus jajoanus* Backeb. (The Caryophyllales Network 2024), while others recognize it as a valid species (Ostolaza 2019, Pauca & Quipuscoa 2017). Additionally, it is not listed as an endemic species in Arakaki et al. (2006). However, this is not surprising due to the confusion surrounding *L. riomajensis* since its first description in 1956. The protologue (Backeberg 1956) included only vegetative characters and even suggested it might be a species of *Haageocereus* Backeb. This research aims to clarify the taxonomic status of *L. riomajensis*, as well as analyze its current distribution and conservation situation.

This work focuses on the lectotypification of *Loxanthocereus riomajensis*, after evaluating samples collected from both the type locality and adjacent areas. Geographic coordinates of the specimens observed during this study, as well as those housed in herbarium collections and museums such as HEID, were used to generate a distribution map for *L. riomajensis*.

Materials and methods

Type locality. The species is in the Pacaychacra sector, Iray, Condesuyos, Arequipa, (at approximately 15°53'31.36" S, 72°34'20.69" W) and an altitude of 1740 m (Fig. 1). This area is a plain situated on the western edge of the Pacaychacra ravine, which from southwest to northeast transitions into terrain with steep slopes that are difficult to climb. The climate is typically arid, with two distinct seasons, wet and dry. The wet season occurs during the austral summer months, with an average precipitation of 15.9 mm and an average temperature of 18.9 °C; on the other hand, the dry season occurs during the rest of the year, with an average precipitation of 1.4 mm and an average temperature of 17.9 °C (Pauca-Tanco et al. 2023). The soils lack developed horizons and predominantly feature a sandy-clay texture, with a notable presence of scattered rocks on the surface (INRENA 1996). Regarding vegetation, the area is dominated by the columnar cactus *Neoraimondia arequipensis* (Meyen) Backeb*.*, with some scattered shrubs such as *Ambrosia artemisioides* Meyen & Walp. and other cacti like *Armatocereus riomajensis* Rauh & Backeb., *Weberbauerocereus rauhii* Backeb., *Haageocereus pluriflorus* Rauh & Backeb., and *Cumulopuntia crassicylindrica* (Rauh & Backeb.) F. Ritter ex Eggli; annual plants are mainly represented by Poaceae such as *Aristida adscensionis* L.

Study area. The study was conducted in the Arequipa Department, encompassing the arid valleys of the Majes river, Santa Isabel de Siguas, and Ocoña river, along an attitudinal gradient from 1000 to 2500 m, within the provinces of Arequipa, Caravelí, Castilla, Caylloma, Condesuyos and La Unión (Fig. 2). The terrain in the study area is rugged, characterized by steep slopes and dry gullies that eventually connect to their respective main valleys. The soils are categorized as dystrophic leptosol and lithic leptosol, characterized by being of recent formation, with only a superficial horizon due to their location in high slope areas where the bedrock decomposes due to erosion (INRENA 1996). In this landscape, the soil is sandy at the bases and edges of the ravines, with high proportion of pebbles. While ascending through the gullies, small plains may be present in some areas, where the terrain becomes undulating, and the soil is a mixture of sand and clay, with scattered rocks. However, towards the valley slopes, the terrain becomes rocky and steep, making access difficult. However, at higher elevations (between 2000 and 2500 meters), to harness the slopes,

Figure 1. Panoramic view of the type locality: Pacaychacra, Iray, Condesuyos, Arequipa. Photo by Anthony Pauca-Tanco.

terraces known as 'andenes' are used for cultivation. According to Holdrige's life zones, the study area is located in the lower subtropical perarid-montane desert, in the Andean shrubland ecosystem, being the dominant vegetation annuals and xerophytic shrubs (INRENA 1995, MINAM 2019). The climate is typically arid, with a maximum average temperature of 16.4 °C and a minimum annual average of 10.6 °C, precipitation has a maximum annual average of 102.2 mm and a minimum average of 63.5 mm. The solar radiation is high and rainfall scarce during the austral summer (humidity from the Andean transverse), but during the winter, occasional fine rainfall may also occur (humidity from the coast), reaching up an elevation of 1700 m (Pauca-Tanco et al. 2023).

Field visits. Field trips were conducted to the Arequipa Department during the austral summers of 2022 and 2023, across the provinces of Caravelí, Castilla, Caylloma, Condesuyos and, La Unión, and spanning elevations from 0 to 4200 m. Routes followed are depicted in Figure 2 (red lines). The type locality for *L. riomajensis*, Pacaychacra (Iray, Condesuyos), was the first site visited. Subsequent field trips aimed to verify the presence of the target species in the arid valleys of the Arequipa Department. Notable visits included the Yura Valley and the road to Huanca, in the Arequipa province; the Siguas River valley, Huacán gorge, and the lower reaches of the Colca Canyon in Caylloma, including Soro, Malata, the road to Choco, and the Canco valley. In Castilla, surveys covered Ayo, the road to Andahua, and the route from Viraco to Aplao via Uñón. In Condesuyos, the Aplao - Chuquibamba route was followed, touching base at locales such as Pacaychacra, Arequipilla, and Iray, progressing through the Ocoña valley to areas including San Juan de Chorunga and La Barrera, and then ascending to Yanaquihua and Ispacas. Additional observations were made in Chichas and Salamanca. In La Unión, a transect from Cotahuasi to Velinga was executed, and in Caravelí, the Atico - Caravelí route was explored.

During the fieldwork, upon encountering populations of the species under study, photographs were taken; we also made *in situ* measurements of plant attributes such as stem height and diameter, and registered flower and fruit dimensions and colors. GPS coordinates of these populations were logged alongside notes on the surrounding flora.

For specimen collection, segments of stems, flowers, and fruits were harvested. In the field, stems were stored in labeled boxes, flowers were prepared in a botanical press with a specific code, and fruits were kept in suitably labeled containers. In the laboratory, stems were sectioned both transversely (to count the number of ribs) and longitudinally (to examine spines and areoles). Parenchyma was extracted from the longitudinal sections, and both types of sections were subsequently dried in a botanical press with either salt or borax to accelerate drying and prevent mold growth. The fruits were processed to remove the pulp and seeds; the seeds were then cleansed of mucilage and preserved. Flowers and de-pulped fruits were also dried in a botanical press. The samples were regularly checked, and the absorbent

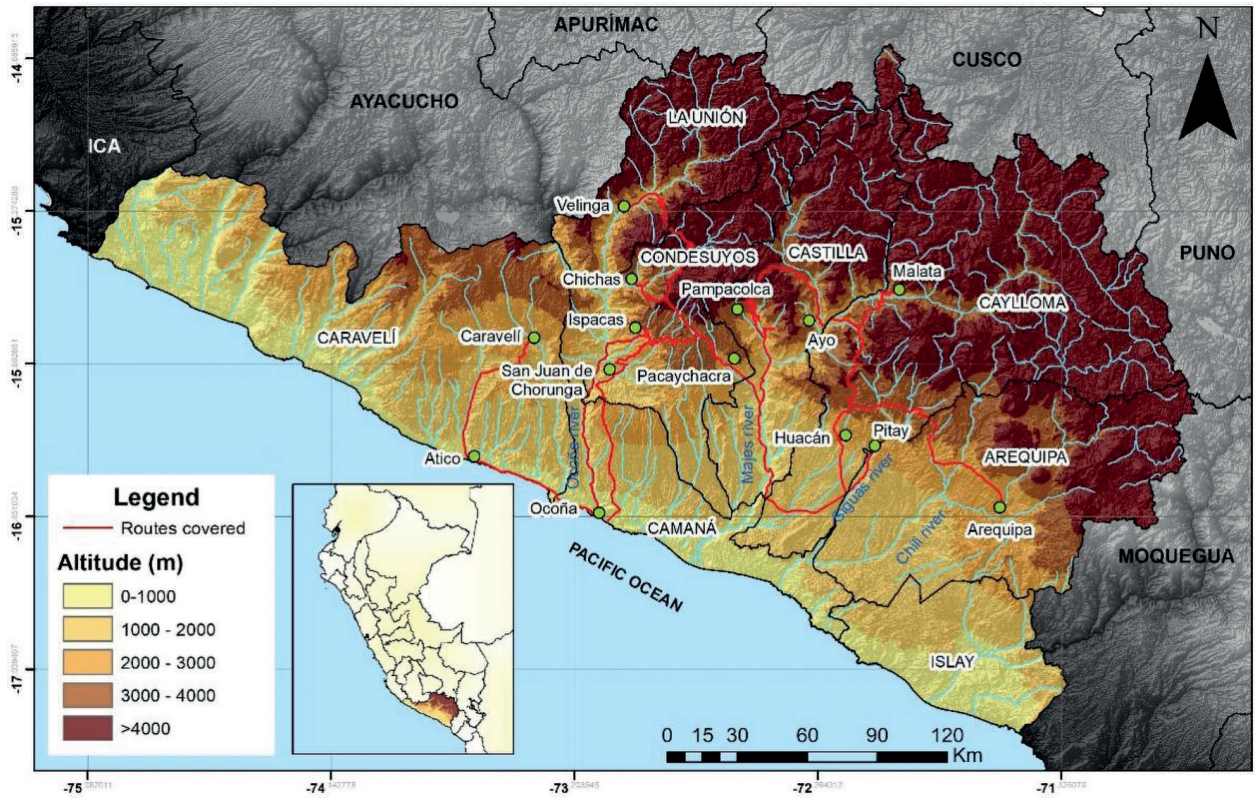

Figure 2. Map of Arequipa showing the study area.

paper was replaced as needed to ensure proper drying. All collected specimens were deposited in the HSP Herbarium (Herbario Sur Peruano) (Thiers 2024).

Taxonomic review. For the taxonomic review, digital databases of herbaria such as NY, US, F, KEW, U, ZSS, HUSA, and B (Thiers 2024) were consulted, as well as online databases such as GBIF (https://www.gbif.org) and iNaturalist (https://www.inaturalist.org). Relevant literature was reviewed, including the species' protologue (Backeberg 1956) and specialized studies (Ostolaza 2019, Pauca & Quipuscoa 2017, Hunt et al. 2006, Anderson 2005, Ritter 1981, Backeberg 1979, Backeberg 1959, Rauh 1958). The HEID herbarium was specifically consulted for the "The Werner Rauh Heritage Project" (Koch et al. 2013) to obtain details on the specimen deposited by Werner Rauh (K153 1956), mentioned in Rauh (1958), and a photograph from the same source was analyzed. The description of the species in this work is based on samples of stems and flowers deposited in the HSP herbarium, as well as on field observations. Finally, the designation of a lectotype was based on Chapter II, Section 2, and Article 9.3 of the International Code of Botanical Nomenclature (IAPT) (Turland et al. 2018).

Geographic Distribution Map and Potential Distribution Model. The geographical distribution map was created using presence points obtained after reviewing the aforementioned herbaria (if it was possible to infer or georeferenced them) and GPS data collected during field visits. The geospatial data (longitude and latitude) were recorded and organized in a spreadsheet, which was then exported to QGIS ver. 3.28. The final presentation of the maps was prepared using the appropriate layers in the software.

The potential distribution model was developed using the Wallace package ver. 2.0 (Kass et al. 2023), which integrates the MaxEnt algorithm ver. 3.4.4 (Phillips et al. 2006). MaxEnt (Maximum Entropy) is a statistical algorithm that uses only presence data and environmental variables. Proper calibration and data input are crucial for accurate modeling (Elith et al. 2011). The modeling processes were carried out in R using RStudio (RStudio team 2020), following the recommendations of Sillero et al. (2021) and Anderson (2015).

Bioclimatic surfaces proposed by Pauca-Tanco et al. (2023) were used, with a resolution of approximately 1 km^2. These surfaces were interpolated using the available climate data taken *in situ*, as well as relevant local climate covariates (orientation, slope, cloud coverage, and topographic moisture index). Fifteen bioclimatic variables were used (Table 1) excluding those that represent temperature and precipitation combinations (bio8, bio9, bio18, and bio19) due to discontinuities (Escobar et al. 2014). To avoid overfitting, presence data were treated to remove duplicates and ensure that each presence point was at least 1 km apart using the spThin package in R (Aiello-Lammens et al. 2015, Boria et al. 2014). The calibration area was established based on the species' potential dispersal area (Peterson et al. 2011). This means that the geographic presence points obtained for the species under study were used to create a minimum convex polygon, to which a buffer of 0.5 degrees was applied. Model evaluation was performed using the

Table 1. List of variables used in the potential distribution analysis. These are derived from the interpolation of monthly averages of maximum and minimum temperatures and precipitation data, at a resolution of 1 km². * Variables that were not used for the analysis.

N°	Code	Description
1	Bio1	Annual Mean Temperature (°C)
2	Bio2	Mean Diurnal Temp Range (Mean of monthly (max temp—min temp)) (°C)
3	Bio3	Isothermality (Bio2/Bio7) (x 100)
4	Bio4	Temperature Seasonality (standard deviation x 100)
5	Bio5	Max Temperature of Warmest Month (°C)
6	Bio6	Min Temperature of Coldest Month (°C)
7	Bio7	Temperature Annual Range (Bio5–Bio6) (°C)
8	Bio8*	Mean Temperature of Wettest Quarter (°C)
9	Bio9*	Mean Temperature of Driest Quarter (°C)
10	Bio10	Mean Temperature of Warmest Quarter (°C)
11	Bio11	Mean Temperature of Coldest Quarter (°C)
12	Bio12	Annual Precipitation (mm)
13	Bio13	Precipitation of Wettest Month (mm)
14	Bio14	Precipitation of Driest Month (mm)
15	Bio15	Precipitation Seasonality (Coefficient of Variation)
16	Bio16	Precipitation of Wettest Quarter (mm)
17	Bio17	Precipitation of Driest Quarter (mm)
18	Bio18*	Precipitation of Warmest Quarter (mm)
19	Bio19*	Precipitation of Coldest Quarter (mm)

ENMeval package (Muscarella et al. 2014) with a spatial partition of a chessboard (k=2), as no model transfer to past or future projections was intended. Models were generated using classes L, Q, H, P, and their combinations, with regularization multipliers ranging from 0.5 to 1.

Model selection was based on the resulting maps, considering the consistency of the areas with the species' habitat. Additionally, statistical values such as AUC (Area Under the Curve), omission rate, and Boyce index were used. Higher AUC values and lower omission rates and Boyce index values indicate more robust models. The potential distribution area was determined using the 10 percent presence in the training data.

Conservation status. The conservation status was assessed using criteria B of the International Union for Conservation of Nature (IUCN) (IUCN 2024). In this case, criterion B was evaluated using the GeoCat program (Bachman et al. 2011), considering the Extent of Occurrence (EOO) and the Area of Occupancy (AOO). Additionally, criterion B also took into account the number of locations or subpopulations and the observed decline in individuals.

Results

Taxonomy

Loxanthocereus ***Backeb.***

Cact. Jahrb. Deutsch. Kakt. Gess. 24, 1937.

Type: *Loxanthocereus acanthurus* (Vaupel) Backeb., Jahrb. Deutsch. Kakteen-Ges. 1937, 1st Teil, 24 (1937). ≡ Cereus *acanthurus* Vaupel, Bot. Jahrb. Syst. 50 (2-3, Beibl. 111): 13 (1913). ≡ *Borzicactus acanthurus* (Vaupel) Britton & Rose, Cactaceae (Britton & Rose) 2: 161, pl. 25 (1920). ≡ *Cleistocactus acanthurus* (Vaupel) D.R. Hunt, Bradleya 5: 92 (1987).

Plants with erect, prostrate, decumbent, or ascending stems. Areoles usually circular or oval, often separated by a V-shaped notch; typically small, rarely up to 1 cm in diameter. The spines are numerous, and variable in length and thickness. Flowers zygomorphic, opening during the day and night, without fragrance; scarlet, red, or red-orange in color; perianth tube narrow, commonly S-shaped; tube covered by scales with long hairs originating from the axils (between the scale and the tube); numerous stamens with yellow anthers or sometimes purple, reduced or absent ring of hairs at the base of the stamens; stig-

ma with several stigma lobes, typically exerted; nectar chamber elongated, closed by the filaments of the inner circle of stamens, with a rudimentary diaphragm. Fruits relatively small, with white pulp, covered with scales and hairs. Seeds small, generally with a matt luster.

Endemic to Peru, distributed along the coast and western slopes of the Peruvian Andes, from La Libertad to Tacna, reaching up to 3600 m. Within the genus, there are approximately 15 to 25 species (Ostolaza 2019, Lodé 2015, Ritter 1981; Backeberg 1959; Rauh 1958).

Lectotification

Loxanthocereus riomajensis Rauh & Backeb.

Descr. Cact. Nov. (1): 15, 1957.

TYPE: PERU. Arequipa, Condesuyos, Iray, *Peruvia australis* (Majes River Valley), in dry sloping places, 1500 m asl, ca. 05 October 1956, *W. Rauh K153 (1956)* (Lectotype, here designated, HEID702366!) (Fig. 3).

Description. Plants up to 1.5 m tall with basal branching. Stems erect, sometimes ascending, 3.8–5 cm in diameter. Ribs 13–15, 8 mm wide, and 3–4 mm tall. Areoles covered with grayish-white felt, 3–5 mm in diameter. Spines up to 35 per areole, initially brown or yellow later gray with age. Central spines 1–2, 15–22 mm long. Radial spines 20–33, 3–10 mm long. Flowers with diurnal and nocturnal anthesis, zygomorphic, with a curved, S-shaped tube, ranging from brownish (in the pericarpel) to red-orange (inner perianth segments), 79–86 mm long and 22.4–31.5 mm in diameter at anthesis. Pericarpel brownish, 8–12 mm in diameter, covered with small brown deltoid scales, from which whitish-brown hairs emerge. Hypanthium tube 6.9–7.4 mm in diameter, covered with deltoid scales and whitish-brown hairs, brownish at the base and becoming reddish-orange towards the tepals. Tepals reddish-orange, sometimes with slightly purplish edges, glabrous, with acute apex, 14–22 x 4–7 mm. Androecium with numerous stamens, glabrous filaments, 32–51 mm long, ranging from whitish (at the base), becoming orange, and reddish near the anthers. Anthers 0.13–0.16mm x 0.05–0.06mm, initially yellow but becoming purple due to pollen dehiscence. Gynoecium with an inferior ovary, whitish, 4–8 mm in diameter. Style whitish at the base and becoming reddish-orange towards the stigmas, glabrous, 8.4–9.0 cm long. Stigmas with 10–11 stigma lobes, exerted, light green or purplish, with a papillose surface. Nectar chamber greenish-white, without a diaphragm, 1.1–1.6 cm x 0.3–0.5 cm. Globular fruits, up to 35 mm in diameter, greenish-violet, sour-tasting, without spines. Small reddish-brown scales, separated by 10 mm, with white hairs and firm white pulp. Small blackseeds with a matt luster.

Iconography. Rauh (1958: 319).

Etymology. The epithet "*riomajensis*" alludes to the locality where the species was found, "*Valle del río Majes*" (the Majes River valley).

Common name. Unknown.

Distribution and habitat. Endemic to the department of Arequipa. Populations of *Loxanthocereus riomajensis* were found only in the provinces of Caylloma, Castilla, and Condesuyos, near the settlements of Pitay, Pacaychacra, Ispacas, and Yanaquihua, growing at intermediate elevations (between 1640 – 2140 m of altitude) (Figs. 4, 5, 6). It thrives in very arid places with scarce vegetation, and individuals are widely scattered. It prefers rocky soils with moderately steep slopes. Most accompanying species are annual or sometimes perennial plants and other cacti (*Weberbauerocereus rauhii* Backeb., *Neoraimondia arequipensis* (Meyen) Backeb., *Melocactus peruvianus* Vaupel*, Cumulopuntia leucophaea* (Phil.) Hoxey*, Cumulopuntia sphaerica* (C.F. Först.) E.F. Anderson, *Haageocereus pluriflorus* Rauh & Backeb., *Ambrosia artemisioides* Meyen & Walp., *Jatropha macrantha* Müll. Arg.

Other materials examined. PERU: Dpto. Arequipa: Prov. Condesuyos, Iray, Pacaychacra, Below Chuquibamba. Very dry slopes, with loose stones and dusty grey-white soils, dried grasses, 1700 m, 15°54'05.1623" S, 72°33'15.6924" W, 03 March 2023, *P. Hoxey & A. Pauca T.* 200 (HSP); Yanaquihua, between Ayanca and Ispacas, step arid slope with dusty soil and stones, 1950 m, 15°46'30.5580" S, 72°59'51.1332" W, 29 May 2023, *P. Hoxey et al*., 206, (HSP). Prov. Castilla, Lluta, Pitay, Rio Siguas, base of ravine with rocks and dusty soils 1800 m, 16°11'04.0092" S, 72°03'16.6355" W, 03 march 2023, *P. Hoxey & A. Pauca* T. 203 (HSP).

Distribution. As for the review of museums, it was not possible to find any specimens of *Loxanthocereus riomajensis*, nor was it possible to obtain any records in the databases of GBIF and INaturalis. On the other hand, the field visits carried out show that *L. riomajensis* is distributed in the provinces of Condesuyos and Caylloma, specifically in the districts of Iray and Yanaquihua (belonging to Condesuyos), Lluta and Majes (Caylloma). The species was observed in four discrete sectors (Table 2), with widely scattered individuals and a low population density. In Condesuyos, plants were observed near the localities of Pacaychacra, Ispacas, and Cerro Rico, while in Caylloma, plants were observed near Pitay and Huacán (Fig. 6). Regarding the elevational distribution, *L. riomajensis* was recorded from 1640 m of altitude in Pacaychacra to 2140 m on the way to Ispacas.

Regarding the potential distribution, after processing the bioclimatic variables and known distribution, it was found that *L. riomajensis* is found in areas where the mean monthly temperature varies between 16.9 – 18.5 °C (with an average of 18 °C), and the annual precipitation ranges from 18.4 to 94.7 mm (with an average of 50.8 mm). The best model was obtained with the combination of classes LQH, using a regularization multiplier of 1. This model fit well with the known habitat of the species and displayed suitable values for AUC, omission rate, and Boyce's continuous index (0.88, 0.42, and 0.63, respectively).

Figure 3. Photograph of the lectotype of ***Loxanthocereus riomajensis*** deposited in the HEID herbarium (702366) in Germany by Werner Rauh under number K 153 (1956). Photo: © Heidelberg Botanic Garden and Herbarium, Universität Heidelberg- HEID.

The model predicts suitable areas for *L. riomajensis* are found approximately between 15°21' and 16°32' South latitude, and between 73°16' and 71°37' West longitude, covering an area of 1135.3 km^2, with an elevation ranging from 1000 to 2600 m. These areas are in the provinces of Arequipa, Caylloma, Castilla, Condesuyos, La Unión, and Caravelí (with limited presence in the last two). The potential distribution largely occurred along the margins of the Ocoña River valley (Condesuyos) and the Majes River valley (Castilla). Additionally, potential areas were observed in the lower zones of the volcanic cordillera, near the Ampato and Chachani volcanoes, in the provinces of Caylloma and Arequipa, respectively, reaching the northwest of the granodioritic formation of the Caldera Batolith (Fig. 8). In the case of the Ocoña River valley, the areas with potential distribution were found near the localities of Cerro Rico, Yanaquihua, Andaray, Ispacas, Lamapampa, Chillihuay, Chaucalla, and Chichas. In the Majes River valley, potential areas were observed near Pacaychacra, Andamayo, Capiza, Canco, and Ayo. In the Caylloma province, potential areas were identified in the localities of Sicera, Huacán, and Pitay, while in the Arequipa province, the potential areas covered Yuramayo, Palca, and Uchumayo.

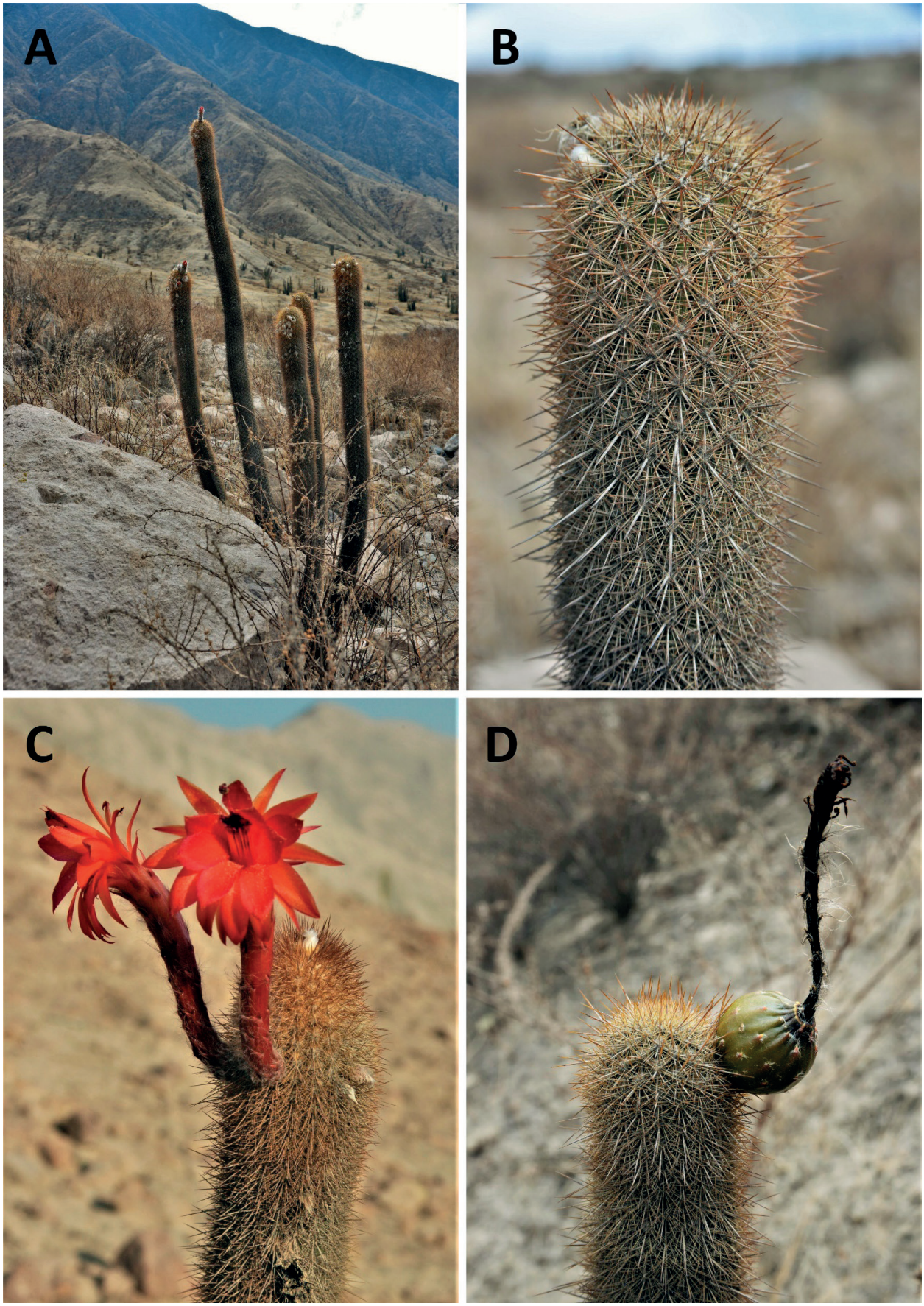

Figure 4. A. Habit of ***L. riomajensis*** (Paychacra locality, Iray, Condesuyos), B. Detail of the stem of ***L. riomajensis*** (notice the density of the spines, obscuring the stem epidermis) (locality like A), C. Flowers of ***L. riomajensis*** (Pitay locality, Yuta, Caylloma), and D. Fruit of ***L. riomajensis*** (locality like A). Photos by Paul Hoxey.

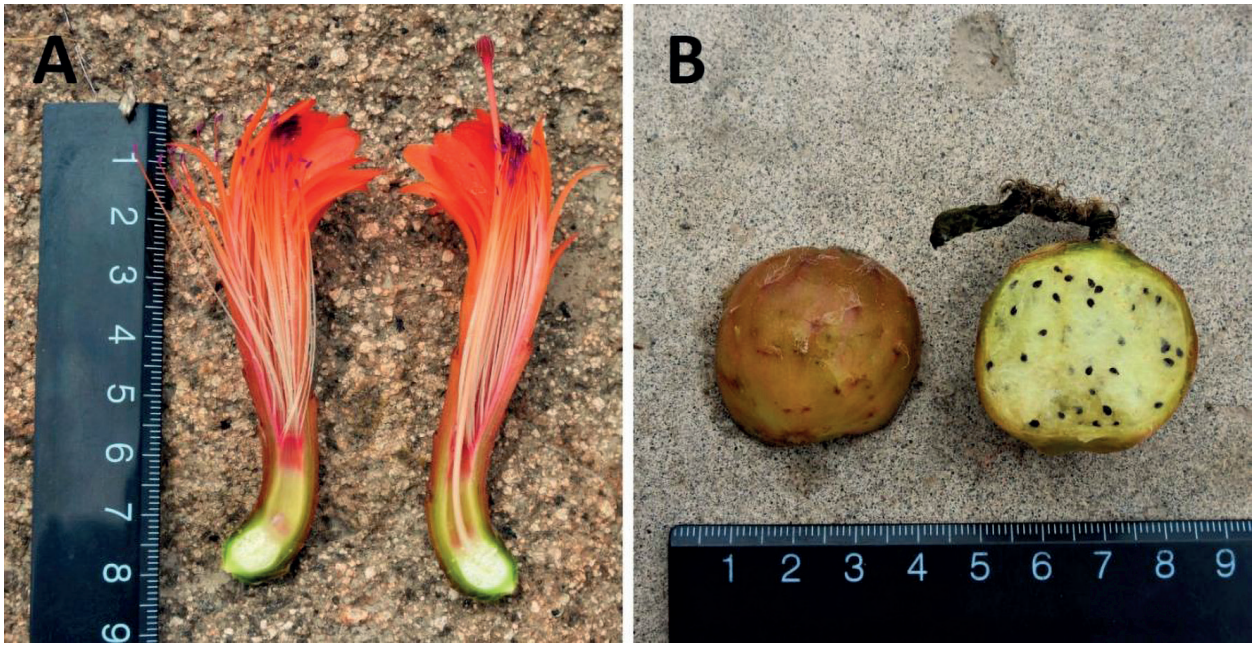

Figure 5. A. Longitudinal section of a flower of ***L. riomajensis***, and B. Longitudinal section of a fruit of ***L. riomajensis*** in the road from San Juan de Churunga to Yanaquihua. Photos by Paul Hoxey.

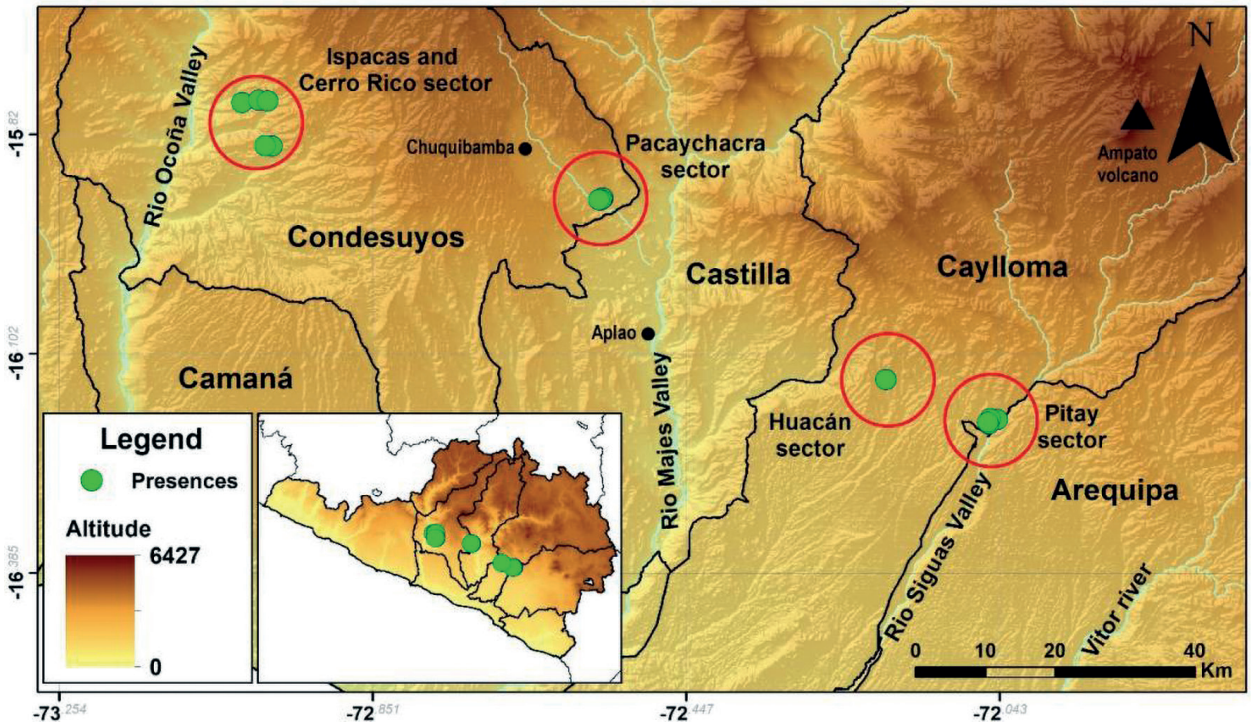

Figure 6. Localities where populations of ***Loxanthocereus riomajensis*** were recorded.

Conservation Status. Currently, *Loxanthocereus riomajensis* has not been evaluated or included in the IUCN Red List. However, it is classified as VU (Vulnerable) according to R.M. 0505-2016-MINAGRI. Nevertheless, the evaluation conducted here for criterion B shows an Extent of Occurrence (EOO) of 803.9 km^2 and an Area of Occupancy (AOO) of 36 km^2. Additionally, it can be noted that population fragmentation is observed (≤5) (a), a reduction in the extent of occurrence (i) and area of occupancy (ii), a decline in habitat quality (iii), and a reduction in the number of locations or subpopulations (iv). Based on all the assessments above, the conservation status of *L. riomajensis* can be designated as Endangered (EN B1ab(i,iii,iv); B2ab(ii,iii,iv)).

Discussion

Since its initial publication, *L. riomajensis* has been a subject of various opinions regarding its identity. The designation of a lectotype is made because the original publication does not designate a type, but only refers to a

Table 2. Location of observed populations of ***Loxanthocereus riomajensis*** in the provinces of Caylloma and Condesuyos, Arequipa.

Province	Sector	Locality	Coordinates	Altitude (m)	Date
Condesuyos	1	Pacaychacra	15°54'18.3"S, 72°33'38.1"W	1640	03/03/2022
			15°53'35.6"S, 72°34'11.9"W	1740	03/03/2022
			15°54'05.2"S, 72°33'15.7"W	1700	03/03/2022
	2	Between Churunga and Cerro Rico	15°50'01.9"S, 72°58'48.8"W	2060	03/04/2022
		Between Ayanca and Ispacas	15°46'30.6"S, 72°59'51.1"W	1950	29/04/2023
			15°46'36.1"S, 72°59'06.9"W	2140	29/04/2023
			15°46'42.0"S, 73°01'06.7"W	1820	28/04/2023
Caylloma	3	Pitay, Río Siguas	16°11'45.4"S, 72°03'24.8"W	1730	04/03/2022
			16°11'25.8"S, 72°03'30.1"W	1850	04/03/2022
			16°11'19.2"S, 72°03'32.6"W	1840	04/03/2022
			16°11'04.0"S, 72°03'16.6"W	1800	04/03/2022
	4	Near bridge, below Huacán	16°08'06.5"S, 72°11'22.5"W	1980	04/03/2022

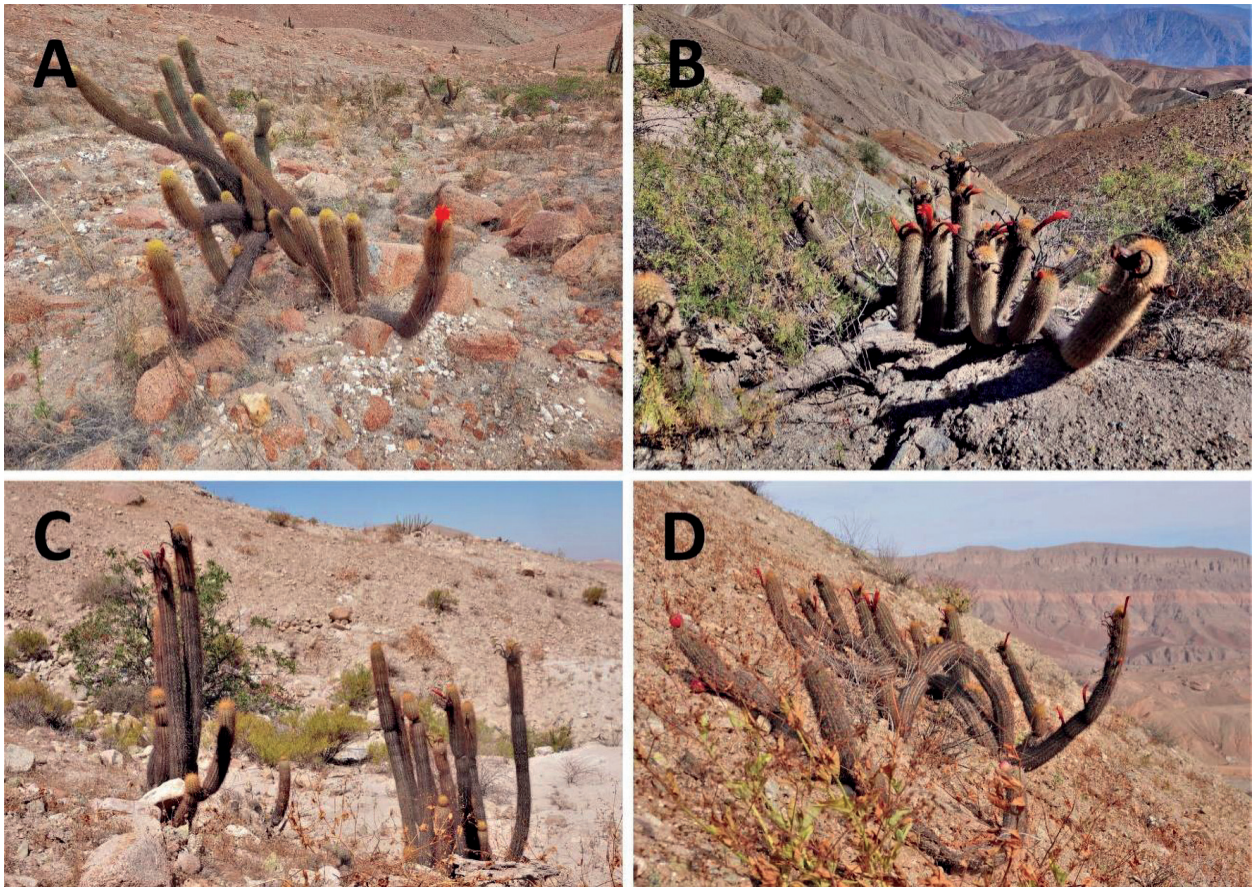

Figure 7. Habitat of ***L. riomajensis***. A. San Juan de Churunga-Yanaquihua road, B. Ayanca-Ispacas road, C. Huacán ravine, and D. Surroundings of Pitay. Photos by G. Anthony Pauca-Tanco (B) and Paul Hoxey (A, C, D).

collection under the number K153 (1956). Rauh (1958), indicates in relation to number K153 (1956), that it was a living plant taken to Germany for cultivation, however, it died and was entered as an herbarium specimen in the Botanical Institute of the University of Heidelberg. Additionally, Rauh (1958) suggested that this species could be considered within *Haageocereus*, as the protologue did not mention the characteristics of flowers and fruits, which could not be found during evaluations. Subsequent authors had differing views as well. Backeberg (1959) accepted *L. riomajensis*, while Ritter (1981) later labeled it as a "*nomen dubium delendum"* (doubtful name) due to the inadequate characteristics provided in the protologue for satisfactory species determination.

Later on, Hunt (1999), Anderson (2001, 2011), Hunt et al. (2006), and Lodé (2015) considered *L. riomajensis* as synonymous with *L. sextonianus*. More recently, Pauca & Quipuscoa (2017) and Ostolaza (2019) asserted that *L. riomajensis* is indeed a valid species. To clarify its taxonomic status, extensive field visits were conducted during this research, focusing initially on the highly pro-

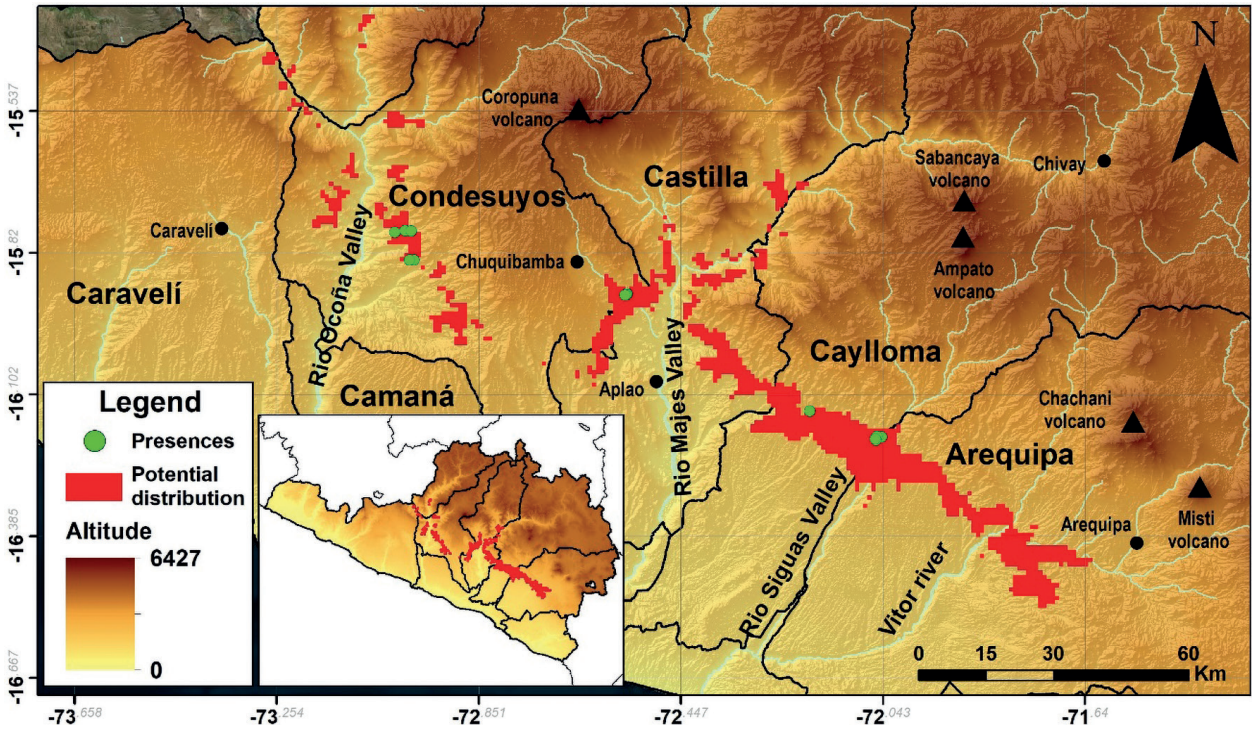

Figure 8. Potential distribution of *L. riomajensis*.

bable type locality, Pacaychacra. Although the exact type locality was not mentioned in the protologue, a review of Rauh's travel itinerary during 1956 strongly suggested it to be Pacaychacra. Intensive searches resulted in finding individuals with the vegetative characters described in the protologue, closely resembling the photograph of the type specimen. Specimens with flowers and fruits were also discovered, conclusively confirming the generic identity of the species within *Loxanthocereus* (scarlet, diurnal, zygomorphic flowers with a slender perianth tube). This rediscovery is remarkable as *L. riomajensis* has been absent from records for approximately 70 years. Although Ostolaza (2019) and Pauca y Quipuscoa (2017) display images for *L. riomajensis*, the plants are incorrectly identified as *L. riomajensis* and do not illustrate this taxon.

Regarding its relationship with other *Loxanthocereus* species, some authors, such as Hunt (1999), Anderson (2001, 2005), Hunt et al. (2006), and Lodé (2015), have considered *L. riomajensis* to be the same entity as *L. sextonianus*. However, we disagree, as *L. riomajensis* is easily distinguishable by its erect stems (in contrast to decumbent or ascending stems in *L. sextonianus*), flower diameter during anthesis (exceeding 4 cm in *L. sextonianus*, up to 3.2 cm in *L. riomajensis*), anther color (purple in *L. riomajensis*, yellow in *L. sextonianus*), and non-coastal distribution. *Loxanthocereus sextonianus* is found in the lomas ecosystems (Pauca & Quipuscoa 2017) up to a maximum elevation of 1000 m, while *L. riomajensis* is found on the western slopes of the Andes, more than 50 km from the coast, at elevations ranging from 1600 to 2140 m of altitude. Regarding the relationship with *Borzicactus jajoanus* or *Loxanthocereus jajoanus* (Backeb.) Backeb. (The Caryophyllales Network 2024), this is ruled out, as *L. riomajensis* is easily distinguishable from *L. jajoanus* in the number of central spines (1-2 in *L. riomajensis*, 1-4 in *L. jajoanus*), number of ribs (up to 12 in *L. jajoanus*, 13-15 in *L. riomajensis*), and the spination (the green epidermis is difficult to observe in *L. riomajensis*, while in *L. jajoanus* it is easily noticeable). On the other hand, *L. riomajensis* shows some affinity with *Loxanthocereus* species distributed towards the central region of Peru, particularly those found at similar elevations, such as *L. acanthurus* (Vaupel) Backeb. and *L. peculiaris* Rauh & Backeb. These species share characteristics such as an erect habit, arrangement of the areoles on the stems, and size and number of radial spines (which give the impression of grayish-brown stems due to the proximity of the areoles and the density of the radial spines). However, they can be distinguished by the length of the central spines (longer in *L. acanthurus* and *L. peculiaris*, reaching up to 35 mm), flower length (6-8 cm in *L. acanthurus* and *L. peculiaris*, 8-9 cm in *L. riomajensis*), and anther color (yellow in *L. acanthurus* and *L. peculiaris*, purple in *L. riomajensis*).

As known, the distribution of plants is to some extent conditioned by certain temperature and precipitation gradients (Arita & Rodríguez 2001), as well as soil characteristics (Duval et al. 2015), which is evident in some plant groups, such as cacti (Aquino et al. 2021, Lebgue-Keleng et al. 2014, Texeira et al. 2004). The genus *Loxanthocereus*, endemic to Peru (Ostolaza 2019), has species restricted to specific localities, which can be arid valleys or fog-dependent lomas communities on the coast (Hoxey 2020, Ostolaza 2019, Charles, 2013).

It appears that the populations of *L. riomajensis* are confined to the provinces of Caylloma, Condesuyos, and

likely Castilla, spanning an elevation range of approximately 500 meters (from 1640 to 2140 meters). The environmental conditions at these "intermediate" elevations may be favorable for a considerable number of cactus species in southern Peru, as indicated by some authors who have documented an overlap in altitudinal distribution within these ranges (Pauca-Tanco et al. 2020, Ostolaza 2019, Pauca & Quipuscoa 2017, Brako & Zarucchi 1993), showing a pattern termed as mid-domain dominance (McCain & Grytnes 2010). This dominance pattern arises due to a higher diversity of species at intermediate altitudes, suggesting that the environmental requirements for certain species may coincide, either persisting within this range, or marking the beginning or end of their altitudinal distribution (McCain & Grytnes 2010). Indeed, observations of mid-domain dominance also align with bioclimatic and phytosociological perspectives, such as Weberbauer (1945), who identifies the zone between 1100 to 2400 m as the fringe for columnar cacti ("*piso de las cactáceas columnares*"), and Galan de Mera et al. (2009; 2010), whose mesotropical bioclimatic floor and arid ombroclimate coincide with the altitudinal distribution of *L. riomajensis*. Therefore, it can be noted that *L. riomajensis* is located within the Oruro-Arequipeña biogeographical province, and is restricted to the western zones of the Coropuna volcano and Lluta-Sabancaya sectors, whose landscapes and phytogeography are distinctive (Galan de Mera et al. 2010).

Ecological niche models show zones of habitat suitability, i.e., places with favorable conditions for the probable development of the species, considering certain inherent aspects, such as their inter- and intra-specific relationships and their interaction with the environment (Mota et al. 2019, Soberón et al. 2017, Peterson et al. 2011). Thus, the selection of variables for modeling the distribution of *L. riomajensis* was made according to the recommendations by Booth (2022) and Escobar et al. (2014). Additionally, the species' habitat (as a criterion of the researcher) and the use of statistics were considered to select the "best" model.

Regarding the calibration of the study area, as recommended by Peterson et al. (2011) and Peterson (2014), the species' dispersal range was considered. This was established based on the locations where *L. riomajensis* was found and areas where it was not observed (such as Caravelí, the lower part of the Cotahuasi Canyon, the lower Colca River valley, and the Arequipa-Yura road). Consequently, the calibration area limits were set to the polygon formed by connecting the points of the species' presence, with a buffer of 0.5° added around the resulting shape.

The selection of the appropriate model for *L. riomajensis* was based on its complexity, meaning that it did not use complex transformations for the variables (such as LQHP), had a high Area Under the Curve (AUC) value, a low omission rate for presences, a low value in the continuous Boice index, as well as the use of a regularization parameter of 1 (Kass et al. 2023, Sillero et al. 2021). All these considerations, together with habitat consistency, prevent results lacking biological interpretation (which could occur when choosing overly complex models, in terms of low regularization values and high use of variable conversions), present low omission rates, and ensure that the results differ from random outcomes (high AUC) (Kass et al. 2023, Cobos et al. 2021, Wei et al. 2021). Regarding the selection of the model's cutoff threshold, although this may be indicated by the evaluator, it was decided to use 10% as recommended by Kass et al. (2023), as it did not discard any presence of the species under study nor did it exaggerate the potential distribution area.

The potential distribution may include areas where the species is absent, which is considered a commission error, or it may exclude areas where the species is present, referred to as omission errors, the latter being critical (Flores-Tolentino et al. 2019, Peterson et al. 2008). Commission errors could suggest that the species is indeed present but not documented due to insufficient exploration by specialists, specific environmental factors, or biological interactions (such as competition) inhibiting the species' presence, or that natural barriers restrict its dispersal (Villasante et al. 2021; Peterson et al. 2011).

By comparing field observations with the potential distribution map, areas such as Ayo (Castilla), Chichas (Condesuyos), Velinga (La Unión), and Arequipa (Arequipa) stand out, where the map predicts potential presence, but no individuals of *L. riomajensis* were found. The absence in these locations may be related to the success of seed dispersal or the historical presence of the species, which has subsequently disappeared. The study area (Ayo, Chichas, Velinga) is characterized by large ravines with steep, rocky slopes and water streams at their bottom, often without other cacti.

The dispersal of *L. riomajensis* seeds likely depends on mastofauna, as no evidence of fruit consumption by birds was observed. Seeds could travel within the digestive tracts of animals, making it challenging to cross ravines and rivers. Additionally, the potential historical presence and subsequent disappearance of *L. riomajensis* in these areas is feasible; currently, in the Pitay area, the species is in poor condition, likely due to pests from the Pseudococcidae family. Furthermore, the absence of *L. riomajensis* in the province of Arequipa could be attributed to the soil type. Non-colonization in areas such as Palca and Yuramayo may be due to ignimbritic soils, formed by volcanic activity approximately 4.9-1.6 million years ago (Lebti et al. 2006).

Taxonomic studies of species are fundamental for conservation as they help establish the true diversity within the treated group. In Cactaceae, there is much debate about the validity of species, which ultimately leads to adopting what is mentioned in specialized literature. The problem arises when decisions are made to lump different species under one name, without a thorough critical study (e.g., reviewing protologues, verifying type specimens, conducting field visits to obtain *in situ* characteristics), resulting in several consequences, inclu-

ding incorrect conservation categorizations. This was the case with *L. riomajensis*, which was considered a synonym of *L. sextonianus* (Brako & Zarucchi 1993, Hunt 1999, Anderson 2001, Hunt et al. 2006). This likely led to it not being considered in the list of species categorizations in the D.S. N° 043-2006-AG (first list of species categorization promulgated by the Peruvian government) and in the Red Book of endemic plants of Peru (Arakaki et al. 2006). However, in 2016, in the R.M. 0505-2016-MINAGRI, *L. riomajensis* was categorized as VU (vulnerable), so by that time, *L. riomajensis* was recognized as a valid species. Nevertheless, limited information on a taxon only allows for a subjective opinion, and gathering more data enables more assertive and objective analyses. In this regard, the category suggested here (EN-endangered), which was obtained considering field information, appears to be the most precise.

Regarding the observed threats to this species, the most concerning is habitat destruction due to intense mining activity in its distribution area (especially in the Rio Ocoña valley). Other issues negatively impacting *L. riomajensis* populations include road construction for transportation, soil removal for land leveling, paths for mining shafts, and dust settling on the plants (due to these activities). Another worrying situation is that the *L. riomajensis* population near Pitay (and other cactus species located there) is infested with cottony cochineal insect (Pseudococcidae), causing the cacti to be in poor condition. Another threat, is climate change, as this species, with its restricted distribution, is adapted to certain climatic requirements or patterns. Rapid changes in these parameters could lead to the rapid decline plant numbers and population size.

Conclusions

Loxanthocereus riomajensis is a species endemic of the western slopes of Peru, from the department of Arequipa. Its taxonomy has been subject to debate since its publication, with associations to a different genus (*Haageocereus*), designation as a dubious name, or inclusion within another species.

However, the characteristics described herein undeniably establish its generic identity and set it apart from other related species. Among the most notable features are its spination, as it presents a large number of radial spines, which, combined with the proximity of its areoles, gives the impression of a gray instead of a green stem.

On the other hand, *L. riomajensis* may be related to other *Loxanthocereus* species with similar spination such as *L. acanthurus* or *L. peculiaris*, nevertheless, characteristics such as flower size, and more notably, the color of the anthers, provide good diagnostic characters for distinguishing between them.

Regarding its distribution, *L. riomajensis* populations are likely forming a belt of presence at intermediate altitudes (1600 to 2100 m), with an altitude range of 500 m, at the foot of the volcanic range, covering the provinces of Condesuyos and Caylloma. The potential distribution shows suitable areas in the provinces of Condesuyos, Castilla, Caylloma, Arequipa, and to a lesser extent in the provinces of La Unión and Caravelí. Finally, based on the field data, the conservation status of *L. riomajensis* is assessed as "EN" (endangered). The threats currently facing this species are due to human activity (extractive mining activities) and climate change. It is necessary to plan conservation strategies for the protection of this species.

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Agradecimientos / Acknowledgments:

A los miembros del Instituto Científico Michael Owen Dillon por brindar las instalaciones del herbario HSP.

Conflicto de intereses / Competing interests:

The authors declare no conflict of interest.

Rol de los autores / Authors Roles:

GAPT: Conceptualización; Metodología; Validación; Investigación; Recursos; Curación de datos; Escritura-Preparación del borrador original; Redacción-revisión y edición; Supervisión.

PH: Conceptualización; Metodología; Validación; Análisis formal; Investigación; Recursos; Curación de datos; Escritura- Preparación del borrador original; Redacción-revisión y edición.

Fuentes de financiamiento / Funding:

This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Aspectos éticos / legales; Ethics / legals:

Authors declare that they did not violate or omit ethical or legal norms in this research.

In situ observations of L. riomajensis were carried out on its habitat and specimens according to the research authorization issued by the Servicio Nacional Forestal y de Fauna Silvestre (SERFOR) del MIDAGRI, Resolución Directoral N°D000160-2022-MINAGRI-SERFOR-DGGSPFFS-DGSPF.

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