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Review article

Revisión del estado actual del conocimiento sobre el género *Brahea* Mart. en México

Review of the current knowledge of the *Brahea* Mart. genus in Mexico

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Abstract

Palm species in Mexico have played a significant role in rural development; they have great biological, cultural, and economic relevance. The *Brahea* genus is the most widely used in rural and indigenous communities in the country. The objective of this review is to present a synthesis of the scientific studies carried out in Mexico on this genus. A review of several sources, such as publications, researchers and institutions that research the subject was carried out. A total of 44 publications were identified, from which eight were books and 36 were articles; 77 % of these were research articles, 14 % were popular science articles, and 9 %, were review articles. Of the first authors of each publication, 60 % are from Mexican institutions, and 40 % from foreign institutions. Studies on Ethnobiology accounted for 23 % of the publications, which mainly address the cultural and economic importance of the use of species of this genus. The analysis shows that four of the 13 species included in the review were the most studied. The results show that the studies carried out on this genus by various institutions have been insufficient, and the need for further research from the perspective of linking the studies with actions for the sustainable use of palms of this genus is discussed herein.

Keywords: *Brahea* Mart., knowledge, genus, Mexico, palms, non-timber forest resources.

Resumen

Las especies de palmas en la república mexicana han desempeñado un papel significativo en el desarrollo de las comunidades rurales; poseen gran relevancia biológica, cultural y económica. El género *Brahea* es el de mayor uso en comunidades campesinas e indígenas del país. El objetivo de esta revisión fue exponer una síntesis de los estudios científicos realizados en México sobre este género. Se hizo una revisión de diversas fuentes, como publicaciones, investigadores e instituciones que hacen investigaciones sobre el particular. Se identificó un total de 44 publicaciones,

de las cuales ocho fueron libros y 36 artículos; de estos, 77 % son artículos de investigación, 14 % artículos de divulgación científica y 9 % artículos de revisión. De los primeros autores de cada publicación, 60 % tiene su adscripción en alguna institución mexicana y 40 % en instituciones extranjeras. Los estudios sobre Etnobiología representaron 23 % de las publicaciones en las que se aborda, principalmente, la importancia cultural y económica del aprovechamiento de especies del género *Brahea*. El análisis muestra que, de las 13 especies incluidas en la revisión, cuatro son las más estudiadas. Los resultados evidencian que los estudios realizados alrededor de este género en las distintas instituciones han sido insuficientes, y se discute la necesidad de continuar realizando investigaciones con la perspectiva de vincular los estudios con acciones para el aprovechamiento sustentable de las palmas de este género.

Palabras clave: *Brahea* Mart., conocimiento, género, México, palmas, recursos forestales no maderables.

Introduction

Non-timber forest products (NTFPs) are a set of products and services of biological origin (animal and plant) derived from forests and agroforestry areas, as well as trees outside the forest that do not yield timber (*Organización de las Naciones Unidas para la Agricultura y la Alimentación* [ONUAA], 2002; Tapia-Tapia & Reyes-Chilpa, 2008). Their collection and management involve various practices and generate different types of benefits for the societies that profit from them. The variety of benefits depends on the diversity of resources present in the systems in use (López, 2008), their seasonality (Anastacio-Martínez et al., 2016) and their distribution and abundance, among other ecological and social aspects (Blancas et al., 2010). In many regions of the world, these resources are indispensable for the livelihoods of communities, and in some cases, they are their only source of income (León-Merino et al., 2017).

One of the most important non-timber forest resources in Mexico are palms, belonging to the Arecaceae family, which includes about 181 genera worldwide (Baker & Dransfield, 2016); 21 of these are present in the country (Pulido-Silva et al., 2023; Quero, 1994, 2004). Palms are of ecological and social importance, not

only for their biological attributes but also for their cultural and economic attributes; some of them are even important elements of identity in rural communities (López, 2008; Vázquez-García & Munguía-Lino, 2015).

Brahea Mart. palms are the most widely used non-timber forest genus in the arid and sub-humid zones of Mexico (Coronel & Pulido, 2011). Mainly in the states of *Guerrero*, *Morelos*, *Oaxaca* and *Puebla*, they are a resource of cultural and economic importance (Martínez-Pérez et al., 2012).

This is practically a Mexican genus; certain authors point out that it is made up of 10 (Hodel, 2018) or 11 species (Andrade-Erazo et al., 2022; Pérez-Valladares et al., 2020). However, one of our references in this research is the work of Quero (2000), in which 13 valid species are recognized, 10 of them, endemic to the Mexican Republic, distributed in less than 1 % of the total surface area of the country (Rzedowski, 2006). Due to overexploitation, some of these species are included in the International Union for Conservation of Nature (IUCN) list and NOM-059-SEMARNAT-2010 (Andrade-Erazo et al., 2022; NOM-059-SEMARNAT-2010). Its distribution is broad, within an altitude range of sea level to 2 500 m, in semi-humid and dry environments, mainly in limestone soils (Quero, 2000; Rzedowski, 2006). The genus tends to form associations with different vegetation types and is abundant in disturbed sites and in anthropogenic palm groves (Andrade-Erazo et al., 2022; Illsley et al., 1997; Quero, 2000).

The palms of the *Brahea* genus have been utilized since prehistoric times (Smith, 1965, 1967) and are still used today, mainly for the construction and elaboration of handicrafts, medicinal, ornamental and ceremonial ends (León-Merino et al., 2017; Vázquez-García & Munguía-Lino, 2015), among others. The seeds and fruits are used as food or for the fat and soap industry; the stems, for building construction and the manufacture of *cuaxtles* (cushioned objects used as rigging); the leaves, for roofing rooms, and the foliage shoots are extracted for the manufacture of handicrafts, especially the weaving of hats, mats, *tenates* and baskets (Casas et al., 2008; Rangel-

Landa et al., 2014), as well as numerous objects that artisans have developed in recent years. They also play an important role in the ecosystems that host them, as they provide conditions for the survival of animal species, some of which are dispersers of their seeds (Marez-López et al., 2020; Pulido & Coronel-Ortega, 2015).

However, due to unmanaged harvesting, numerous populations of *Brahea* spp. are subject to overexploitation (Pavón et al., 2006; Quero, 2000), which may determine negative changes in the structural and morphological traits of the individual trees, as well as affect vital rates and population dynamics (López-Toledo et al., 2018).

However, ecological, cultural, and social aspects of several of the species of this genus are still unknown, so the question arises as to what the current state of knowledge about *Brahea* taxa in Mexico. In order to answer this question, the present study undertook a systematic review of the information published in the last 29 years; in addition, the studies carried out in Mexico in different fields were categorized in order to identify the main gaps in knowledge about this important genus of plants.

From September 2022 to August 2023, a search was carried out for articles published between 1994 and 2023 on research conducted in Mexico. The following search engines were consulted: Google scholar, Pubmed, the Network of Scientific Journals in Latin America and the Caribbean, Spain and Portugal (Redalyc), ScienceDirect, Scopus, Web of Science and the National Consortium of Scientific and Technological Information Resources of Mexico (*Conricyt*). In addition, a targeted consultation was carried out on academic social networks ResearchGate and Academia. Manuals and books generated in Mexico addressing social and ecological issues about *Brahea* were compiled. In November 2022, the Google Books database was consulted for the period from 1994 to 2022.

The criteria for the search were narrow and strict, using the words "*Brahea*" and "*palmas*" or "palms" in Spanish and English. The authors then filtered only those articles that deal with the genus of interest and eliminated repeated references. The final database was classified according to the type of contribution (research,

dissemination and review), species, main themes, institutions, and academic affiliation of both the first and the corresponding authors as well as the collaborating institutions. The first author was assumed to be the corresponding author unless stated otherwise. In order to analyze the type of contribution of the documents, twelve main themes were established (Table 1). Each article was classified into one or more of these main themes according to its topic. The taxonomic treatment of the species was based on the work of Quero (2000).

Table 1. Main themes and references.

Main themes	References
(A) Ethnobiology and leaf harvesting	Andrade-Erazo et al. (2022); Briseño-Tellez et al. (2023); Briseño-Tellez y Pulido-Silva (2023); Casas et al. (1994); Coronel y Pulido (2010, 2011); Felger y Joyal (1999); Illsley et al. (2001, 2006); López-Toledo et al. (2011, 2015, 2018); Pavón et al. (2006); Pérez-Valladares (2022); Pérez-Valladares et al. (2020, 2022); Pulido (2023); Pulido y Coronel-Ortega (2015); Ramírez-Rodríguez et al. (2012); Rangel-Landa et al. (2014); Sánchez (1998).
(B) Spatial distribution and environmental conditions	Felger y Joyal (1999); Garcillán et al. (2012); Klimova et al. (2017, 2018); López-Toledo et al. (2011, 2013); Minnich et al. (2011); Pérez-Valladares et al. (2020, 2022); Pulido (2023); Rangel-Landa et al. (2014); Wehncke et al. (2010).
(C) Population dynamics and parameters	Bullock y Heath (2006); Klimova et al. (2018, 2021); López-Toledo et al. (2011, 2015, 2018); Pavón et al. (2006); Pérez-Valladares et al. (2020); Pulido y Coronel-Ortega (2015); Wehncke et al. (2010).
(D) Taxonomy or systematics	Andrade-Erazo et al. (2022); Barrett et al. (2019); Felger y Joyal (1999); Klimova et al. (2017, 2018); Pulido-Silva et al. (2023); Quero (1994, 2004); Ramírez-Rodríguez et al. (2011).
(E) Molecular and genetics	Barrett et al. (2019); Klimova et al. (2017, 2018, 2021); Pérez-Alquicira et al. (2023); Poghosyan et al. (2016, 2019, 2023); Ramírez-Rodríguez et al. (2011, 2012).
(F) Marketing and manufacturing	Briseño-Téllez et al. (2023); Briseño-Téllez y Pulido-Silva (2023); Casas et al. (1994); Coronel y Pulido (2010); Illsley et al. (2006); Pérez-Valladares et al. (2020); Pulido (2023); Rojas et al. (2010); Sánchez (1998).
(G) Patterns of frugivory, seed dispersal and predation	Klimova et al. (2018); López-Toledo et al. (2013); Marez-López et al. (2020); Reyes-Zepeda et al. (2021); Wehncke et al. (2009, 2010, 2013).

(H) Pests and diseases	Heinz-Castro et al. (2022); Poghosyan et al. (2016, 2019, 2023).
(I) Social or gender aspects	Briseño-Téllez et al. (2023); Briseño-Téllez y Pulido-Silva (2023); Pérez-Valladares et al. (2020); Rojas et al. (2010).
(J) Phenology	Coronel y Pulido (2010); Wehncke et al. (2013).
(K) Morphology/allometry	Bullock y Heath (2006); López-Toledo et al. (2018).
(L) Biotechnology	Poghosyan et al. (2016).

Source: Prepared by the authors.

Research conducted in Mexico

Based on the search carried out until August 2023 and having filtered the base of repeated references, 44 publications were obtained, between articles and books from 1994 to 2023, by a total of 178 authors.

Of these references, eight were published in books, and 36 in articles; of these, 77 % were research articles, 14% were popular articles and 9 % were review articles. Of the 13 species considered in the review, only nine studies have been conducted on the genus, covering only seven species: *Brahea dulcis* (Kunth) Mart. (17), B*. armata* S. Watson (6), *B. aculeata* (Brandegee) H. E. Moore (4), *B. brandegeei* (Purpus) H. E. Moore (4), *B. edulis* H. Wendl. *ex* S. Watson (3), *B. berlandieri* Bartlett (3) y *B. nitida* Schaedtler (1) (Table 2).

Table 2. Number of publications mentioning each species of the genus *Brahea* Mart.

Species	Number of publications	Species	Number of publications
***B. aculeata* (Brandegee) H. E.**	4	*B. elegans* (Franceschi *ex*	0

Moore		Becc.) H. E. Moore	
***B. armata* S. Watson**	6	*B. moorei* L. H. Bailey *ex* H. E. Moore	0
***B. berlandieri* Bartlett**	3	*B. nitida* Schaedtler	1
***B. brandegeei* (Purpus) H. E. Moore**	4	*B. salvadorensis* H. Wendl. *ex* Becc.	0
***B. decumbens* Rzed.**	0	*B. sarukhanii* H. J. Quero	0
***B. dulcis* (Kunth) Mart.**	17	*B. pimo* Becc.	0
***B. edulis* H. Wendl. *ex* S. Watson**	3		

Source: Prepared by the authors according to the taxonomic arrangement of Quero (2000), which recognizes 13 species.

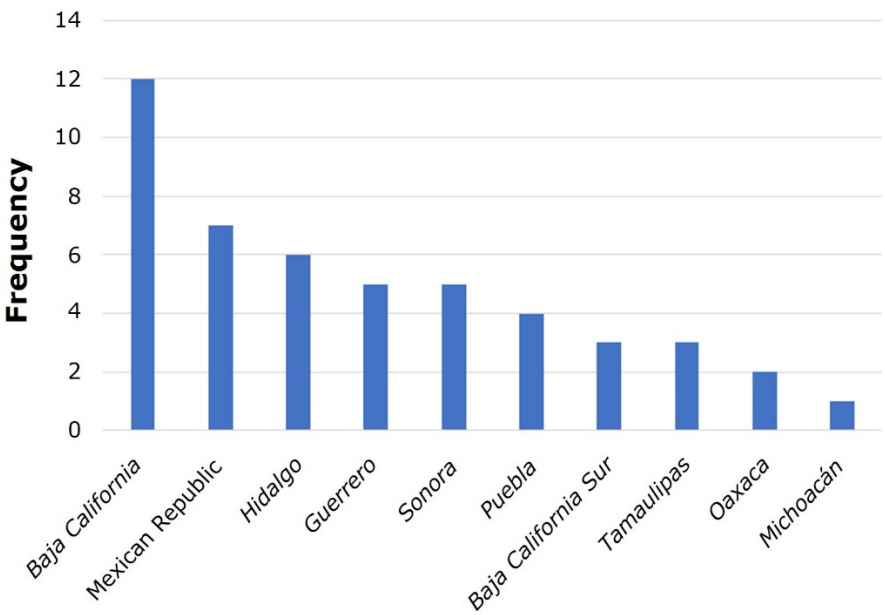
Given the first author's affiliation, of the 44 publications considered, 60 % were written by researchers based in Mexico and 40 % by researchers working in foreign institutions. The former are attached to seven universities, three research centers, and one civic association; while the latter are attached to four universities, one institute, and one research center.

The main affiliations of the first authors in descending order by number of articles published were as follows: *Universidad Nacional Autónoma de México* (8), *Universidad Autónoma del Estado de Hidalgo* (8), *Centro de Investigaciones Biológicas del Noroeste* (7), *Universidad Michoacana de San Nicolás de Hidalgo* (4), *Universidad Autónoma del Estado de Morelos* (3), *Grupo de Estudios Ambientales A. C.* (2), *Universidad Autónoma de Tamaulipas* (2), *Colegio de Postgraduados* (1), *Centro de Investigación Científica y de Educación Superior de Ensenada Baja California* (1), *Universidad Autónoma de San Luis Potosí* (1), and *Universidad de Guadalajara* (1), in Mexico. Abroad, they were the Institute for Conservation Research, San Diego Zoo Global (3), the Biodiversity Research Center of the California, San Diego Natural History Museum (3), the University of Bielefeld,

Germany (1), the West Virginia University (1), the University of California, Riverside (1), and the Arizona State University (1).

In 70 % of the cases, the corresponding authors were affiliated with the same institution as the first author; in 64 % of the publications, the affiliation was with Mexican institutions and in the other 36 %, with foreign institutions. In addition, 15 institutions collaborated on the publications.

The research was carried out in nine states; of these, *Baja California* is where the most studies were conducted (12), followed by *Hidalgo* (6), *Sonora* and *Guerrero* (5), *Puebla* (4), *Baja California Sur* and T*amaulipas* (3), *Oaxaca* (2) and *Michoacán* (1). Seven studies had a nationwide geographic scope and were therefore classified into the Mexican Republic category (Figure 1).



Source: Prepared by the authors.

Figure 1. Research conducted in the states of the Mexican Republic.

Main themes studied

The following main themes were considered in most publications: (A) Ethnobiology and leaf harvesting, in 23 %; (B) Spatial distribution and environmental conditions, in 15 %; (C) Population dynamics and parameters, in 11 %; (D) Taxonomy or systematics, in 10 %; (E) Molecular and genetic, in 10 %; (F) Marketing and manufacturing, in 10 %; (G) Patterns of frugivory, seed dispersal, and predation, in 8 %; (H) Pests and diseases, in 4 %; (I) Social or gender aspects, 4 %; (J) Phenology, in 2 %; (K) Morphology/allometry, in 2 %; and (I) Biotechnology, in 1 %.

As shown in Table 3, there are two main areas in which work has been sustained over time: Ethnobiology and leaf harvesting, and Taxonomy or systematics. Between 2009 and 2018 there was a boom of publications on the genus *Brahea*, particularly on the topics of Ethnobiology and leaf harvesting, Spatial distribution and environmental conditions, Dynamics and population parameters, but also an emergence of new topics, such as Frugivory patterns, dispersal, predation, and Molecular and genetics.

Table 3. Main themes studied in the 1994-2023 period.

Years	1994-1998	1999-2003	2004-2008	2009-2013	2014-2018	2019-2023	Total by Topic
(A) Ethnobiology and leaf harvesting	2	2	2	4	4	7	21
(B) Spatial distribution and environmental conditions	0	1	0	5	3	4	13
(C) Population dynamics and parameters	0	0	2	2	4	2	10
(D) Taxonomy or systematics	1	1	1	1	3	2	9
(E) Molecular and	0	0	0	2	3	4	9

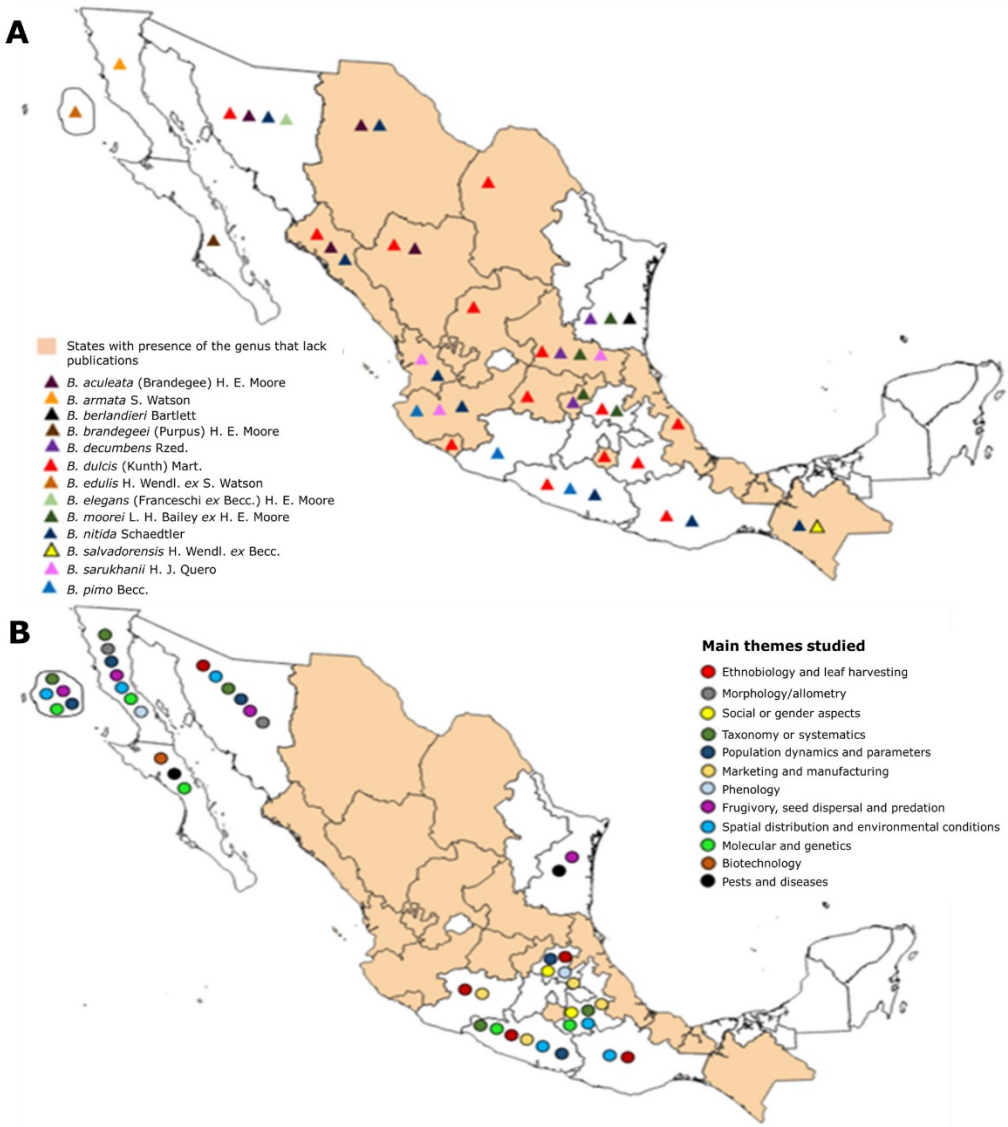
genetics							
(F) Marketing and manufacturing	2	0	1	2	0	4	9
(G) Patterns of frugivory, seed dispersal and predation	0	0	0	5	1	1	7
(H) Pests and diseases	0	0	0	0	1	3	4
(I) Social or gender aspects	0	0	0	1	0	3	4
(J) Phenology	0	0	0	2	0	0	2
(K) Morphology/allometry	0	0	1	0	1	0	2
(L) Biotechnology	0	0	0	0	1	0	1
Total per period	5	4	7	24	21	30	91

Publications in the other areas have varied over the analyzed period. Some topics (Phenology, Frugivory, dispersal and predation, Social/gender and genetics and Molecular and genetics) emerged from 2009 to 2013; some others (Biotechnology, Pests and diseases) from 2014 to 2018 (Table 3).

The most studied theme has been Ethnobiology; however, the number of publications is still insufficient, since most of them are specific to the states of *Baja California Sur*, *Hidalgo*, *Guerrero*, *Michoacán*, *Oaxaca*, *Puebla* and *Sonora*, and therefore are not representative of other areas where these palms are distributed. Hence, further studies are required in order to know the details of its use in other regions of Mexico and how it can contribute to the design of strategies for its conservation.

The increase in molecular studies together with those on Spatial distribution and environmental conditions, Taxonomy and systematics in the 2014-2023 period is linked to the rise of and access to new methodologies and computational capabilities, making it possible to carry out studies in less time than ever before. For example, it is now possible to determine genetic structure, hybridization, distribution, and ecological divergence in a relatively short time.

The results show that, although the *Brahea* genus is practically endemic to Mexico and is one of the most important groups of palms from a cultural, ecological, and economic point of view, relatively little attention has been paid to it. According to Quero (2000), the International Union for Conservation of Nature Red List (IUCN, 2023), and studies published in the analyzed period, species of the *Brahea* genus have been listed in 24 states; however, research has been carried out in only nine of them (Figure 2A).



A = Map of the distribution of species of the *Brahea* Mart. genus in Mexico (triangles) based on Quero (2000) and IUCN (2023); B = Map of studies conducted with species of the *Brahea* genus in Mexico. The colored circles refer to the main themes studied. Source: Prepared by the authors.

Figure 2. Presence of species of the genus *Brahea* Mart. and entities in which genus studies have been carried out.

There are publications for seven of the 13 species of the genus considered in this review; among them, the most studied were *B. aculeata*, *B. armata*, *B. brandegeei*, and *B. dulcis*; however, no information was found on the following six species: *B. decumbens* Rzed., *B. elegans* (Franceschi *ex* Becc.) H. E. Moore, *B. moorei* L. H. Bailey *ex* H. E. Moore, *B. salvadorensis* H. Wendl. *ex* Becc., *B. sarukhanii* H. J. Quero, and *B. pimo* Becc. (Figure 2A). It should be noted that these species are distributed in 14 states of Mexico, and the presence of several taxa has been recorded in more than one state (Quero, 2000; IUCN, 2023). On the other hand, as shown in Figure 2B, the presence of these taxa as well as of teams that have researched the taxa *B. berlandieri* and *B. dulcis* have been recorded in the states of *Guerrero*, *Hidalgo*, *Jalisco*, *Michoacán*, *Nayarit*, *Querétaro*, *San Luis Potosí*, *Tamaulipas* and *Zacatecas*. In other words, it is important to analyze why research on the genus has been generated in so few states and why only for certain species.

For example, the presence of *B. dulcis*, *B. pimo*, and *B. nitida* has been cited for *Guerrero*, but documented studies deal only with *B. dulcis*. This bias is probably due to the economic and cultural importance of the species as well as to its wide distribution and its proximity to research centers. Furthermore, according to the distribution indicated by Quero (2000) and IUCN (2023) (it should be noted that the coordinates of this map are not so specific), *B. pimo* and *B. nitida* are distributed in the North of the state (*Taxco de Alarcón* municipality near *Morelos* and *Estado de México*) and its Western part (*Zirándaro de los Chávez* municipality, bordering with *Michoacán*); however, there is no specific record on the locations where these

species grow. The fact that they are distributed in these geographic areas and have not been studied could be justified because for years they have been occupied by criminal groups that limit their access.

Another example is *San Luis Potosí*, where the species *B. dulcis*, *B. sarukhanii*, *B. moorei*, and *B. decumbens* are present, yet no research on them has been published, which reflects the lack of research groups interested in their study.

The factors that determine the lack of research in the states of *Chiapas*, *Chihuahua*, *Mexico City*, *Coahuila*, *Colima*, *Durango*, *Guanajuato*, *Jalisco*, *Nayarit*, *Nuevo León*, *Querétaro*, *San Luis Potosí*, *Sinaloa* and *Veracruz* are unknown, even where populations of some *Brahea* species are present. A possible explanation is the lack of interest of the researchers (Pulido-Silva et al., 2023) or the difficulties of access to the areas where they are distributed. For example, Klimova et al. (2018) mention that populations of *B. edulis*, *B. armata* and *B. brandegeei* in *Baja California* are small and grow in isolated stands, so access to them requires walking long distances.

It would be important to pay attention particularly to *B. sarukhanii* and *B. pimo*, as they are included in the IUCN Red List (2023) under the endangered and vulnerable categories, respectively, due to their low population level.

Finally, the analysis of institutional affiliation for the first author of the publications reviewed showed that 32 % of these stem from *Universidad Autónoma del Estado de Hidalgo* and *Universidad Nacional Autónoma de Méxic*o.

Conclusions

The articles reviewed include: (1) Assessments of the status and dynamics of the populations of the species considered; (2) Determination of the availability, demand, exploitation rate, and expansion of palm groves; (3) Identification of market routes; and (4) Development of management plans for the use of this resource. The review shows the need to promote studies on certain aspects of the palms of the genus *Brahea*; therefore, the authors propose the following research agenda:

(I) Promote projects with a multidisciplinary approach, since a better understanding of this genus requires a clear understanding of the socio-ecological and economic context in which the populations develop and are exploited. Also, to work together with the various stakeholders —academia, non-governmental organizations, government agencies, and local populations— that carry out their exploitation.

(II) Generate studies that relate harvesting rates and the validity of the different uses with the growth and regeneration times of the palm groves, the species and parts used, the current state of their populations in different regions, and the impact of anthropic activities. Details about the management, such as the extraction rates, the techniques utilized to obtain the resource, the places and forms of extraction, and the community norms that regulate access to the resource are also important. This information would allow evaluation and proposals for sustainable management alternatives that could benefit producers.

(III) Analyze the socioeconomic importance of the resource and the context of its commercialization and manufacture. Although this is not a simple task, it is important to monitor the production and marketing chains, identify intermediaries, and determine whether or not there are local support groups such as cooperatives in order to propose better utilization scenarios and fairer sales markets.

(IV) To analyze the role of palms in cultural and ritual aspects, given that, since ancient times, they have played a fundamental role for various ethnic groups, which would provide knowledge for their valuation and evidence of the importance of conserving the species of the genus *Brahea*.

(V) Deepen the study of the taxonomy of palms, as there are still gaps; therefore, it is relevant to generate morphological, phylogenetic, and molecular research to distinguish between species of the genus. As a result, priority should be given to population and conservation studies of those species considered threatened or with restricted distribution, namely *B. moorei*, *B. aculeata*, *B. salvadorensis*, *B. sarukhanii*, *B. nitida*, *B. edulis*, and *B. pimo*.

(VI) Study gender relations and the division of labor existing in the communities with respect to the use of this resource.

(VII) Develop research on the possibilities and experiences of growing or favoring the most commonly used species and study domestication patterns generated in the communities that make use of this resource.

(VIII) Generate guidelines for the study, use, and conservation of the genus *Brahea* that will lead to updating and making efficient the legal framework that regulates the exploitation of its species.

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Conflict of interest

The authors declare that they have no conflict of interest.

Contributions by author

Janet Vargas Añorve: information search, data analysis, drafting, revision, and editing of the manuscript; Alfredo Méndez Bahena and Alejandro Casas: drafting, revision, and validation of the manuscript; Carmen González Soberanis: revision, editing, and validation of the manuscript.

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