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Article

Health condition of palm trees of Mexico City, with an emphasis on "crowns"

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Abstract: The government of Mexico City carried out the introduction of palm trees in the 50s to increase the visual appearance of the main avenues. As a result of introduction of these exotic species, phytosanitary problems appeared. Currently there is scarce information on how to evaluate the health of these majestic monocots, in this sense, it is necessary to implement assessment scales to determine the health condition of the most frequently found species to advance on their care and management. The present study had the following objectives: 1) To determine the current state of health of palm trees by means of a scale of visual evaluation of the crown; 2) To know the diversity and structural characteristics of palm trees and 3) To determine the influence of composite variables on the ecosystem services such as the amount of shade provided. Health of palm trees were evaluated two times (dry and rainy seasons in 2022) on 35 transects of 200 m length. An imaginary circle divided into twelfths was overlapped on palm tree "crowns", and through it, two absolute variables, Live Crown Ratio (LCR) and Crown Quality (CQ) were evaluated. Composite variables were also calculated. The 12/12 health scale adapted in the present study was useful. Four health categories were obtained for the Live crown ratio (LCR): 7.62% of the palm trees were in critical condition, 7.80% were in intermediate condition, 80.36% were in normal condition, and 4.20% were in excellent condition. Meanwhile, for crown quality (CQ), the percentages were 13.50%, 20.00%, 56.96% and 0.43%, respectively. The total height and "crown" diameter showed a positive correlation with the volume composite variables. The shadow area projected as an important ecosystem service increased as the health of the palm trees improved. This is the first study on palm trees health assessment in Mexico City.

Keywords: *Phoenix* sp., Arecaceae, Visual Assessment, Crown Quality, Ecosystem Services

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1. Introduction

To increase the visual appeal of current and potential residents [1], the government and private companies modernize and expand urban infrastructure. These actions have resulted in the introduction of exotic plant species to urban green areas in various parts of the world. As claimed by McKinney (2006) [2], non-native plants represent a high percentage of the biological diversity of urban forests, and although some scientists consider it acceptable, others argue this is a long-term problem. Non-native plants can be a problem because of the subsequent excessive management costs and because there is great uncertainty regarding the possible outbreaks of pests and diseases. As a result of exotic species, the stock of iconic species in various countries has decreased over time [3, 4].

According to CONAFOR (2019) [5], in Mexico, there are 116,449 hectares of palm groves, of which 83% is plantation; in the states of Tamaulipas, Chiapas and Oaxaca, the main species are *Sabal* spp., *Scheelea* spp., *Washingtonia* spp., *Paurotis* spp. and *Erythea* spp., among others [6]. A case that stands out in our country and in many other is the introduction of different species of palm trees into the urban environment; these introduced species may be used as ornamental plants or may be in the form of monoculture [7]. In accordance with Muscarella et al. (2020) [8] y Hodel (2009) [9], no plant species captures the exoticism of the tropics, such as palm trees. These monocots are the most distinctive of the urban landscape, and unlike other woody species, their anatomical and morphological features make them unique.

The palm is considered the tree of life, since humans can sustain themselves exclusively from this type of plant. In accord with Gómez-Amador (2015) [10], the palm provides not only sustenance but also content; for example, the sap of many species can be used to make fermented and distilled beverages that provide joy to the body, soul and mind. Belonging to the Arecaceae family, palm trees were introduced to Mexico for the sole purpose of simulating the tropical and luxurious environment of other cities. It is believed that Miguel Alemán Valdés, who was president of Mexico in the six-year term from 1946-1952, was captivated by these majestic specimens during a brief visit to the United States, and on his return, he ordered the transport and planting of hundreds of palm trees in different colonies of the capital, including Narvarte, Lindavista and, of course, the iconic Paseo de las Palmas in Chapultepec. Today, it is common to see these evergreen palms in almost any green area [11].

Palm trees are not trees, and although most of them prefer warm climates, some of the palm species have adapted perfectly to the climate of Mexico City (CDMX), so much that their propagation occurs naturally when their drupes are deposited on almost any substrate. Depending on the species, they can reach 30 m in height, provide excellent shade and refresh the air. Their enormous foliar area can reflect a shadow equivalent to 15 m^2, or even more, depending on their vigor [12]. Even so, there is controversy regarding the benefits they provide, which according to McPherson et al. (2005) [13] and Hosek and Roloff (2016) [14], are fewer than those obtained from trees. In addition, their rapid acclimatization to the urban environment has caused some species to be considered invasive, so the native species are in danger of being replaced, according to the risk analysis carried out by Rodríguez-Estrella (2019) [15].

More research on palm trees has been carried out in the Middle East (Egypt, Saudi Arabia, Sudan, Iran, Iraq, Pakistan, Oman) [12], East and West Africa, the United States [16], and Spain [17], and this research has focused on phytosanitary problems [18,19]. However, there is little information on how to evaluate the health of these huge monocots, unlike ornamental trees whose health condition has been explored in different contexts [20-22]. Given the complexity, the main studies have focused on different pruning intensities and transplant (e.g., *Phoenix roebelenii* and *Sabal palmetto* cases); nutritional deficiencies [23]; selection of plantation sites [14]; survival from severe climatic events (hurricanes) [24, 25]; preventive endotherapy [17] and, to a lesser extent, health assessment studies.

Pursuant to Blair et al. (2019ab) [26, 27] and Bond et al. (2012) [28], one of the main obstacles is the lack of research on the characterization of palm health within urban green areas; therefore, it is necessary to implement assessment scales that allow determining the current health condition of the most frequently found species to advance their care and management. There have been no previous studies on this issue in Mexico, and concerned about the current decline and death of palm trees (SEDEMA 2022) [29], the present study had the following objectives: 1) To determine the current state of health of palm trees by means of a scale of visual evaluation of the crown; 2) To know the diversity and structural characteristics of palm trees and 3) To determine the influence of composite variables on the ecosystem service such as the amount of shade provided.

2. Materials and Methods

2.1. Study area

Due to the lack of knowledge about the distribution of palm trees in Mexico City, Google Earth images were used to locate and analyze 40 green areas (parks, gardens, sports areas, avenues, etc.) in the search for potential study individuals. Additionally, virtual tours were carried out through the streets and avenues of the city using the same platform and with the support of SEDEMA, SEMARNAT and private companies, more than 20 land tours. Finally, 35 monitoring sites were established in the form of transects with a length of 200 m to evaluate the health condition of the palm trees of Mexico City. The mayoralties included were Azcapotzalco, Benito Juárez, Cuauhtémoc, Gustavo A. Madero, Iztapalapa, Iztacalco, Miguel Hidalgo, Xochimilco, Tlalpan, and Venustiano Carranza (Figure 1).

To observe possible trends in the health of the palm trees, the transects were evaluated on two occasions, taking into account the dry and rainy seasons in 2022 in CDMX. The first was held from May 13 to July 22, 2022, and the second was from August 22 to November 2, 2022.

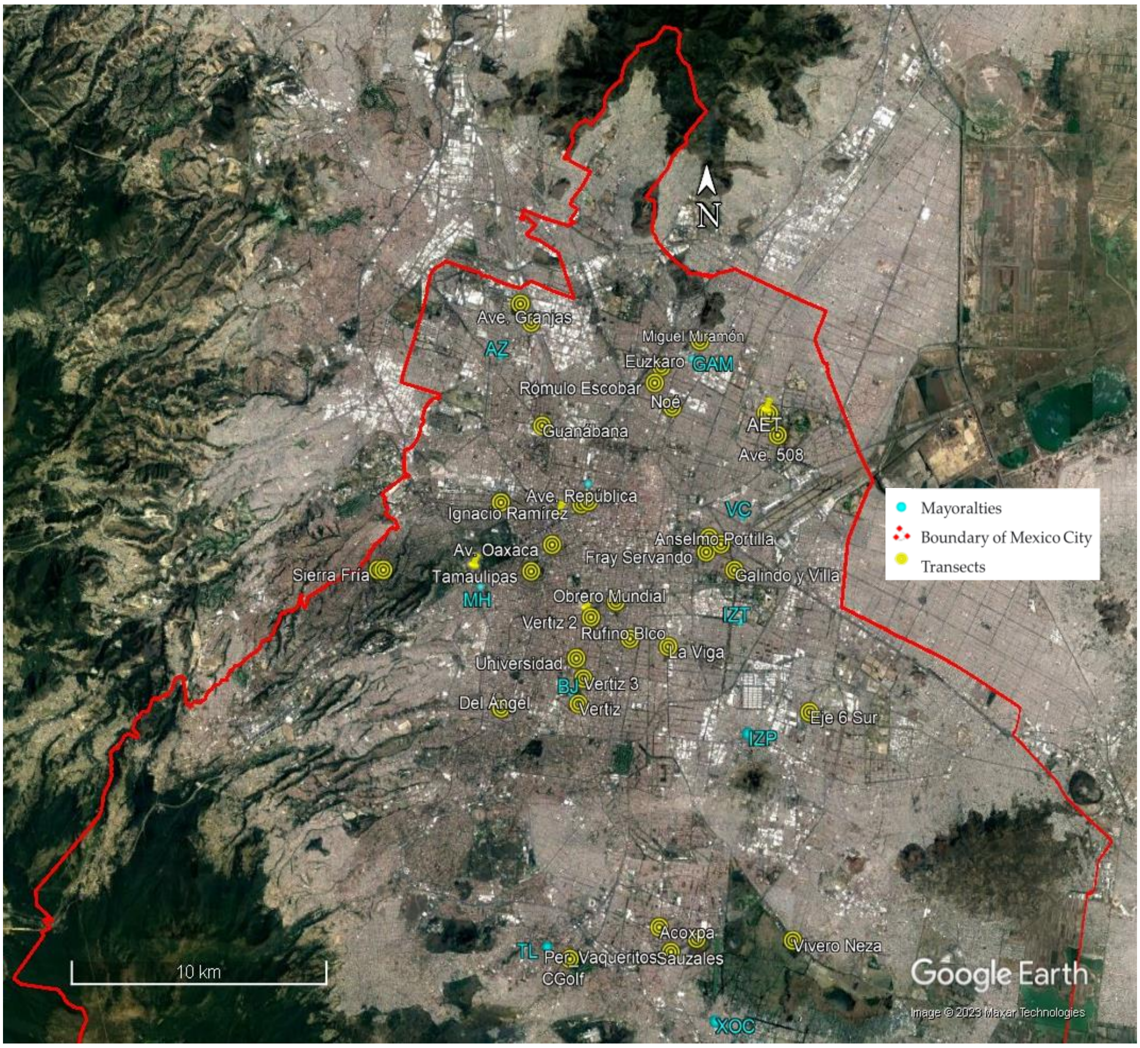


Figure 1. Spatial distribution of the 35 transects in Mexico City, based on the Google Earth 2023.

2.2. *Visual health assessment scale*

Based on the visual health assessment protocols proposed by Blair et al. (2019ab) [26, 27] and Bond (2012) [28], the present scale was adapted to determine the current health status of CDMX palm trees. Considering the spherical shape of the palm trees, the modified scale was composed of an imaginary circle divided into twelfths similar to a clock; this was the first modification (Figure 2), since the scale of Blair et al. (2019a) [26] used segments of tenths. Through it, two absolute health variables were evaluated, and two more referring to the condition and abundance of dead fronds assessed. This method was used for all palm trees in the transects of study. The protocol for the correct use of the scale is described below.

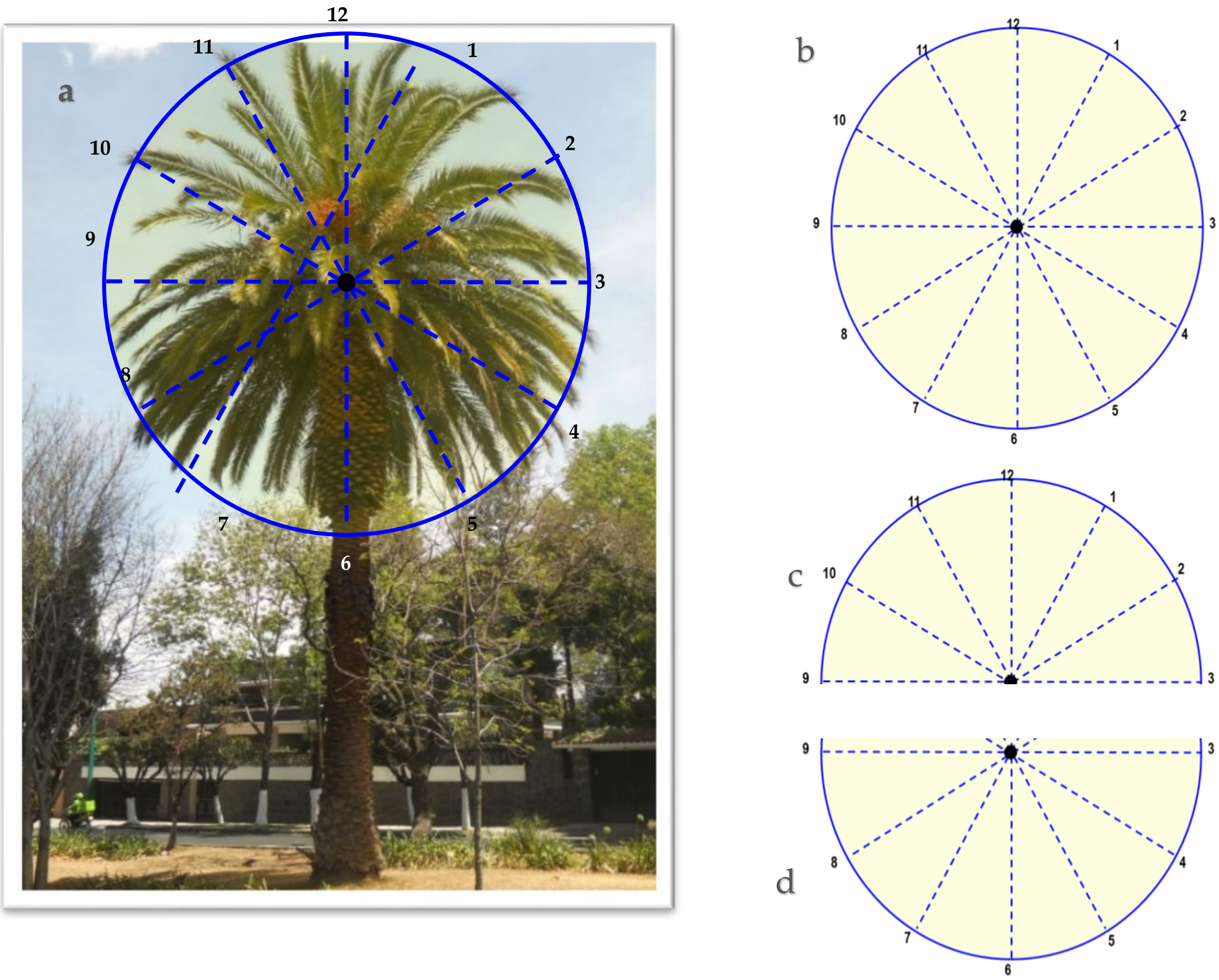


Figure 2. Representation of the visual health assessment scale in palm trees [modified from 26,27,28]. A. Diagrammatic 12-section scale overlapped on the "crown" of a *Phoenix canariensis* specimen. AB. Circumference to evaluate live crown ratio (LCR). C. Upper semicircle, e.g., 9:00-3:00 h, used to determine crown quality (CQ). D. Lower semicircle, e.g., 3:00 to 9:00, used to determine the abundance of dead fronds.

2.3 *Absolute health variables*

2.3.1. Live crown ratio (LCR)

This variable determines the amount of living fronds (young, mature and adult), regardless of their coloration. Use the circle divided into 12 sections (Figure 2AB).

- Enter "0" if the "crown" of the palm tree does not exist or is dead.

- Visualize the center of the circle over the insertion point of the spear blade (Figure 2) and extend the perimeter of the circle to the apex of the fronds (moving the circle closer to or away from eye level).
- Assess each palm tree from a uniform distance (take two measurements, the second in the opposite direction from the first).
- Count the sections of the circle occupied by living fronds, regardless of whether the tissues are discolored due to deficiency or senescence, and go in the clockwise direction (e.g., 10:00-2:00 h).

2.3.2. Crown quality (CQ).

It considers the parts of the semicircle exclusively occupied by green fronds (healthy or asymptomatic, or incipient chlorosis-necrosis at the apex of the leaflets). Chlorotic, brown, senescent or dead fronds were not included. Use the upper semicircle (e.g., hours 9:00-3:00) (Figure 2C). This area would include young and adult fronds that theoretically should be healthy. Blair et al. (2019a) [26] considered only the green, vertical and erect fronds, representing a second modification.

- If the “crown” is dead or missing, enter "0".
- Determine the occupied sections based on the hours of the clock (e.g., 11:00-1:00). Take two measurements, the second in the opposite direction to the first.

2.4. Condition of live crown ratio, and abundance of dead fronds

2.4.1. Condition of the LCR.

The degree of chlorosis and/or necrosis present in fronds in the proportion of living “crown” was determined using the following categories: chlorotic fronds (1-initial, 2-intermediate and 3-advanced) and necrotic fronds (1-initial, 2- intermediate and 3- advanced).

2.4.2. Abundance of dead fronds

The abundance of dead fronds was quantified, specifically in the lower part of the “crown” (lower semicircle, e.g., hours 3:00 to 9:00), assigning the options 1-light, 2-intermediate, and 3-abundant (Figure 2D). This information was collected with the objective of proposing appropriate pruning activities in the short term; in contrast, Blair et al. (2019a) [26] and Bond (2012) [28] did not consider this variable.

2.5. Absolute and composite structural variables

In addition to the identification of the palm species, the following variables were measured in the field: diameter at breast height (DBH, with Haglöf), total height (TH, with Haga gun), crown diameter (CRD, with tape measure), planting ridge width (PRW) and planting distance (PD). Five composite variables, previously studied were calculated [30,31]: Total crown volume (TCV) – it was determined using the formula of a sphere [1]; Volume of the live crown ratio (VLCR); Volume of the crown quality (VCQ); Shadow projection area (SPA) [2] and Basal area (BA) [3].

$$TCV = 4/3\ (\pi\ r^3) \tag{1}$$

$$SPA = \pi\ cr^2 \tag{2}$$

$$BA = 0.7854 * DBH^2 \tag{3}$$

Where: r: radius; cr: “crown” radius; DBH: diameter at breast height.

2.6. Data analysis

With the information collected in the field, a data matrix was created in Microsoft Excel. Dynamic tables were used to organize the information, and the "grouping" function of the same software was used to establish intervals of diameter classes and heights [32]. Linear regression tests and correlation tests (Pearson) were performed between the variables studied, and finally, principal component analysis (PCA) was applied to determine the interrelationships between the absolute and composite variables obtained in the study.

For PCA, a data matrix of 1202 rows (dry and rainy seasons) and 12 columns was analyzed that corresponded to the following variables: diameter at breast height (DBH), total height (TH), crown diameter (CRD), basal area (BA), live crown ratio (LCR), crown quality (CQ), total crown volume (TCV), volume of the live crown ratio (VLCR), volume of the crown quality (VCQ), shadow area projected (SPA), planting ridge width (PRW) and planting distance (PD). Prior to the application of PCA, the data were standardized to a mean = 0 and standard deviation = 1. Only the components with eigenvalues ≥1 that explained high percentages of the total variance were selected. The analysis was performed with InfoStat software ver. 2020 [33] and XLSTAT.

3. Results and Discussion

3.1. Diversity and structure

Palm trees are a multifaceted group of superior plants that, due to their qualities, classify them as makers of new "ecosystems" [34]; therefore, their use as ornamentals has increased substantially for the creation of green areas in residential areas and commercial complexes. Furthermore, has been used as alignment “trees” [14, 35]. In this context, Mexico City is not the exception, since it is estimated that there are approximately 15 thousand palm trees in the entire city [29]; however, basic information on its diversity and dimensions are unknown.

Based on the above, in the present study, 601 palm trees were inventoried in the 35 evaluated transects (Figure 1), and these palms belonged to three species, *Phoenix canariensis* H. Wildpret; *Washingtonia robusta* H. Wendl., and *Syagrus romanzoffiana* (Cham.) Glassman, which represented 77.2%, 20.16% and 2.16% of the population, respectively. The average values of the absolute and composite variables and their respective 95% confidence intervals are shown in Tables 1 and 2.

On average, 17 palm trees were recorded per 200 m transect, which was equivalent to a plantation distance of 11.7 m, an acceptable distance for the optimal development of this type of vegetation [36]. However, palm trees in CDMX are used mainly as alignment elements, so the space was limited to one dimension (i.e., length of the transect). Large specimens are mostly planted in ridges up to 1 m wide, and due to their umbrella shape, it is vitally important that they be planted in open spaces (e.g., roundabouts and monumental sites) [37]; however, in most of the transects, this was not observed.

Table 1. Averages of absolute and composite structural variables of 601 palm trees evaluated at the transects in Mexico City in 2022.

				Confidence interval (95%)	
Variable	**Acronym**	**Average**	**E.E.**	**Lower limit**	**Upper limit**
Diameter at breast height	DBH	73.92	0.82	72.34	75.49
Total height	TH	10.58	0.11	10.37	10.78
Crown diameter	CD	5.71	0.05	5.61	5.82
Total crown volume	TCV	126.36	2.86	120.76	131.97
Basal area	BA	4893.91	94.65	4707.68	5079.09
Planting ridge width	PRW	8.50	0.32	7.87	9.12
Planting distance	PD	11.35	0.17	11.01	11.68

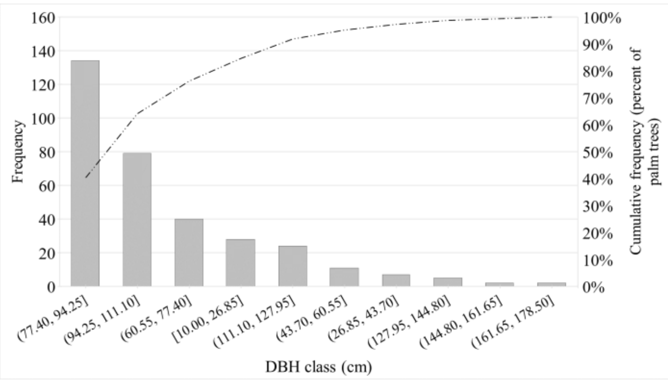
Table 2. Average dendrometric variables by palm tree species.

Variable	*Phoenix canariensis*	*Syagrus romanzoffianna*	*Washingtonia robusta*
DBH	73.92	0.82	72.34
TH	10.58	0.11	10.37
CD	5.71	0.05	5.61
TCV	126.36	2.86	120.76
BA	4893.91	94.65	4707.68
PRW	8.50	0.32	7.87
PD	11.35	0.17	11.01

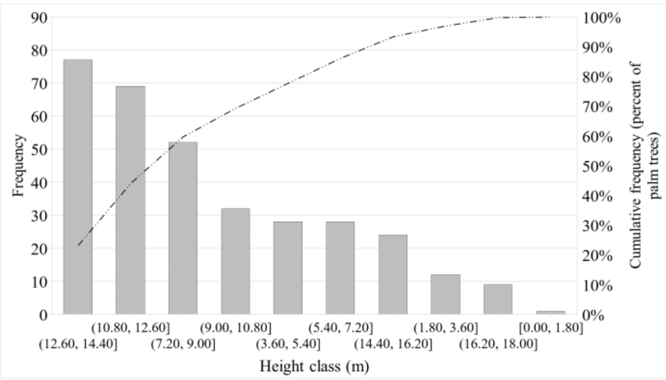
The frequency histograms revealed two predominant diameter classes, the first from 77.40 to 94.25 cm and the second from 94.25 to 111.10 cm (Figure 3A), and two predominant height classes, from 8.40 to 10 m and from 11.60 to 13.20 m (Figure 3B).

By mayoralty, the number of palm trees evaluated, as well as their dimensions, were variable (Figure 4AB), with Gustavo A. Madero, Benito Juárez and Venustiano Carranza having the greatest number of individuals, with 18%, 17% and 13%, respectively. Although the sampling was directed at sites with the presence of palm trees, it is not entirely true that there is a lower abundance of palm trees in the Mayoralties with lower percentages; therefore, it is suggested to extend the study points to the 16 Mayoralties of the CDMX.

Endemic to the Canary Archipelago, *Phoenix canariensis* (Arecaceae) [38] is a long-lived species that has an open growth habitat; in accordance with Sosa et al. (2007) [39], in its center of origin, it is distributed from 50 to 788 meters above sea level and is more abundant in the La Gomera and La Gran Canaria (Canary Islands). This arborescent species reaches 12 to 18 m in height, with a trunk diameter ranging from 0.6 to 1.2 m and a crown diameter ranging from 10 to 12 m, with pinnate and arcuate fronds up to 8 m in length and between 150 and 200 in number. A typical characteristic of the Canarian palm is the abscission scars of the diamond-shaped (rhomboid) fronds, which give the trunk a helical appearance.

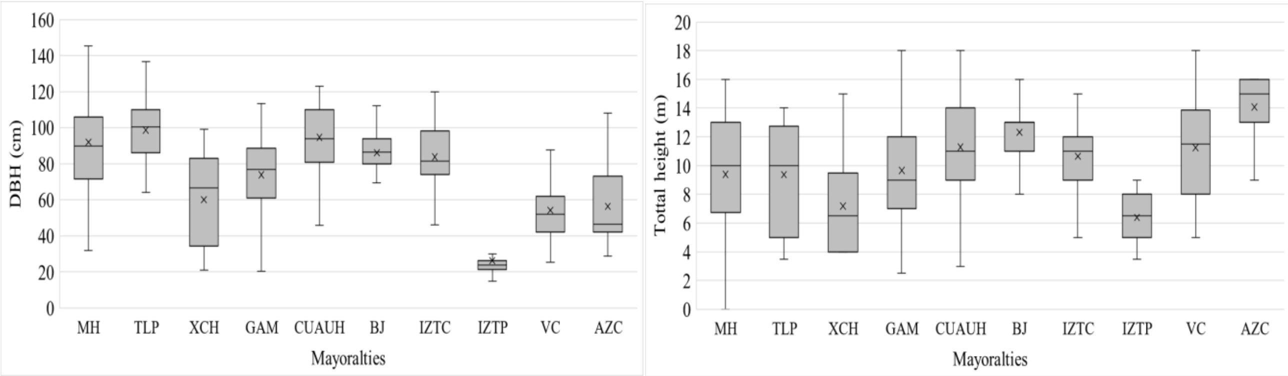


a



b

Figure 3. A. Histograms of frequency and cumulative frequency for diameter at breast height. B. Total height of the 601 palm trees evaluated in the CDMX.



a **b**

Figure 4. A. Diameter at breast height. B. Total height of the 601 palm trees evaluated in the 10 Mayoralties of Mexico City.

Due to the sizes that *P. canariensis* can reach, a minimum planting distance of 5 m is recommended. Its rapid germination (83 to 110 days) at temperatures between 5 and 45 °C and its prolific production of seeds (drupes) (5,000 to 30,000 per year) [36] have made it an invasive species according to Rodríguez-Estrella (2019) [15] (in the case of Mexico), while in countries of the Australasia region (New South Wales, South Australia, Victoria, Norfolk Island, New Zealand, etc.), it is considered a naturalized species, that is, a nonnative species that has been introduced to an area since historical times but is currently maintaining a stable population in balance with the rest of the biological community [40].

Unlike the Canarian palm, *Washingtonia robusta* can reach a height of 15 to 20 m and a diameter similar to that of the first. Its coast-palm fronds are 30 to 1.8 m long and have a high seed production of up to 100,000 a year that can germinate in just 14 days. It is also considered a naturalized species, especially in New South Wales, Western Australia, and the North Island of New Zealand [35].

Syagrus romanzoffiana can reach 10 to 12 m in height and between 30 and 60 in trunk diameter, with pinnate leaves up to 3.5 m long. Its germination is slow, taking between 3 and 6 months.

In accord with Spennemann (2018) [35], the first two species provide important ecosystem services, especially provisioning services, in modified urban and peri-urban areas, and although the entire plant provides various materials, the main contribution to the construction of rural homes is the leaf. It does not need to be coupled with other construction elements [10].

The proper management of urban trees is key in maintaining and increasing their ecosystem services [41]. In this context, managers of green areas must have basic knowledge about the technical data sheet of the species they want to plant to avoid excessive costs in its future maintenance [42], especially when there are health problems. An important element used to assess the health of trees are the crowns, which, depending on their size and condition, can magnify or reduce the different ecosystem services they provide [43]. For example, the mitigation of heat islands, capture of suspended particles and production of shade are some of the most controversial services, as some studies conclude that palm trees provide fewer ecosystem services than their woody counterparts (e.g., ash, oak, pine) [13,14].

Considering this particular ecosystem service, the production of shade, a high correlation was observed between the diameter of the "crown" and the projected shadow area (SPA) (R^2=0.95), which coincides with the results of Franceschi et al. (2022) [30] for ornamental tree species. In CDMX, the identified palms, *P. canariensis, S. romanzofiana* and *W. robusta*, are part of the urban landscape, and their function of beautifying the environment also provides shade for urban and mobile infrastructure, supporting the importance of its preservation.

Although absolute and composite crown variables have been formulated for natural forest species [20,22] and urban green areas [30,44,45], the benefits of the latter are increased because they use multiple dimensions of the crown; therefore, the combined use of both variables can provide information on trends that are unusual for palm resources, thus making monitoring more robust [31].

3.2. Health conditions associated with Live crown ratio and Crown quality

Palm trees are evolutionarily, physiologically and morphologically different from other woody species, which means they provide different ecosystem services [46, 8]; however, these benefits must be quantified regarding the species and region, taking special consideration of their health status. However, palm trees have been excluded from most urban inventories, and few studies have addressed how to evaluate their health [26, 27, 47, 48]. Bond (2021) [49], mentioned some of the variables used to estimate the health condition of urban trees, among which included *vitality, proportion,* and *quality;* however, not all of these variables can be applied for research on Arecaceae. First, *vitality* is defined as the percentage of the upper crown that is free of recent branch death, with fine twigs [= dieback; 22]. Palm trees do not branch, and although there are multicaules such as *Chamaerops humilis* L. and *Dypsis lutescens* (H. Wendl; Beentje & J. Dransf), they do not form true branches; in general, they are formed by one or more rosettes of fronds [50]. Therefore, the vitality could not be measured. Second, the *proportion*, understood as the height of the living crown [31], would give us an erroneous measure, since palm trees such as *P. canariensis* have a geometrically spherical "crown", and indeed, although its diameter could be equated with the height, in such measurements the dead fronds would be included in the lower part of the "crown". Thus, this variable should be adjusted based on tree morphology, which was done in the present study. Finally, *quality* is the percentage of the upper crown absent of necrotic, chlorotic, or smaller tissues.

Based on the above mentioned, in the present study, it was determined that the variables of live crown ratio (LCR) and crown quality (CQ) were important to determine the health condition of palm trees in Mexico City. Thus, it was observed that the LCR presented an average of 8.29 ± 2.01 (mean ± standard deviation), while the CQ had an average of 4.87 ± 1.47. The averages for the variables mentioned in raw form and their standardized values are shown in Table 3.

Table 3. Raw and standardized values for the health variables, crown live ratio (LCR) and crown quality (CQ), in the palms evaluated in the dry and rainy season in Mexico City.

Variable	SD	Min	Q1	Q2	Q3	Max
LCR	2.01	1.0	8.00	8.00	10.00	12.00
CQ	1.47	1.0	4.00	6.00	6.00	10.00
ST_LCR*	1.0	-3.63	-0.15	-0.15	0.85	1.84
ST_CQ*	1.0	-3-32	-0.59	0.77	0.77	3.50

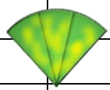
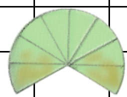
*Standardized LCR and CQ values.

The establishment of health thresholds in woody species is a controversial issue [51] because there are innumerable environmental and genetic factors that influence their condition. In the case of palm trees, it should be taken into account that these are exotic species that are apparently adapted to the city environment of CDMX; however, they do not have the optimal conditions offered by their place of origin [38].

Given the lack of studies and using the research of Blair et al. (2019ab) [26,27] and Bond (2012) [28] as a reference, the standardized values of the LCR and CQ and the raw values (Table 4) were used to determine four health categories. In this sense, palm trees with values in the range of ± 1.0 SD (standard deviation) were considered normal with respect to their LCR, that is, from -0.64 to 0.85 (standardized values), and the excellent category was ≥1.35 (Figure 5A).

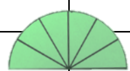
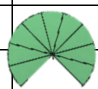
Regarding the CQ, the normal values ranged from 0.09 to 0.77, and those ≥ 2.14 were considered excellent (Figure 5B). Figure 6 uses a color palette to represent the four mentioned categories, including a simple "sketch" of the appearance and condition of the "crown" in each case.

A	ST_LCR											
RAW_ LCR	-3.63	-3.13	-2.63	-2.14	-1.64	-1.14	-0.64	-0.15	0.35	0.85	1.35	1.84
1	C											
2		C										
3			C									
4				C								
5					M							
6						M						
7							N					
8								N				
9									N			
10										N		
11											E	
12												E


Percentages by category: C: 7.62%; M: 7.80%; N: 80.36%; E:4.20%.

B	ST_CQ							
RAW_CQ	-2.64	-1.95	-1.27	-0.59	0.09	0.77	2.14	3.50
1	C							
2		C						
3			C					
4				M				
5					N			
6						N		
8							E	
10								E

Percentages by category: C: 13.50%; M:20.00%; N:56.96%; E:0.43%

Figure 5. Health categories of palm trees obtained from the visual health assessment scale (12/12), adapted from the studies of Blair et al. (2010ab) [26,27] and Bond (2012) [28]. In the vertical dimension, the raw values of the LCR (A) and CQ (B), and in the horizontal dimension, the standardized data (mean = 0, SD = 1.0). *Key colors*: red-critical condition (C), orange-medium condition (M), light green-normal condition (N), and dark green-excellent condition (E). A simple "sketch" of the appearance and condition of the "crown" is included in each case.

At the population level (601 palm trees), 80.36% of the palm trees presented a normal LCR (young, mature and adult living fronds in a range of green and yellowish-green colors) in eight-twelfths of the "crown", while 56.96% presented a normal CQ (Green fronds in the upper six-sixths) (Figure 5 and Figure 6).

Regarding the Condition of live crown ratio, 44% of the palms showed initial chlorosis and 35% initial necrosis. Finally, regarding the Abundance of dead fronds, around 75% of palm trees were qualified with 3-abundant.

a b c d

Figure 6. Categories established to describe the "quality" and quantity of fronds. A. Excellent condition. B. Normal condition. C. Medium condition. D. Critical condition.

In theory, in Phoenix-type palms [52], the youngest and highest quality fronds should be found in the upper part of the "crown" (hours: 10:30-12:00-13:30), the adult (9:00-10:30 and 1:30-3:00) and mature (7:00-9:00 and 3:00-5:00), however, the palm trees evaluated in Mexico City showed chlorosis, necrosis and abnormal size in different sections of the crown. Therefore, through the proposed scale it is possible to obtain: (a) Quantity of live foliage; (b) Quantity of healthy foliage, and (c) Its location. In other words, a CQ=4, in the position from 10:00 to 2:00 (consecutive twelfths) (Figure 2), is better than a CQ=4, in a position from 10:00-11:00 and 13:00-15:00 (discontinuous twelfths). This seemingly basic information, together with the fact that palm fronds are perennial and more prone to increased damage from stressors [14], adds a number of possibilities for defining "quality" categories (Figure 6) and for predicting the probable death of an individual.

Regarding damage categories, it should be noted that due to the low number of palm trees in the advanced category, it was not possible to make comparisons on a statistical basis. Finally, by applying the appropriate criteria and restrictions, the quality (CQ) and quantity (LCR) of live fronds can be added to other quantitative and repeatable evaluation systems to estimate the health of palm trees in other environmental conditions.

Canopy cover, or specifically, the amount and distribution of leaf area, is the driving force behind the capacity of urban trees to produce ecosystem services. As canopy coverage increases, the benefits provided by the foliar area also increase [53]. Therefore, we conclude that with a greater number of fronds, that is, a higher LCR and CQ, the provided benefits will be better, including the amount of shade. According to Robinson (2004) [54], the greener leaves a palm tree has, the more food and growth it will produce; reductions in the green leaf area reduce the production, health and growth of palm trees and indicate the tree is in serious danger.

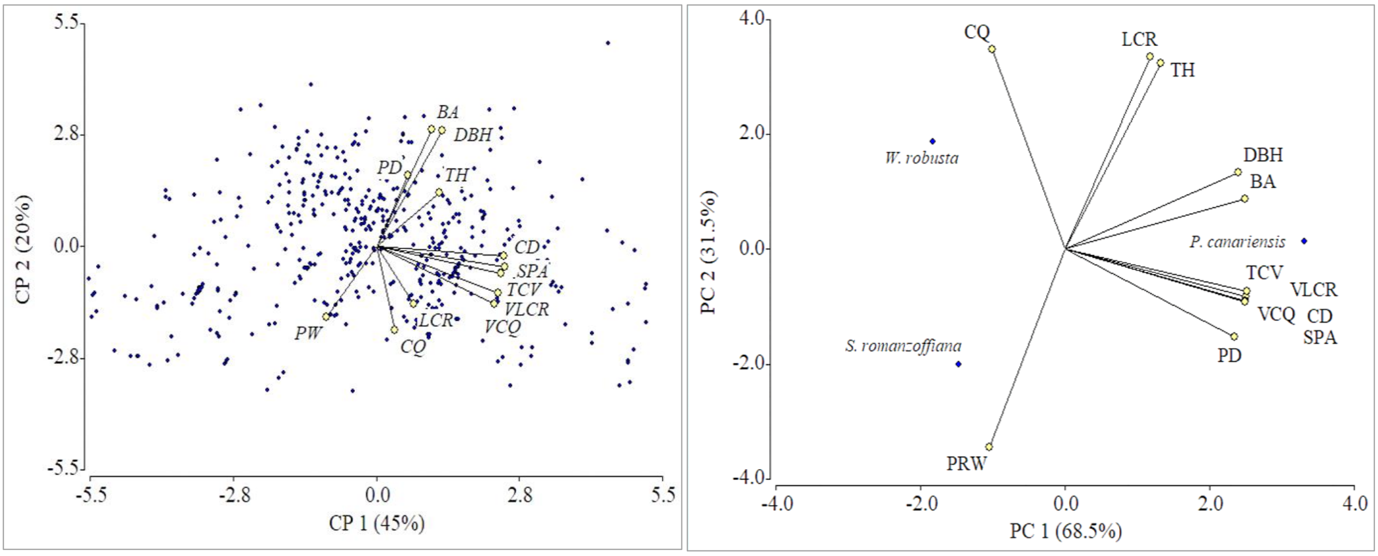
In a previous analysis of the main components, there were no differences by season (dry and rainy). Two more analyses were carried out, where only the data of the dry season were included. The first was a general analysis, and the second considered the species of palm (Table 4).

For the general PCA, three components were obtained, which explained 76% of the total variance. PC1 and PC2, with positive correlation coefficients (in gray shadow), were associated with the dimensions of the palm trees (Table 4). For PC1, at a higher height (0.48) and crown diameter (0.96), the three types of crown volume (TCV, VLCR and VCQ) and the projected shadow area (0.96) also increased, while for PC2, the greater the planting distance (0.46) was, the higher the DBH (0.75) and basal area (0.76) were. Finally, PC3 was associated with the health variables, which presented a negative correlation with the width of the plantation ridge (Table 4; Figure 7a).

Tabla 4. Correlation coefficients with the original variables.

	General			By species	
Variable	**PC 1**	**PC 2**	**PC 3**	**PC 1**	**PC 2**
DBH	0.49	0.75	0.21	0.93	0.36
TH	0.48	0.35	-3.8 E-03	0.52	0.86
CD	0.96	-0.06	-0.15	0.98	-0.22
BA	0.42	0.76	-0.18	0.97	0.23
LCR	0.28	-0.37	0.73	0.46	0.89
CQ	0.14	-0.54	0.63	-0.39	0.92
TCV	0.94	-0.18	-0.24	0.97	-0.24
VLCR	0.92	-0.30	-0.07	0.98	-0.19
VCQ	0.89	-0.37	-0.02	0.98	-0.19
SPA	0.96	-0.13	-0.21	0.97	-0.24
PRW	-0.37	-0.46	-0.50	-0.41	-0.91
PD	0.24	0.46	-0.04	0.92	-0.41

Regarding PCA by palm tree species, two components were obtained (Table 4), which explained 100% of the total variance (Figure 7b). In PC1, eight variables showed positive correlations (in gray shade), showing that the greater the distance from the plantation was, the greater the dimensions of the palm trees were, with respect to the DBH (0.93), CD (0.98), BA (0.97), three volume types (0.97, 0.98, 0.98, respectively) and SPA (0.97), indicating a better relationship for *P. canariensis*. In PC2, the health variables LCR, CQ and TH showed a negative correlation with the width of the ridge and a positive correlation with the planting distance. Therefore, a greater planting distance between individuals along the transect favors the growth in height and health of the palms.



a b

Figure 7. Principal component analysis (PCA). (a) General (only the first two components are shown). (b) By species, as a classification variable.

A final question would be, why is it important to evaluate the health condition of trees and palms in an urban setting? In simple terms, the importance lies in the preservation of the resource and the close relationship with the ecosystem services they provide, and although this study addressed only the ecosystem service of the shadow projection area, there is a long list of other benefits that could be calculated.

Urban "trees" contribute to improving human health and well-being through a multitude of services, some of them including the capture of particulate matter from the atmosphere and the capacity to provide shade [55]. Without doubt, this has contributed to the aspiration of urban planning, and is part of the New Urban Agenda 2030, of which the objectives are to increase the surface of green spaces within cities while also being safe, accessible and of high quality [56]. Knowing the current state of health of our green areas will allow us to predict their future health and the associated risks and plan management activities.

4. Conclusions

The visual health assessment scale adapted in the present study was useful to determine the health condition of the palm "crowns" in the evaluated transects. Its application *in situ* was effective and agile and allowed us to determine the quantity, quality and condition of palms.

Four health categories were obtained for the Live crown ratio (LCR): 7.62% of the palm trees were in critical condition, 7.80% were in intermediate condition, 80.36% were in normal condition, and 4.20% were in excellent condition. Meanwhile, for crown quality (CQ), the percentages were 13.50%, 20.00%, 56.96% and 0.43%, respectively.

The composite variables increased as the total height and crown diameter of the palm trees increased. The shadow area projected, as an important ecosystem service, increased as the health of the palm trees improved.

The dimensions of the palm trees increased as the planting distance increased. In the period between the two evaluations (dry and rainy seasons), no differences were detected in the "crown" condition of the evaluated palms, so it is suggested to continue health monitoring and increase the transects in Mexico City.

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