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El Comité Editorial de Acta Biológica Mexicana revista de la Facultad de Biología de la Universidad Autónoma de Sinaloa, agradece la colaboración realizada como pares evaluadores a investigadores, alumnos, personal académico y administrativo de nuestra institución, así como autores e investigadores de nivel nacional e internacional pertenecientes a universidades, centros de investigación e instituciones tecnológicas. En reconocimiento a sus aportaciones, se divulgan sus nombres y procedencia, lo que permite una publicación de acceso abierto manteniendo la integridad del procedimiento de evaluación de la calidad en Acta Biológica Mexicana Núm. 4, Vol. 1, enero-junio, 2026.

CINTILLO LEGAL

Acta Biológica Mexicana es una publicación semestral editada por la Universidad Autónoma de Sinaloa, a través de la Facultad de Biología, con el domicilio en Ave. Universitarios y Blvd. de las Américas s/n. Ciudad Universitaria, Culiacán Rosales, Sinaloa, México. C.P. 80013. Teléfonos: (667)716-11-39. Editor responsable: Edith Hilario Torres Montoya. Correo electrónico: acbiomex@uas.edu.mx. Reservas de Derechos al Uso Exclusivo Núm. ISSN: 3122-4024. La fecha de última modificación, junio de 2026.

Contenido

Carta del Comité Editorial

Estimadas y estimados lectores,

Acta Biológica Mexicana presenta su cuarta entrega, donde seguimos atentos de los logros científicos del noroeste y México. Esta vez nos complace compartir nuestra primera entrega internacional, lo que nos coloca como una revista que en poco tiempo se posiciona en el contexto de la divulgación científica con alcance regional y nacional. Este número resulta muy versátil, donde destacan tópicos como: el análisis de un sistema de producción de cafetales bajo sombra con importancia en la elaboración tradicional del papel amate en una región de Puebla; el potencial de los fitosomas como sistemas de administración de compuestos bioactivos; un importante aporte en el campo de la etología sobre trasmisión cultural en animales no humanos. Por otra parte, se presenta un importante reporte sobre una especie de caracol invasor en una región de Brasil.

Nuevamente, invitamos a nuestros amables lectores a contribuir con Acta Biológica Mexicana; sus aportaciones, descargas y lecturas hacen la diferencia. Asimismo, nos permiten acrecentar el acervo bibliográfico en materia de biología y biomedicina. Seguimos convencidos de que la divulgación del conocimiento es fundamental para la transformación de las conciencias y el avance de los pueblos, por lo que continuaremos trabajando en esta labor.

Culiacán, Sinaloa, junio de 2026.

ANALYSIS AND QUANTIFICATION OF TEMPERATURE TRENDS BY DIFFERENT METHODS IN THE CENTRAL REGION OF SINALOA, MEXICO

ANÁLISIS Y CUANTIFICACIÓN DE TENDENCIAS DE TEMPERATURA POR DIFERENTES MÉTODOS EN LA REGIÓN CENTRAL DE SINALOA, MÉXICO

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Abstract

Temperature annual trends have been widely used to describe the impact of climate change. Based on daily temperature data of six stations from central Sinaloa, Mexico, we calculated annual temperature means, number of days within temperature ranges, winter and summer seasons and first and fourth quarter means of the estimated temperature variables. Temperature variation among stations was quantified as well as their temporal trends with the Mann-Kendal method. Multivariate analyses were performed for the quarter data sets. Increasing trends were detected for mean temperatures, number of days with elevated temperatures summer days and decreasing trends were detected for days with low temperatures and winter days. Multivariate analyses depicted the homogenization of urban stations. Frequencies of days within temperature ranges and seasonality were important in the description of temperature trends and variation.

Keywords: Climate change, temperature trends, Sinaloa, quantifying methods

Resumen

Las tendencias anuales de temperatura han sido ampliamente usadas para describir el impacto del cambio climático. Con base en datos diarios de temperatura de seis estaciones del centro de Sinaloa, México, se calcularon promedios anuales de temperatura, número de días con rangos de temperatura, estaciones de invierno y

verano; se estimaron promedios de variables del primer y último cuarto de datos. Se cuantificó la variación de temperaturas entre estaciones y sus tendencias con el método Mann-Kendall. Se realizaron análisis multivariados en los cuartos de datos. Se detectaron tendencias positivas de temperaturas medias, días con temperaturas altas y de días de verano, tendencias negativas para reducción de días con temperaturas bajas y de días de invierno. Los análisis multivariados describieron homogeneización de estaciones urbanas. Las frecuencias de días dentro de rangos de temperatura y la estacionalidad son relevantes en la descripción de la variación de temperaturas y sus tendencias.

Palabras Clave: Cambio climático, cuantificación, métodos, Sinaloa, temperatura.

Introduction

According to the Intergovernmental Panel on Climate Change Assessment (IPCC, 2023), recent variations in temperature trends are essentially driven by anthropogenic forced climate change, caused chiefly by CO_2 and other greenhouse gases emissions. The most common approach to analyze temperature trends involve recording daily temperature value: minimum, mean and maximum. From these datum, annual means are calculated (Trewin, 2010). Then, annual means are compared over time using appropriate statistical procedures (Sonali & Kumar, 2013; Mudelsee, 2019). Rising temperatures are widely reported and are one of the main consequences of climate change (Martínez-Austria et al. 2016). In Mexico, climate change by analyzing temperature trends has been reported since the 1950s decade through field data (Wallén, 1955) and has increased steadily incorporating different types of evidence (Metcalfe, 1987) and computer modelling (Liverman & O'Brien, 1991). In northwest Mexico, Gutiérrez-Ruacho et al. (2010) using multivariate analysis found warmer winter conditions; Martínez-Austria et al. (2015) found increasing maximum temperatures for Baja California and southern Sonora.

Another repercussion of climate change is the alteration of seasonality, that is summers lengthening and winters shortening (Wang et al., 2021). In Mexico, Medina-García et al. (2019), reported a decline in typical winter conditions in northwestern

Mexico; Weiss & Overpeck (2005), also documented rising winter temperatures in this region. A common method to quantify seasonal changes is to count the number of days exceeding (or falling below) an arbitrary temperature threshold (Ding et al., 2009; Dong et al., 2009). To date, no such analysis has been done in Mexico.

In Sinaloa, mean temperature differences are more evident along an altitudinal gradient rather than latitudinal. Below 1000 m, annual mean temperatures range from 24°C to 26°C, while above such altitude, means vary between 14 to 22°C. Seasonally, some locations can experience a 10°C differential between summer and winter (Flores-Campaña et al., 2012). This pattern is more pronounced towards the north, where the seasonal temperature differences increase due to an increasing aridity gradient.

Given its geographical position, northwestern Mexico is particularly vulnerable to climate change, which has warmed more rapidly than other regions (Murray-Tortaloro, 2021). Regarding the state of Sinaloa, most studies on climate change have focused on the effects on primary economic activities such as agriculture (Estrada et al., 2022), livestock (Cuevas-Reyes et al., 2024) and shrimp farming (Cota-Durán et al., 2021). Few or none works have examined potential ecosystem responses (Prieto-Torres et al., 2016),

Here, based on the daily data availability of five stations from central Sinaloa, and one from the adjacent state of Durango in Mexico, we estimated the annual trends of the following temperature variables: (1) annual means of minimum, mean and maximum temperatures, (2) quantity of the number of days within an arbitrary temperature rank, (3) length of winter and summer seasons and (4) means of the first and fourth quarter of data sets of the aforementioned variables.

Materials and Methods

Data

Daily temperature data from five meteorological stations of central Sinaloa and eastern Durango in Mexico, was downloaded from the Comisión Nacional del Agua website and processed for its analysis. Selected stations are described in Table 1.

Table 1. Abbreviations, years of data and geographical descriptors of analyzed stations.

Stations	Abbreviation	Years	Latitude (N)	Longitude (W)	Altitude (m)
El Dorado	EDR	1970-1982 1994-1996 2006-2024	24°19’	-107°21’	13
Navolato	NVT	1980, 1983 1999-2024	24°45’	-107°41’	16
Culiacán-CNA	CNA	1961-2024	24°48’	-107°24’	37
Culiacán-UAS	UAS	1995-2000 2002-2024	24°49’	-107°22’	59
Sanalona	SNL	1961-2024	24°48’	-107°08’	154
Tamazula	TMZ	1961-1992 2007, 2010-2024	24°58’	-106°57’	255

The influence of physical environmental features is of paramount relevance for meteorological and climatological variability. Along a transect from the Coastal Plains to the Sierra Foothills, proximity to the coastline can significantly affect temperature regimes via sea-breeze humidity dynamic, which dampens daily temperature oscillation (Zhou et al., 2019). Marine breezes can go inland up to 40 km (Zhou et al., 2021), determining the local climate regime.

Another factor is urbanization, which typically exhibit higher temperatures compared to unmodified (natural) landscapes (Bülüt et al., 2008; Mishra et al., 2015; Chapman et al., 2017). The degree of warming is directly correlated with the spatial extent of the urbanized area such as paved surfaces, built concrete areas and reduced vegetation cover (Liu et al., 2022). Urbanization often reduces the diurnal temperature oscillation by decreasing the difference between daily maximum and nocturnal minimum temperatures (Xu et al., 2013; Tam et al., 2015). This urban-induced warming is particularly relevant in the context of climate change, as it tends to homogenize climatic

characteristics across cities (Groffman et al., 2014). For temperature measurements and trend analyses this is significant, the thermal environment surrounding meteorological stations -whether semi-rural or urban- can introduce bias (Zhang et al., 2021).

The location, character and spatial dynamics of the sampled stations vary considerably. Tamazula, Durango expanded its urban surface from 0.41 km^2 in the early 1980s to 1.2 km^2 in 2022 (INEGI Durango, 2022). Likewise, Sanalona increased its urban area in the same period from 0.41 km^2 to 0.61 km^2. These two stations are situated in very small towns in the Sierra Foothills of the Sierra Madre Occidental, and are predominantly covered by the tropical dry forest, which in recent years has been severely modified with slash-and-burn practices to settle agave plantations or to develop large rural residential plots.

Navolato and El Dorado, located in the Coastal Plains, also experienced urban growth. Navolato increased its size from 3.3 to 7.3 km^2 and El Dorado from 3.6 to 5.2 km^2. These two stations are surrounded by large crop fields. In contrast, both Culiacán stations (Culiacán-CNA and Culiacán-UAS) are embedded in the urban environment of Culiacán, the largest city of the Sinaloa state, whose area has expanded from 62 to 183 km^2 from the late 1970s through 2022 (INEGI Sinaloa, 2022).

According to INEGI (2022), the stations are located along a west-to-east transect spanning three distinct climate zones. Based on the Köppen classification (Fig. 1), at the western extreme El Dorado and Navolato stations are found within a BS0(h') climate: very dry, warm, semi-arid regime with irregular summer rainfall. Moving eastward, the Culiacán-CNA and Culiacán-UAS lie within the urban core of Culiacán, which climate is classified as BS1(h')w, a warm semiarid climate with a summer rainfall regime. Finally, the Sanalona and Tamazula stations situated in the Sierra Foothills, are within an Aw climate area, defined as warm, sub-humid.

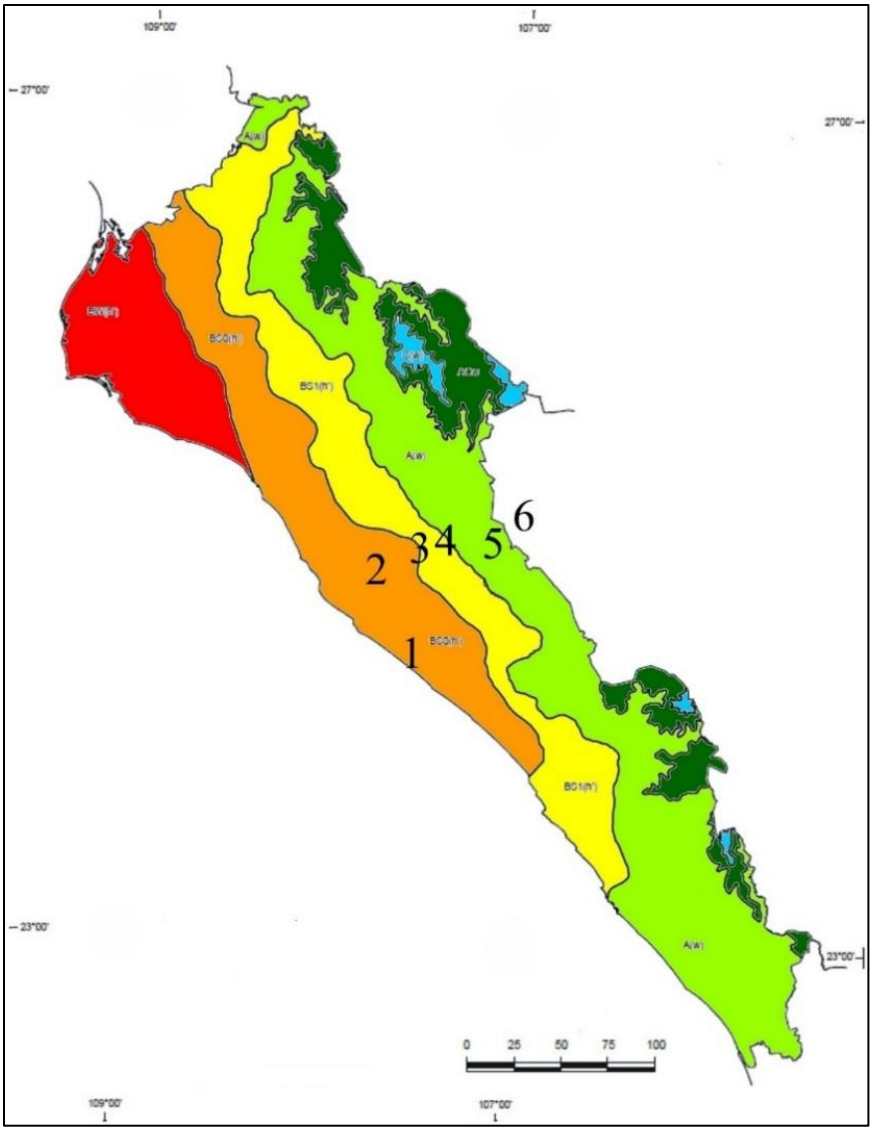

Figure 1. Climate zones of the analyzed stations in central Sinaloa and eastern Durango according to Köppen classification. Colors indicate climate types: dark orange: BS0(h')1; yellow: BS1(h')w; light green: Aw. Station codes: 1= El Dorado, 2 = Navolato, 3 = Culiacán-CNA, 4 = Culiacán-UAS, 5 = Sanalona and 6 = Tamazula.

Annual Means

To analyze temporal changes in annual temperature means, we calculated three basic daily temperature metrics (minimum, mean and maximum) in each station. For minimum temperatures we defined two variables: TMinL the lowest recorded temperature

in each year and TMinL as the annual average of daily minimum records. The annual mean temperature was designated as TMean, estimated as the annual average of daily mean records. For maximum temperatures we considered TMax as the annual average of daily records and TMaxH as the maximum temperature of a particular year. The temperature range (TR) was estimated as the annual average of the daily differences between TMax minus TMin.

Number of Days per Year

To quantify the frequencies of days within determined temperature ranges, we classified daily temperature variation into nine intervals measured in °C: <0, 0-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40 and ≥ 40. For each year of each station, we counted the number of days falling into each bin of minimum (L), mean (M) and maximum (H) temperatures.

Seasonality Dating

To estimate the length of winter and summer seasons, we numbered days of the year sequentially from 1 (January 1st) to 365 (December 31st). Winter End was defined as the last day before summer with a temperature below 10°C; Winter Start was defined as the first day after summer and before December 31st to record a temperature below 10°C.

For summer, we quantified the longest streak of consecutive days with temperatures equal or above 25°C; recognizing that summer heavy rainfall can transiently reduce daily means below this threshold, we required the streak to persist for more than three consecutive days to define season boundaries. The first day was labeled as Summer Start and the last day as Summer End.

Analysis by Data Quarters

As described above, the annual data set is not homogeneous among stations, therefore an alternative approach was adopted to quantify the temporal variation of temperatures *within* each station. To assess the magnitude of change in the proposed variables, for each station the averages of each temperature metric in the first %25 and fourth 25% of its temporal data series were estimated. This approach allowed for direct

contrast, since we could compare the magnitude of change in their respective units of measurements: for temperature annual means in °C, in days for frequencies in Number of Days and for seasonality, specific dates for winter and summer. At each station we tested the differences between the first and fourth quarters with a Mann-Whitney *U* test ($P<0.05$).

Data temporal analysis

First, we estimated temperature mean differences among stations; then, to detect upward or downward trends within temporal variation applying the non-parametric correlation Mann-Kendall test; if a significant trend was detected, then the Sen's slope estimator was computed. To evaluate temperature variation from a wider perspective, we performed multivariate analysis for each quarter of data set.

Results

Annual Means

We detected significant differences for the annual temperature metrics considered among stations. Sanalona exhibited the lowest mean values for TMinL and TMin, while paradoxically displaying the highest values for TMax and TMaxH. The highest minimum temperatures and highest mean temperatures were recorded at Culiacán-UAS station. The largest mean temperature range (TR) occurred at Sanalona, whereas the smallest TR was observed at Culiacán-UAS (Table 2).

Table 2. Means (± SE) of annual temperature from six stations in central Sinaloa. Superscripts letters indicate Tukey *post-hoc* tests ($P<0.05$). Abbreviations as Table 1.

Station	TMinL	TMin	TMin	TMax	TMaxH	TR
EDR	6.5 ± 0.3^{ab}	18.4 ± 0.1^{a}	25.6 ± 0.1^{b}	32.7 ± 0.2^{c}	39.2 ± 0.3^{d}	14.3 ± 0.2^{cd}
NVT	5.6 ± 0.4^{bc}	17.5 ± 0.1^{c}	25.5 ± 0.1^{b}	33.6 ± 0.1^{ab}	42.1 ± 0.3^{a}	16.1 ± 0.2^{b}
CNA	5.8 ± 0.3^{bc}	17.9 ± 0.2^{bc}	25.3 ± 0.2^{bc}	32.7 ± 0.2^{c}	40.5 ± 0.2^{c}	14.8 ± 0.1^{c}
UAS	7.2 ± 0.4^{a}	19.4 ± 0.2^{a}	26.2 ± 0.1^{a}	33.1 ± 0.1^{bc}	40.8 ± 0.1^{bc}	13.7 ± 0.2^{d}
SNL	2.4 ± 0.2^{d}	15.8 ± 0.1^{e}	24.8 ± 0.1^{c}	33.8 ± 0.1^{a}	41.5 ± 0.2^{ab}	18.0 ± 0.2^{a}
TMZ	4.9 ± 0.3^{c}	16.9 ± 0.1^{d}	25.2 ± 0.1^{bc}	33.6 ± 0.2^{ab}	42.2 ± 0.2^{a}	16.8 ± 0.2^{b}

Number of Days

Days with freezing temperatures L(<0°C) were recorded in Navolato, Sanalona and Tamazula stations. Sanalona and Tamazula registered the highest amounts of cold days L(0-10°C). El Dorado and Culiacán-UAS showed the largest amounts of days in the L(25-30°C) ranks (Table 3, annex A1). Regarding mean temperatures, only Culiacán-CNA and Culiacán-UAS did not record temperatures in the M(0-10°C) category. The categories of M(20-25°C) and M(25-30°C) amassed the largest amounts in the six analyzed stations. Culiacán-UAS and Navolato showed the largest number of days in the M(30-35°C) rank (Table 3, annex A1). For maximum temperatures, El Dorado recorded the highest number of days in the H(30-35°C). In the H(35-340°C) bin, Navolato and Sanalona displayed the highest values. Finally, for extreme heat days H(≥40°C), Navolato and Tamazula were the stations with the highest mean annual counts (Table 3, annex A2).

Table 3. Means (±SE) of number of days per year within temperature ranks (°C) of six stations of central Sinaloa and eastern Durango, Mexico. Superscripts denote Tukey *post-hoc* tests (P<0.05).

Low	<0°C	0-10°C	10-15°C	15-20°C	20-25°C	25-30°C	30-35°C	35-40°C	>40°C
EDR	0	17.3±1.7^{de}	103.2±3.1^{ab}	85.6±14.2^{b}	86.4±4.1^{c}	72.6±4.5^{a}	0.14±0.1	-	-
NVT	0.04±0.1	30.1±2.7^{c}	108.1±2.4^{a}	77.8±2.7^{bc}	110.1±3.6^{b}	39.1±3.6^{b}	0	-	-
CNA	0	26.9±2.6^{cd}	98.3±2.3^{ab}	80.6±2.3^{bc}	113.3±2.2^{b}	46.0±3.3^{b}	0.1±0.1	-	-
UAS	0	7.2±1.2^{e}	70.3 ± 4.4^{c}	108.3±3.4^{a}	11.9 ± 3.4^{b}	67.1±3.7^{a}	0.1 ± 0.1	-	-
SNL	0.1±0.1	78.7±2.9^{a}	94.2±16.3^{b}	55.8±1.6^{d}	120.8±1.5^{ab}	15.7±1.2^{c}	0	-	-
TMZ	0.1±0.1	42.0±2.5^{b}	104.4±2.1^{ab}	74.0±2.2^{c}	130.0±1.6^{a}	14.9±1.8^{c}	0	-	-
Mean	**0°C**	**0-10°C**	**10-15°C**	**15-20°C**	**20-25°C**	**25-30°C**	**30-35°C**	**35-40°C**	**>40°C**
EDR	-	0.1±0.1	1.8±0.4^{b}	38.6±2.7^{c}	125.3±2.2^{a}	116.3±3.3^{c}	82.2±3.8^{abc}	0.2±0.1	-
NVT	-	0.1±0.1	2.0±0.5^{b}	50.6±3.1^{ab}	108.6±2.7^{c}	118.1±3.2^{bc}	85.7±3.6^{ab}	0.3±0.1	-
CNA	-	0	2.2±0.4^{b}	48.7±2.9^{abc}	114.6±2.0^{bc}	130.0±2.9^{b}	69.4±5.0^{bc}	0.3±0.1	-
UAS	-	0	0.3±0.2^{b}	25.3±1.9^{d}	118.8±2.3^{ab}	144.3±2.9^{b}	90.3±3.4^{a}	0.2±0.1	-
SNL	-	0.1±0.2	2.0±0.3^{b}	57.1±1.7^{a}	116.1±1.8^{abc}	144.3±2.2^{a}	45.6±2.3^{d}	0.1±0.1	-
TMZ	-	0.2±0.1	7.1±1.1^{a}	41.0±2.3^{bc}	120.6±2.3^{ab}	128.9±3.5^{bc}	67.2±3.4^{c}	0.4±0.1	-
High	**<0°C**	**0-10°C**	**10-15°C**	**15-20°C**	**20-25°C**	**25-30°C**	**30-35°C**	**35-40°C**	**>40°C**
EDR	-	-	0	0.3±0.1^{b}	5.3±0.8^{c}	65.9±4.8a	174.7±4.1^{a}	117.4±7.4^{b}	1.8±0.6^{c}
NVT	-	-	0.1±0.1	1.3±0.7^{ab}	12.4±2.1^{a}	60.4±4.0a	121.6±4.2^{c}	156.6±6.4^{a}	13.7±1.4^{ab}
CNA	-	-	0.1±0.2	0.1±0.1^{ab}	12.3±0.9^{a}	70.6±2.3a	151.9±4.3^{b}	122.8±5.7^{b}	6.7±1.2^{bc}

UAS	-	-	0.1±0.1	0.2±0.1^{b}	7.9±1.1^{abc}	65.3±1.9a	148.9±3.1^{b}	139.5±3.1^{ab}	3.5±0.5^{c}
SNL	-	-	0	0.4±0.1^{b}	6.6±0.5^{bc}	42.3±2.0b	148.7±3.1^{b}	156.4±3.3^{a}	10.8±2.0^{ab}
MZ	-	-	0	1.9±0.5^{a}	11.8± .9^{ab}	38.9±2.6b	157.5±5.7^{ab}	139.1±6.9^{ab}	15.9±2.0^{a}

Seasonal Dating

Culiacán-UAS station showed the shortest winter, that lasted until February 16th, the earliest summer start (April 20th), the latest summer end (November 17th) and winter Start (December 23rd). On the contrary, Sanalona showed an exactly inverse pattern, by recording the latest Winter End, Summer Start, earliest Summer End and Winter Start (Table 4).

Table 4. Means ± SE of year day for winter and summer seasons. Lower rows = date. Superscripts denote Tukey *post-hoc* tests (P<0.05).

Stations	Winter End	Summer Start	Summer End	Winter Start
El Dorado	61.6 ± 5.3	124.7 ± 1.8	315.8 ± 1.7	352.3 ± 2.1
	(Mar 2nd)^{c}	(May 5th)^{a}	(Nov 12th)^{ab}	(Dec 18th)^{ab}
Navolato	75.5 ± 4.0	121.3 ± 1.9	316.2 ± 2.1	343.4 ± 2.4
	(Mar 17th)^{bc}	(May 1st)^{ab}	(Nov 12th)^{ab}	(Dec 9th)^{cd}
Culiacán-CNA	68.7 ± 3.9	120.3 ± 2.4	312.1 ± 1.4	347.9 ± 1.9
	(Mar 10th)^{bc}	(Apr 30th)^{ab}	(Nov 8th)^{bc}	(Dec 14th)^{bc}
Culiacán-UAS	47.0 ± 5.1	109.6 ± 2.3	321.0 ± 1.7	357.9 ± 1.7
	(Feb 16th)^{d}	(Apr 20th)^{c}	(Nov 17th)^{a}	(Dec 23rd)^{a}
Sanalona	103.8 ± 1.9	123.7 ± 1.0	303.8 ± 1.1	327.8 ± 1.6
	(Apr 14th)^{a}	(May 4th)^{a}	(Oct 1st)^{d}	(Nov 24th)^{e}
Tamazula	80.5 ± 2.7	114.0 ± 2.0	308.2 ± 1.5	338.6 ± 1.8
	(Mar 22nd)^{b}	(Apr 24th)^{b}	(Nov 4th)^{cd}	(Dec 5th)^{d}

Temporal Trends of Annual Means

Two thirds of the stations temperature annual means exhibited increasing trends. Fourteen trends were statistically significant. TMean showed positive increasing trends in all the stations. TR showed decreasing significant trends in Navolato, Culiacán-CNA and

Culiacán-UAS. Sanalona was the only station that displayed an increasing trend for TR (Table 5).

Table 5. Mann-Kendall Sen's slope values of temporal trend analysis of annual temperature means. Abbreviations as in main text and Table 1. $^{+}$(*P*<0.01), *(*P*<0.05), **(*P*<0.01), ***(*P*<0.001), ns = non-significant, NT = no trend detected.

Station	TMinL	TMin	TMean	TMax	TMaxH	TR
EDR	0.061^{+}	-0.009 ns	0.011 ns	0.038 ns	NT	0.017 ns
NVT	NT	0.035*	0.012 ns	-0.024 ns	NT	-0.068*
CNA	0.075***	0.058***	0.056***	0.054**	0.065***	-0.007^{+}
UAS	0.082 ns	0.052***	0.034***	0.012 ns	NT	-0.040**
SNL	-0.010 ns	-0.018**	0.006*	0.032*	NT	0.049***
TMZ	0.047***	0.035***	0.037***	0.044***	NT	0.010 ns

Temporal Trends of Seasonal Dating

All stations except Sanalona exhibited decreasing trends for Winter End (earlier ending dates). In addition, Winter Start advanced (produced later onset dates) at El Dorado, Culiacán-CNA, Culiacán-UAS and Tamazula. For summer season, El Dorado, Culiacán-CNA, Culiacán-UAS and Tamazula reported trends towards earlier summer onsets and later summer ending (Table 6).

Table 6. Sen's slope values of the Mann-Kendall temporal trend analysis of Seasons Dating variables. *(*P*<0.05), **(*P*<0.05), ***(*P*<0.001), ns = non-significant, NT = no trend detected.

Station	Winter End	Summer Start	Summer End	Winter Start
El Dorado	-1.583*	-0.579***	0.385***	0.333 ns
Navolato	-1.194 ns	-0.167 ns	-0.258 ns	-0.069 ns
Culiacán-CNA	-1.039***	-0.826***	0.457***	0.587***
Culiacán-UAS	-0.575 ns	-0.881***	0.080 ns	0.183*
Sanalona	0.667 ns	0.154 ns	0.333 ns	NT
Tamazula	-0.594***	-0.500***	0.263***	0.267***

Analysis by Data Quarters

Data quarters of annual temperatures

Across all the analyzed stations, the means of TMinL, TMin, TMean, TMax and TMaxL exhibited an overall increase of ≈1.1°C between quarter data sets. The largest average increments detected were observed in TMin (+1.5°C) and TMean (+1.0°C). The comparison of annual temperature metrics between the initial and final quarters within stations revealed that at El Dorado TMinL and TMean showed a significant increase of 2.3 and 0.5°C respectively (annex 1A). In Navolato (annex 1B), TMin increased significantly (+0.63°C). At Culiacán-CNA all the compared variables except TR exhibited significant upward trends: TMinL increased 3.8°C, TMin 3°C, TMean 2.8°C, TMax 2.7°C and TMaxH 3.3°C (annex 1C). For Culiacán-UAS depicted in annex 1D, TMin and TMean increased significantly by 1.1 and 0.72°C respectively, while TR decreased 0.74°C. In Sanalona (annex. 1E), TMin decreased -0.74°C, whereas TMean and TMax increased 0.41°C and 1.6°C. Finally, at Tamazula in annex 1F, TMinL, TMin, TMean and TMax rose significantly 1.6°C, 1.1°C, 1.6°C and 2.1°C respectively, while TR declined 10°C.

Analysis of Number of days by data quarters

For low temperatures, at El Dorado there was a significant increase in the L(20-25°C) rank (+34 days) and a decrease in the L(25-30°C) category (-30 days) (annex 2A). In Navolato, only the L(25-30°C) category showed a significant increase (+26 days) (annex 2B). Culiacán-CNA showed significant decreases in the L(0-10°C) and L(10-15°C) with -43 and -27 days respectively, whilst significant increases in the L(15-20°C) and L(25-30°C) categories (+31 and +49 days) depicted in annex 2C. In Culiacán-UAS, the number of days in the L(0-10°C) rank decreased by 9 days and the L(10-15°C) also decreased (-25 days), but the L(15-20°C) and the L(25-30°C) ranks increased significantly 21 and 26 days respectively (annex 2D). In Sanalona, an increase in the L(0-10°C) rank (+16 days) and significant decreases (-9 days) in L(15-20°C) and L(25-30°C) (annex 2E) was detected. In Tamazula, a decrease in L(0-10°C) and an increase in L(15-20°C) were detected, with -24 and +14 days respectively (annex 2F).

Regarding the ranks for mean temperatures, in El Dorado the M(10-15°C) and M(15-20°C) decreased by -2 and -20 days, whereas M(25-30°C) increased by 27 days (annex 3A). In Navolato, a significant decrease was observed in M(25-30°C) with -27 days, while M(30-35°C) showed an increase of +26 days (annex 3B). At Culiacán-CNA, four significant changes were detected: decreases in M(15-20°C), M(20-25°C), M25-30°C) of -47, -10 and -28 days correspondingly and an increase of +89 days for the M(30-35°C) bin (annex 3C). In Culiacán-UAS there was a significant reduction of -10 days in the M(15-20°C) category and a rise of +23 days for the M(30-35°C) rank (annex 3D). Sanalona showed a positive trend in M(30-35°C) of +15 days (annex 3E). In Tamazula, significant decreases were measured in M(10-15°C) (-6 days), M(15-20°C) (-28 days) and in the M(20-25°C) (-22 days) and increases in the M(25-30°C) and M(30-35°C) with +32 and +25 days per year (annex 3F).

In reference to maximum temperatures, in El Dorado there was a decrease in the H(25-30°C) of -32 days and an increase in extreme heat days H(≥40°C) of +5 days (annex 4A). Navolato did not exhibited any significant change (annex 4B). At Culiacán-CNA significant decreases occurred in the H(20-25°C), H(25-30°C) and H(30-35°C) with -13, -30 and -68 days per year while H(35-40°C) and H(≥40°C) increased by +96 and +16 days respectively (annex 4C). In Culiacán-UAS no significant changes were found (annex 4D). In Sanalona, the number of days decreased in H(20-25°C), H(25-30°C) and H(30-35°C) with -3, -22 and -36 days, yet H(35-40°C) and H(≥40°C) increased by 45 and 16 days per year (annex 4E). In Tamazula, significant declines were observed for H(20-25°C), H(25-30°C) and H(35-40°C) (-6, -23 and -84 days), while H(35-40°C) and H(≥40°C) increased by +103 and +12 days per year (annex 4F).

Analysis of Seasonal Dating by quarters

On average Winter End retreated by 21 days while Winter Start was delayed by 10 days. Summer onset moved earlier by approximately 15 days across all stations and Summer End was extended in average 8 days. In Culiacán-CNA was detected the largest change for Winter End from April 10th to February 12th (-56 days) and Winter Start shifted from December 1st to December 26th (+25 days). Summer Start moved *backwards* from May 21st to April 12th (-40 days) and summer season extended from October 26th to

November 18th (+23 days). The stations of El Dorado, Culiacán-CNA and Tamazula developed the same pattern, with earlier Winter Ends and Summer onsets as well as later Summer Ends and Winter Starts. Culiacán-UAS only showed an earlier significant Summer Start. None of the changes detected in Navolato and Sanalona were statistically significant (Table 7).

Table 7. Seasonal day of the year of the first and fourth quarters of data of six stations of central Sinaloa, Mexico. Asterisks = *U* Mann-Whitney test, **(*P*<0.05), ***(*P*<0.001).

		Winter End		Summer Start		Summer End		Winter First	
		1QT	4QT	1QT	4QT	1QT	4QT	1QT	4QT
EDR	Day	92.7	53.7***	133.2	117.7***	310.6	321.9***	344.7	358.1**
	Date	Apr 3rd	Feb 23rd	May 13th	Apr 27th	Nov 7th	Nov 18th	Dec 11th	Dec 24th
NVT	Day	80.7	82.9	125.3	123.3	319.4	311.9	341.3	344.7
	Date	Mar 22nd	Mar 24th	May 25th	May 3rd	Nov 15th	Nov 8th	Dec 7th	Dec 11th
CNA	Day	99.6	43.3***	141.2	101.6***	299.3	322.0***	335.1	360.4***
	Date	Apr 10th	Feb 12th	May 21st	Apr 12th	Oct 26th	Nov 18th	Dec 1st	Dec 26th
UAS	Day	62.1	56.0	119.4	100.7**	320.0	318.9	352.0	358.6
	Date	Mar 1st	Feb 25th	Apr 29th	Apr 11th	Nov 16th	Nov 19th	Dec 18th	Dec 25th
SNL	Day	109.3	107.8	122.5	126.7	300.3	305.8	326.5	325.8
	Date	Apr 19th	Apr 18th	May 3rd	May 7th	Oct 27th	Nov 2nd	Nov 23rd	Nov 22nd
TMZ	Day	87.4	64.3***	118.5	98.9***	303.9	318.9***	337.1	348.0**
	Date	Mar 28th	Mar 5th	Apr 29th	Apr 9th	Oct 31st	Nov 16th	Dec 3rd	Dec 14th

Multivariate analysis

The principal component analysis (PCA) performed on the first-quarter data set explained almost 70% of the total variation. Principal component 1 (PC1), which accounted 41.9% of variation was positively correlated to TMin, M(30-35°C), L(15-20°C), Winter Start and TMinL, the main negative loadings were: L(0-10°C), M(25-30°C), Winter End, M(15-20°C) and TR. PC2, which explained 26.8% of variation, was built up in its positive side by TMaxH, TMax, H(≥40°C), (H(35-40°C) and TR; on the negative sector, Summer Start, H(25-30°C) M(15-20°C) H(20-25°C) and H(15-20°C) were the main loadings (annex 1).

The PCA of the fourth quarter of data explained over 75% of total variation in their first two principal components. PC1 depicted 53.9% of variation, the main loads were in its positive side: Winter End, L(0-10°C), Summer Start, M(15-20°C) and M(10-15°C); the largest negative loads were: L(15-20°C), TMean, TMin, Winter End and Summer End. For PC2 (23.4% of variation), the positive main loads were: TMax, L(<0°C), M(0-10°C), L(20-25°C) and H(35-40°C), the negative main loadings were: H(25-30°C), L(25-30°C), H(20-25°C), M(30-35°C) and TMin (annex 2).

The bi-plot of *z*-standardized scores for the multivariate analysis (Figure 6), depicts the transition of the stations first quarter data set in blue figures to the fourth quarter data set in red figures. The distribution of the first quarter draws Navolato, UAS and El Dorado associated to variation of TMin, M(30-35°C), L(15-20°C), Winter Start and TMinL. Tamazula, Sanalona and CNA were associated to L(0-10°C), M(25-30°C), Winter End, M(15-20°C) and TR. Also, CNA and El Dorado were clustered in PC2 by Summer Start, H(25-30°C), M(15-20°C), H(20-25°C) and H(15-20°C); Sanalona, Tamazula, Navolato and UAS were correlated in the positive sector to TMaxH, TMax, (H≥40°C), H(35-40°C) and TR.

The fourth quarter *z*-scores depicted in red, congregated Sanalona and Navolato in the positive sector linked to Winter End, L(0-10°C), Summer Start, M(15-20°C) and M(10-15°C); Tamazula, CNA, UAS and El Dorado were clustered by L(15-20°C), TMean, TMin, Winter End and Summer End. PC2 separated Tamazula and Sanalona correlated to TMax, L(<0°C), M(0-10°C), L(20-25°C) and H(35-40°C). CNA, UAS, El Dorado and

Navolato were congregated by Summer Start, H(25-30°C), M(15-20°C), H(20-25°C) and H(15-20°C) (Figure 2).

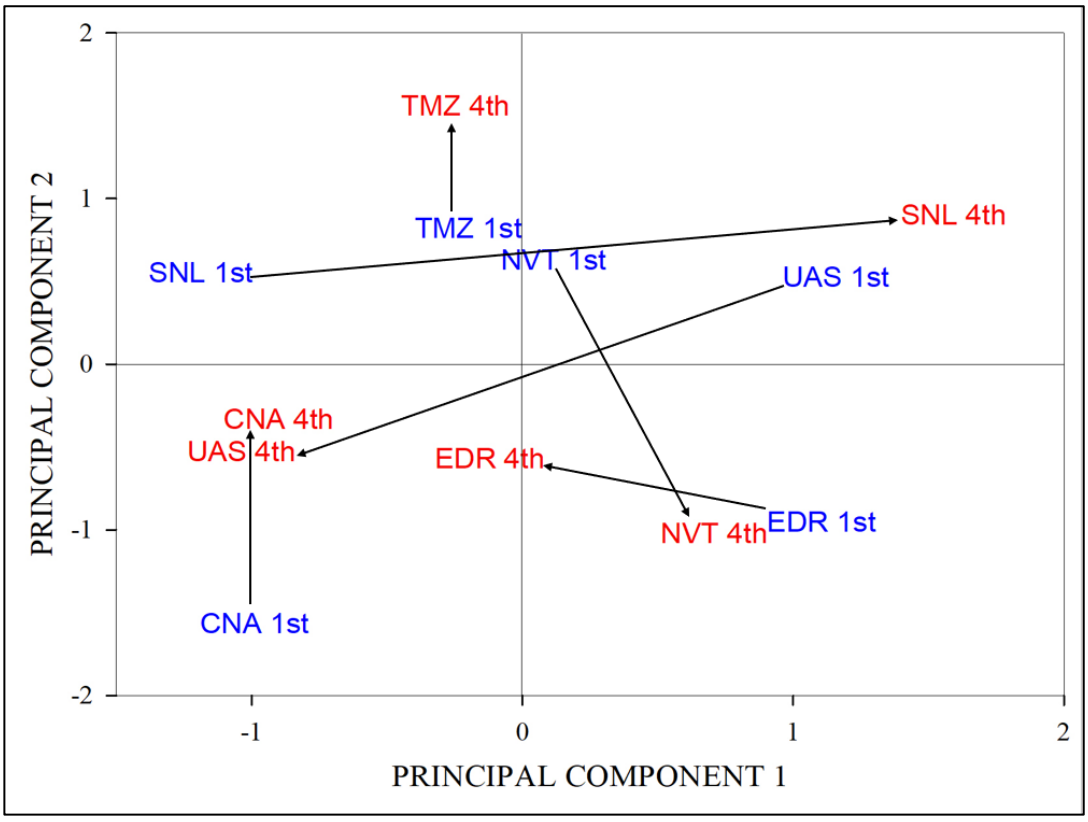

Figure 2. Bi-plot of *z*-scores of first (blue figures) and fourth (red figures) temperature data sets.

Discussion

The analysis of annual temperature means, depicted that temperature metrics TMinL, TMin, TMaxH and TR, exhibited a spatial pattern. The lowest values of TMinL, TMin and conversely the highest values of TMaxH and TR (except Navolato), were observed at Sanalona and Tamazula stations. This pattern can be attributed to a greater distance from the coast (≈90 and ≈110 km, respectively) to these stations, where an absence of marine humidity and sea breezes result in less thermal moderation. Inversely, stations as El Dorado (≈9km) and Navolato (≈25 km), displayed a scarce oscillation in

temperature, most likely due to higher humidity levels associated to coastal proximity as reported by Zhou et al., (2019) and Zhou et al., (2021).

A notable feature is the influence of urban heat-island effect at Culiacán-CNA and Culiacán-UAS stations, which recorded the highest TMin and TMean values. This pattern aligns with the observations of Bülüt et al., (2008), Mishra et al., (2015) and Chapman et al., (2017), as well as the process described by Groffman et al., (2014) and Tam et al., (2015), who reported increased and homogenized temperature variation (i.e. reduced TR).

Although the largest inter-station difference is rather scarce (≈1.4°C) for TMean, this variation is sufficient to divide stations into three distinct groups based solely on this variable. This outcome underscores the importance of interannual variation in TMean at each station, demonstrating its utility for achieving a finer spatial resolution in climatic variation analysis at this scale.

Regarding annual means of Number of Days per Year, in Navolato, Culiacán-CNA, Sanalona and Tamazula stations, a clear pattern was detected in low temperature categorization, where the L(10-15°C) depicted low temperatures of winter days and L(20-25°C) accounted for low records of summer days. The higher number of L(0-10°C) days at Sanalona and Tamazula may be explained by their proximity to the western slopes of the Sierra Madre Occidental. For mean temperatures, the majority of days were in the M(20-25°C) and M(25-30°C) ranks, both accounting for 65.8%% of the year days among stations; however, slight inter-stations differences were detected at El Dorado and Sanalona, where the M(20-25°C) category was more frequent, whereas at Navolato, Culiacán-CNA and Culiacán-UAS the M(25-30°C) category predominated. This pattern might be explained by the influence of greater urbanization, nevertheless data of Tamazula diverge from this pattern and warrant further analysis. As for maximum temperatures, nearly 80% of the accounted Number of Days were classified in the H(30-35°C) and H(35-40°C) ranks. On average, Navolato and Sanalona exhibited a larger proportion of H(35-40°C) days, in the remaining studied stations, the H(30-35°C) ranks proportion was larger.

Seasonality means values illustrated a marked pattern. Based on the temperature-defined dates, Sierra Foothills stations Sanalona and Tamazula showed the longest winters and shorter summers. Coastal stations depicted an inverse pattern: shorter winters and extended summers; within these stations, Culiacán-CNA and Culiacán-UAS showed the earliest summer starts and latest summer ends, this result can be associated to the effect of the large size of Culiacán and its urban heat-island effect, which likely might elevate minimum and mean temperatures and modifies thermal dynamics relative to more rural and less urbanized environments surrounding stations (Bülüt et al., 2008; Mishra et al., 2015; Chapman et al., 2017).

Variables TMin, TMean and TMax exhibited the highest frequency of significant upward trends, corroborating previous findings of Gutiérrez-Ruacho et al., (2010) and Martínez-Austria et al., (2015). Among stations, Culiacán-CNA displayed the greatest number of significant trends, with almost all temperature metrics showing marked increase; its observed decrease in TR indicates that Culiacán climate is becoming warmer, with reduced differences between in temperatures extremes, a clear indication of the effect of urban heat-island effect matching findings of Bülut et al., (2008). In contrast, El Dorado and Navolato, exhibited only slight significant increases in low-temperature metrics, nevertheless these results meet the fading-winter trends described by Weiss & Overpeck (2005) for northwest Mexico.

Shortening of winter and lengthening of summer seasons in El Dorado, Culiacán-CNA, Culiacán-UAS and Tamazula are consistent with trends reported in other regional and global studies (Weiss & Overpeck, 2005; Song et al., 2009; Medina-García et al., 2019; Wang et al., 2019). In contrast, Navolato and Sanalona remained seasonally stable over the time period studied, but their contrasting differences in low and high temperatures indicate a clearcut seasonal change.

By quarters of data, all these observations of mean temperatures are consistent with northwest Mexico warming scenario depicted by Martínez-Austria et al., (2015). Large urbanized areas (Culiacán-CNA, Culiacán-UAS and Navolato) reported increasing temperatures with decreasing TR, a pattern commonly associated to urban heat island-effect, as detailed by Tam et al., (2015). One key driver of this pattern appears to rise

nighttime temperatures, reflected here as an increase in TMin. In El Dorado and Navolato stations, the largest intra-quarter temperature differences occurred in minimum temperatures whereas other variables remained largely unchanged. Such behavior is akin to the reports of Weiss & Overpeck (2005).

The three categories of Number of Days per year -Low, Mean and High temperatures- showed a consistent pattern in the quarter comparisons, lower temperature ranks exhibited decreases whilst higher temperature ranks increased in their frequencies across categories; these patterns coincide with the findings of Park et al., (2018), Ding et al., (2009) and Zhu et al., (2022), who documented a decrease in the number of cold days and increases in warm-day frequencies.

In reference to Seasonal dating through data quarters, the analysis also showed substantial changes. With the exceptions of Navolato, all the stations developed similar patterns of shorter winters and longer summers; this is consistent with the results documented by Wang et al., (2021).

In the PCA analysis, Number of Days was most frequent type of variable making-up the principal component of total variation, with over half of the total main loads. For first quarter PC1, variables related to low temperatures were the main source of variation. Contrastingly, in PC2, eight out of ten of the main loadings were related to high temperatures. For the fourth quarter of data, in PC1, Number of Days and Seasonal Dating were the main types of variables. The fourth quarter of data clearly differentiates Coastal from Sierra Foothills stations, here Tamazula and Sanalona were highly correlated to variables depicting extreme temperatures; even further, Culiacán-CNA, Culiacán-UAS and El Dorado were clustered together related to the three types of variables that depicted median conditions of temperature, these results clearly describe the effects of urbanization as stated by Groffman et al. (2014).

Conclusions

Temperature variables that mainly defined spatial variation among stations were TMinL, TMin and TR, due to the moderating influence of sea breezes at coastal sites. Also, is evident that urban heat-island effect exerts a pronounced effect on temperature

behavior of both Culiacán stations and has less effect in the remaining stations. In the category of low temperature for Number of Days ranks, it is clear a differentiation of cold winter and cool summer records; in a different way, mean and high temperatures occur concentrated on M(20-25°C), M(25-30°C) and H(30-35°C), H(35-40°C) ranks respectively. Urban heat-island effect reduces winter onset and extends summers in Culiacán stations and its effect decreases gradually heading into less urbanized areas.

There is an overall temperature increasing trend in the studied region, that can be mirrored in mean annual temperatures, decreasing Number of Days with low temperature records, shortening winters and lengthening summers. All of these trends, set for a warning as ecosystem alter their functions, primary economic activities can get disrupted and even human daily activities might get interrupted on a daily and seasonal basis.

The multivariate analysis revealed a clear homogenization among the stations Culiacán-CNA, Culiacán-UAS and El Dorado. This result underscores the urban-heat island effect as a key driver of thermal convergence among urbanized sites. Moreover, the analysis demonstrated that additional temperature metrics beyond traditional mean values -such as Number of Days per year and Seasonality dating- are valuable to characterize temperature variability in a more comprehensive way.

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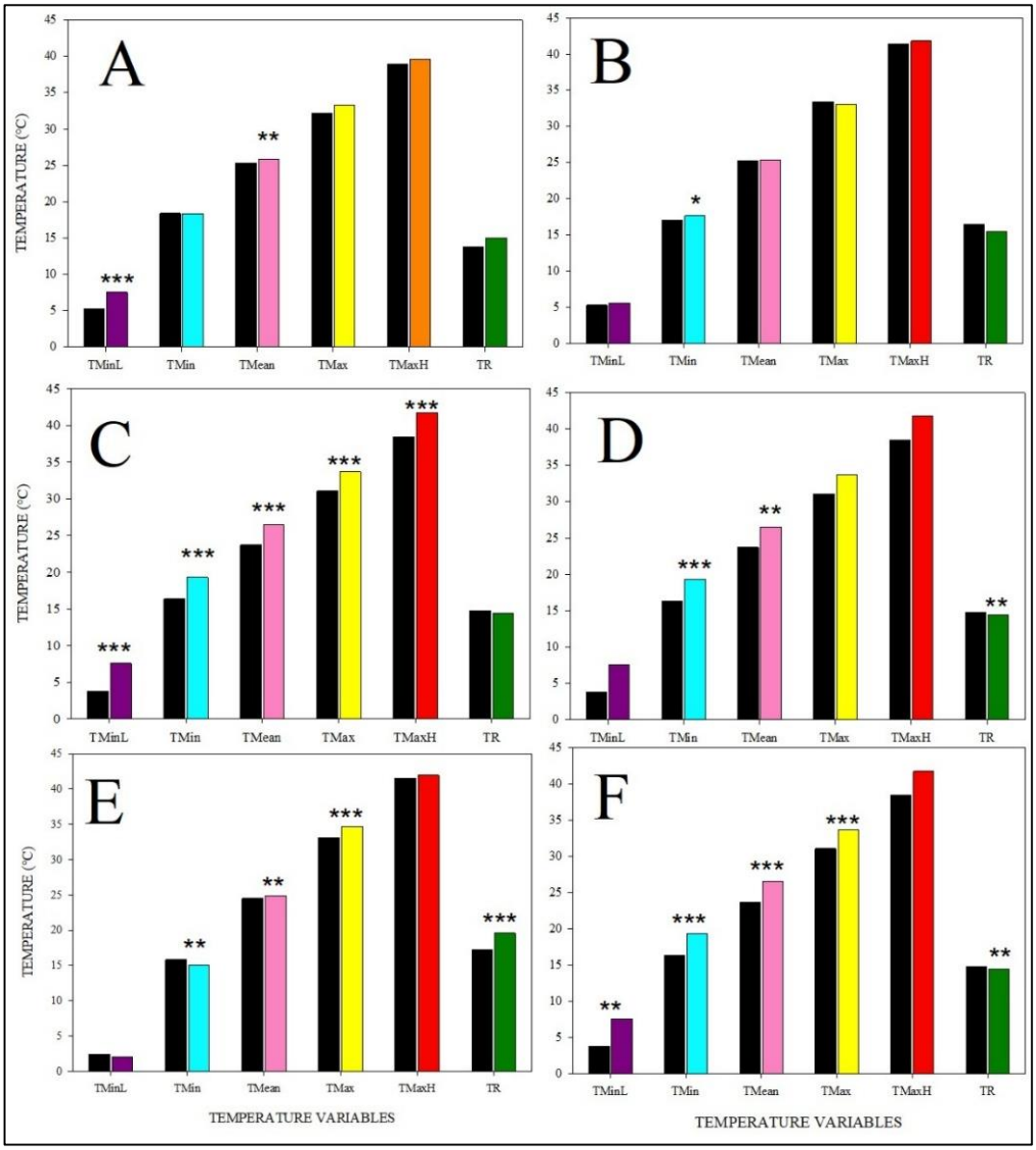
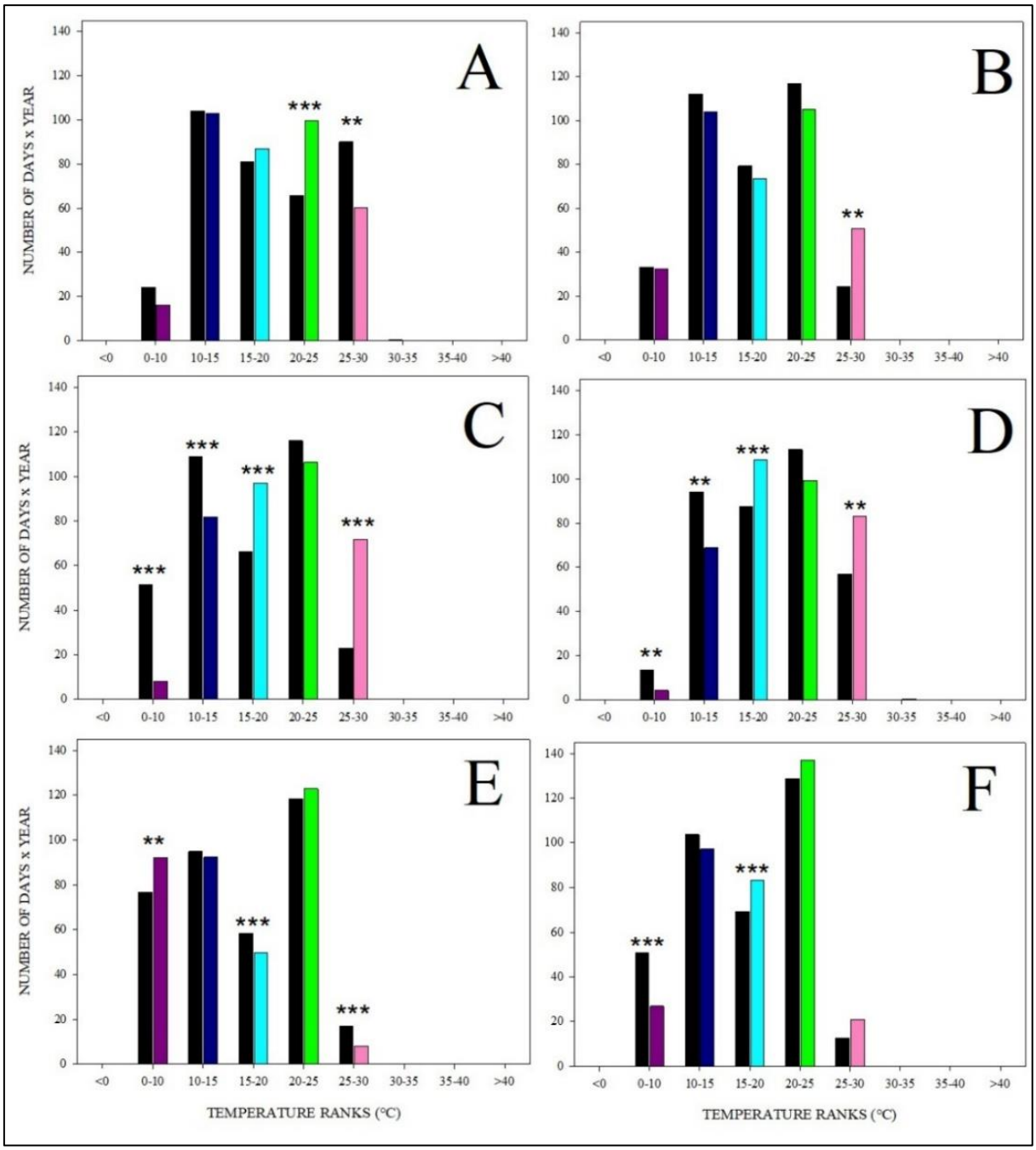
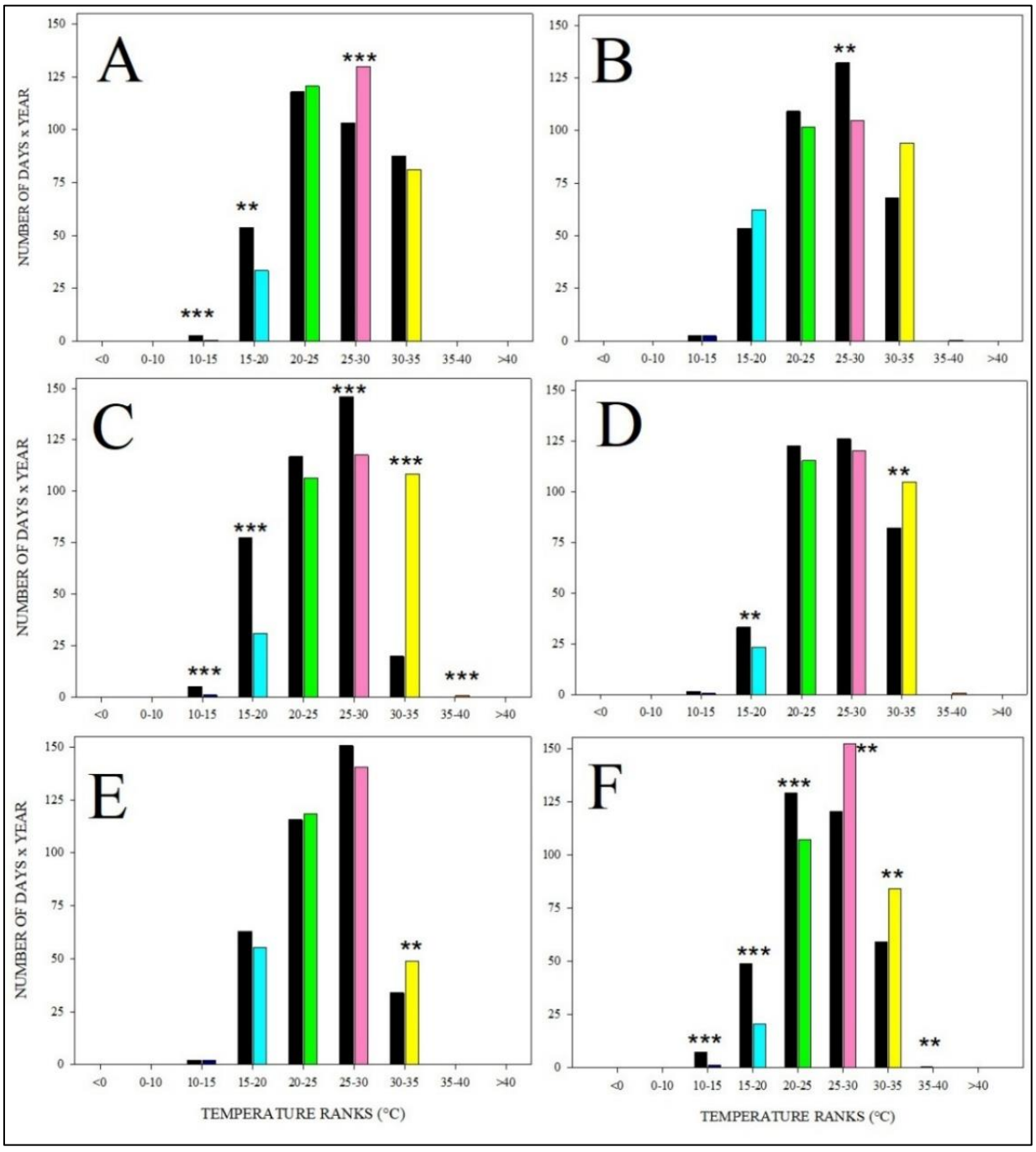
Annexes



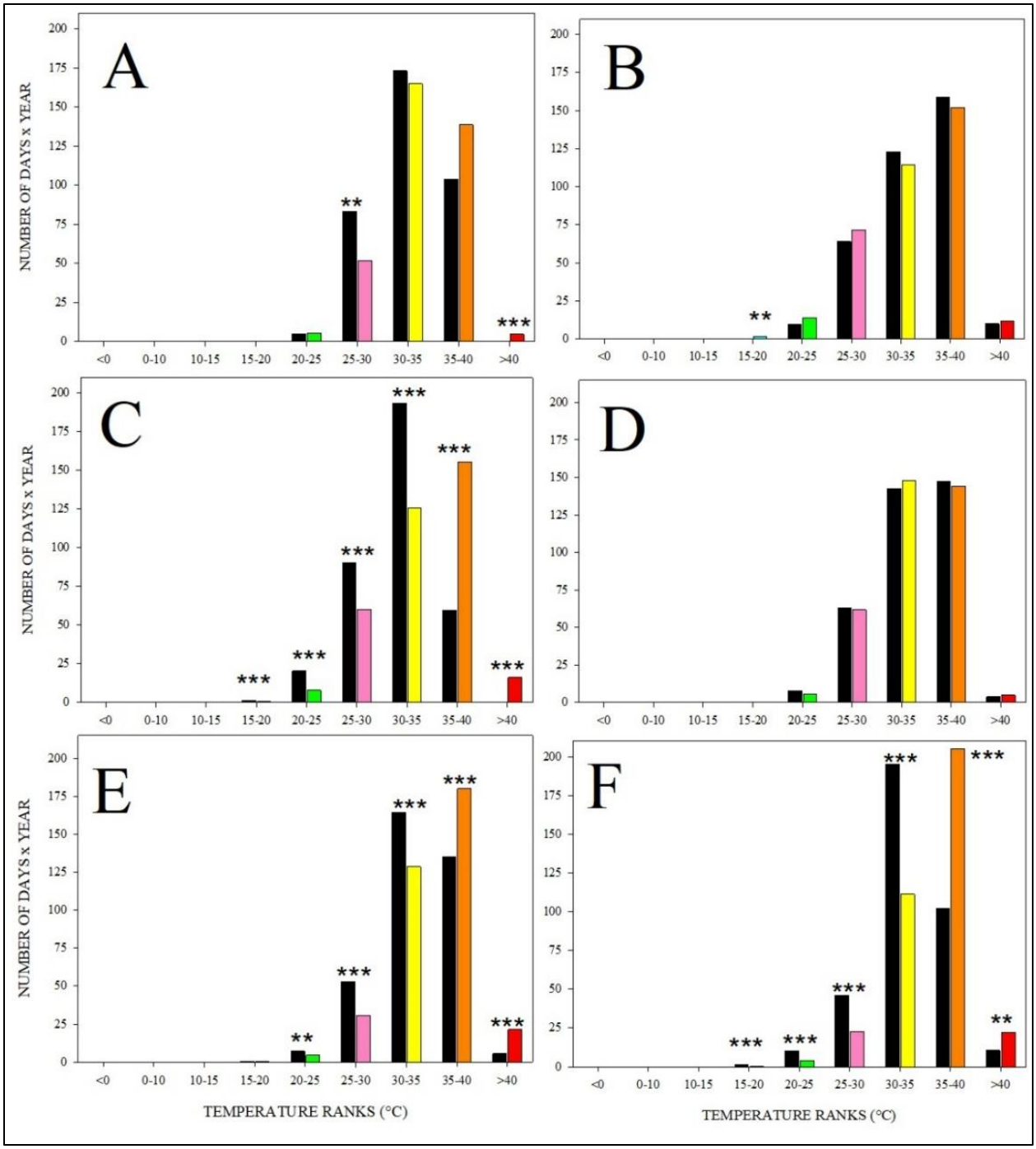
Annex 1. Temperature annual means of first quarter data set (black bars) and annual mean of fourth quarter data set (colored bars) of temperature variables. Asterisks above bars describe *U* Mann-Whitney tests statistical analysis (**P*<0.05, ***P*<0.01).



Annex 2. Number of days per year annual means of first quarter data set (black bars) and annual means of fourth quarter data set (colored bars) of low temperatures. Asterisks above bars denote statistical differences for a *U* Mann-Whitney test *(P<0.05), **(P<0.01), ***(P<0.001).



Annex 3. Number of days per year annual means of first quarter data set (black bars) and annual means of fourth quarter data set (colored bars) of mean temperatures. Asterisks above bars denote statistical differences for a *U* Mann-Whitney test *(P<0.05), **(P<0.01), ***(P<0.001).



Annex 4. Number of days per year annual means of first quarter data set (black bars) and annual means of fourth quarter data set (colored bars) of high temperatures. Asterisks above bars denote statistical differences for a *U* Mann-Whitney test *(P<0.05), **(P<0.01), ***(P<0.001).

CAFETALES BAJO SOMBRA: RESERVORIOS DE TRES IMPORTANTES FIBRAS PARA LA ELABORACIÓN DE PAPEL AMATE

SHADE-GROWN COFFEE PLANTATIONS: RESERVOIRS OF THREE IMPORTANT FIBERS FOR THE PRODUCTION OF AMATE PAPER

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Adolfo de Jesús Rebolledo-Morales y José Daniel Santos de la Puerta

Resumen

La importancia socioeconómica y ecológica de los cafetales bajo sombra en México ha sido notable desde la introducción del café en el país. Este sistema productivo fue adoptado por diversas comunidades indígenas, quienes lo integraron de manera similar a la milpa, debido a la diversidad de productos que pueden obtenerse de las huertas cafetaleras. Entre estos productos destacan, por su disponibilidad a lo largo del año, las cortezas de árboles utilizadas como materia prima para la elaboración de papel amate en la Sierra Norte de Puebla. El papel amate posee una larga tradición de uso entre los pueblos mesoamericanos, quienes lo emplearon como soporte fundamental para la transmisión de conocimientos, como lo evidencian los códices que aún se conservan en distintas partes del mundo. Asimismo, su uso ritual y artesanal ha perdurado hasta la actualidad. En este contexto, la comunidad de San Pablito, ubicada en el municipio de Pahuatlán, constituye el único lugar en México donde se produce papel amate con fines comerciales como artesanía. La extracción de la materia prima para su elaboración ha generado presiones ecológicas sobre los cafetales bajo sombra. Actualmente, tres especies de árboles tropicales que crecen en estos sistemas son las más utilizadas para la obtención de fibras: *Trema micranthum* (L.) Blume, *Morus celtidifolia* Kunth y *Sapium glandulosum* (L) Morong.

Palabras clave: Artesanías, cafetal bajo sombra, cortezas, papel amate.

Abstract

The socioeconomic and ecological importance of shade-grown coffee systems in Mexico has been significant since the introduction of coffee to the country. This productive

system was adopted by various Indigenous communities, who integrated it in a manner similar to the milpa, due to the diversity of products that can be obtained from coffee agroforestry plots. Among these products, tree bark stands out for its year-round availability and its use as raw material for the production of amate paper in the Sierra Norte de Puebla. Amate paper has a long tradition of use among Mesoamerican peoples, who employed it as a fundamental medium for the transmission of knowledge, as evidenced by codices that are still preserved in different parts of the world. Its ritual and artisanal use has also persisted to the present day. In this context, the community of San Pablito, located in the municipality of Pahuatlán, represents the only place in Mexico where amate paper is produced commercially as a handicraft. However, the extraction of raw materials for its production has generated ecological pressures on shade-grown coffee systems. Currently, three species of tropical trees that grow within these systems are the most commonly used for fiber extraction: *Trema micranthum* (L.) Blume, *Morus celtidifolia* Kunth, and *Sapium glandulosum* (L) Morong.

Keywords: Amate paper, bark, handicrafts, shade-grown coffee.

Introducción

El cultivo de café en México se ha considerado como una activad con una gran relevancia ya que la producción y venta del café ha permitido obtener ingresos económicos para la subsistencia de las familias campesinas e indígenas en el centro y sureste del país (Anta, 2006). En los últimos años se ha registrado que en México más del 99% de los cafetales se encuentran bajo una cobertura arbórea, por lo que este sistema agroforestal apoya de forma directa e indirectamente la conservación de la biodiversidad biológica, así como también garantiza el suministro de los servicios ecosistémicos (Moguel y Toledo, 1999). Diversos autores reconocen a los cafetales bajo sombra como agroecosistemas que ayudan al mantenimiento de la diversidad debido a su gran complejidad estructural, ya que sirven en muchas ocasiones como zonas de amortiguamiento o remanentes de vegetación dentro del bosque mesófilo de montaña (Espinoza-Guzmán et al., 2020).

Dentro de la composición y estructura ecológica de los cafetales bajo sombra existen las siguientes tipologías: a) cafetal “rustico” o “de montaña”, el cual es semejante a un bosque o selva, pero que ha sido aclarado en su estrato inferior para introducir las plantas de café, manteniendo los árboles de grandes que le brindan sombra. b) “jardín de café” o “policultivo tradicional”, dentro de este tipo de cafetal el estrato inferior es sustituido por plantas de café y la sombra se compone por arboles naturales e introducidos que tienen diversos usos como las especies maderables y los árboles frutales, entre otros. c) “policultivo comercial”, es el que remueve toda la sombra natural e introduce dos o tres especies de árboles de tipo comercial y otros para la subsistencia local. d) “especializado” o “monocultivo bajo sombra”, se compone después de la remoción de la sombra y se planta árboles de una sola especie (Moguel y Toledo, 1999).

De acuerdo a su tipificación y características los usos de las diferentes especies perennes, nativas o introducidas son parte de los servicios ambientales que brindan los cafetales bajo sombra, ya que en muchos de estos sitios se encuentran con grandes densidades y con un área basal o diámetros mayores a 2 cm (Carreño-Rocabado, 2006).

En el estado de Puebla dentro de la región conocida como la Sierra Norte, se han descrito y registrado estos agroecosistemas como espacios de producción que cuentan con un amplio manejo por parte de los pobladores que se dedican a la siembra de este grano, estableciendo dentro del paisaje local una composición y estructura variada, en donde se pueden encontrar especies nativas, especies cultivadas, silvestres e introducidas, y esto se relaciona con las condiciones culturales, sociales, económicas y ecológicas en las que se ha producido este grano en la región (Martínez et al, 2007). Dentro de las zonas cafetaleras, particularmente aquellas caracterizadas por la presencia de campesinos indígenas minifundistas, el cultivo del café bajo sombra constituye solo una alternativa dentro de un conjunto más amplio de actividades y productos económicos, en este sentido, el paisaje cafetalero de la Sierra Norte de Puebla se configura como un mosaico heterogéneo que integra parcelas de cultivos anuales; maíz, frijol y chile, potreros destinados a la ganadería extensiva, huertos familiares y sistemas de cultivo permanente (Evangelista, 1999).

En esta región se cultivan diversas variedades de café, como Criollo o Típica, Caturra, Garnica, Bourbon, Pacamara, Mundo Novo, Catuai y Azteca Oro, generalmente bajo sombra de especies forestales como *Inga* spp*., Gliricidia sepium (Jacq.) Kunth ex Walp.* y *Alnus acuminata* Kunth, utilizadas principalmente para mejorar la fertilidad del suelo mediante la fijación de nitrógeno, de esta manera los cafetales integran especies maderables y frutales, como cedro rosado, pinos y macadamia, además de plantas con valor cultural y económico, como diferentes árboles a los que se les retira la corteza que es empleada en la elaboración de papel amate. Es precisamente dentro de los cafetales bajo sombra en donde se obtienen las fibras vegetales que son utilizadas como materia prima para la elaboración del papel amate en la comunidad de San Pablito Municipio de Pahuatlán Puebla, las cuales son recolectadas dependiendo el tipo de fibra que los artesanos requieran o de la disponibilidad de las mismas fibras dentro del cafetal (Rebolledo-Morales, 2012; López, 2003).

Las fibras vegetales para la elaboración de papel amate se han registrado desde la época prehispánica, y su uso para la comercialización se registra a principios de la década de 1960, con un gran impacto en la extracción de los árboles conocidos como amates (Ficus) debido al auge del papel amate como artesanía, por lo que los pobladores y artesanos tuvieron que buscar nuevas alternativas de fibras vegetales de diversas especies que se encuentran dentro de los cafetales bajo sombra de la región como materia prima para poder abastecer el mercado creciente de papel amate (Rebolledo-Morales y López, 2024).

Los primeros trabajos realizados que demuestran la diversidad de materias primas que se han utilizado en la elaboración del papel amate comienzan en el siglo XVI, con los trabajos publicados de Martín de Anglería, Fray Diego de Landa, Bernal Díaz del Castillo y Fray Bernardino de Sahagún, plantas como el maguey y las fibras de palmas y de árbol de amate eran utilizadas como superficies para plasmar las representaciones pictográficas prehispánicas, en 1942 el trabajo de Bodil Christensen describe los primeros árboles que eran utilizados para elaborar papel amate de uso ceremonial apoyándose de la descripción taxonómica que llevó a cabo Paul Standley (1923).

Posteriormente Arroyo (1993), describe el uso de algunas especies de higueras silvestres de los estados de Veracruz y Morelos, y López (2003), hace un listado de la introducción de nuevas especies utilizadas como materia prima para la elaboración de papel amate, con lo cual se comienza una nueva etapa en los estudios de crecimiento y extracción de cortezas de diversas especies que se han utilizado en la elaboración de papel amate.

Los registros y actualizaciones de la lista de especies útiles fueron actualizadas en el trabajo de tesis de maestría realizado por Rebolledo-Morales (2012) en el cual se registró el nombre de dos especies botánicas más a la lista de materias primas para la producción de papel amate, y posteriormente en el año 2024, se realizaron algunas modificaciones pertinentes a la clasificación taxonómica de las especies debido a que algunos nombres de las especies botánicas se consideran en la actualidad como sinonimia de una misma especie, por lo que se ha actualizado el listado de especies que se han utilizado como materia prima en la elaboración de papel amate como materia prima a lo largo de la historia con un total de 13 especies identificadas taxonómicamente (Rebolledo-Morales y López, 2024).

Materiales y métodos

Zona de estudio

La Sierra Norte de Puebla se caracteriza por su notable diversidad ambiental, biológica y cultural, presenta un intervalo altitudinal que oscila entre los 100 y los 2,300 msnm, lo que da lugar a un gradiente climático que va de cálido y semicálido húmedo en las zonas bajas, a templado húmedo en las áreas de mayor altitud (Figura1) (Martínez et al., 2007). Este gradiente favorece la presencia de diversos tipos de vegetación, entre los que destacan el bosque tropical perennifolio, el bosque mesófilo de montaña, así como bosques de encino, de pino y asociaciones mixtas de ambos, observándose amplias zonas de transición entre los distintos tipos de vegetación contiguos, desde el punto de vista fisiográfico, la región forma parte de las provincias morfotectónicas de la Sierra Madre Oriental, el Eje Transvolcánico Mexicano y la Llanura Costera del Golfo (Martínez et al., 2007).

Dentro de las zonas cafetaleras, particularmente aquellas caracterizadas por la presencia de campesinos indígenas minifundistas, el cultivo del café bajo sombra constituye solo una alternativa dentro de un conjunto más amplio de actividades y productos económicos, en este sentido, el paisaje cafetalero del norte de Puebla se configura como un mosaico heterogéneo que integra parcelas de cultivos anuales; maíz, frijol y chile, potreros destinados a la ganadería extensiva, huertos familiares y sistemas de cultivo permanente (Evangelista, 1999).

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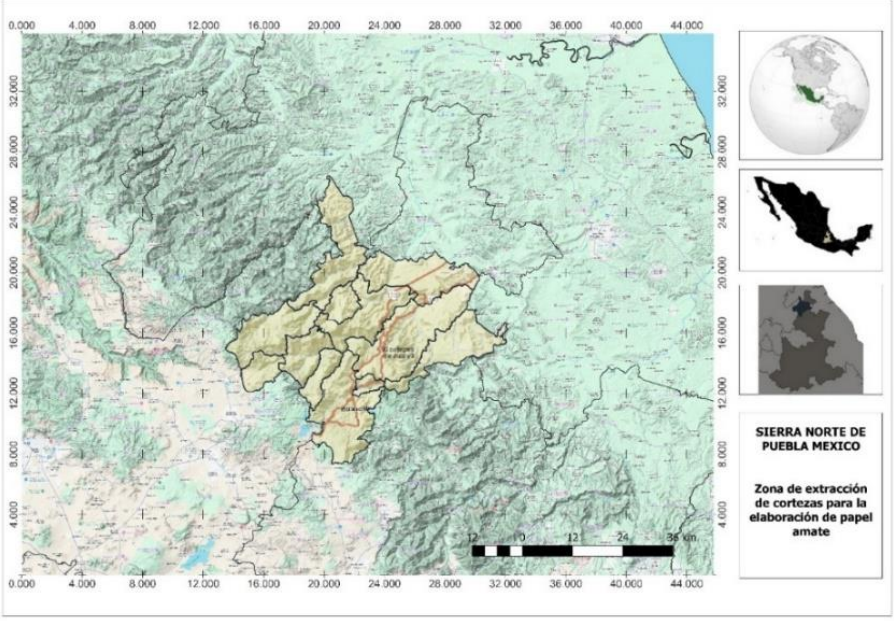


Figura 1. Sierra Norte de Puebla, México, principales zonas de extracción de cortezas para la elaboración de papel amate.

Metodología

La presente investigación se desarrolló bajo un enfoque cualitativo, orientado a comprender las prácticas, conocimientos y percepciones de los actores locales en torno al manejo y aprovechamiento de los recursos forestales no maderables que son utilizados como materia prima en la actualidad para la elaboración de papel amate en la Sierra Norte de Puebla. Para la obtención de información se realizaron entrevistas semiestructuradas dirigidas a artesanos de la comunidad de San Pablito, así como a recolectores de corteza (conocidos localmente como jonoteros) de la región, con el propósito de identificar las especies vegetales cuyas cortezas son mayormente utilizadas y comercializadas para la elaboración de papel amate. Las entrevistas incluyeron preguntas orientadas a documentar aspectos como el reconocimiento local de las especies, los criterios de selección, las técnicas de aprovechamiento, los sitios de recolección y las dinámicas de comercialización (Alexiades, 2003).

La selección de los informantes se llevó a cabo mediante el método de bola de nieve, que se describe como el método de elección de entrevistados de forma al azar (Baltar y Gorjup, 2012). Lo que nos permitió identificar actores clave dentro de la cadena productiva en la recolección de materia prima dentro de los cafetales bajo sombra, así como la identificación de artesanos dedicados a la elaboración de papel amate.

En total, se realizaron 36 entrevistas semiestructuradas con 10 preguntas base en seis talleres o galerías de mayor escala dedicadas a la producción y comercialización de este producto. Este enfoque facilitó la obtención de información diversa y representativa sobre las prácticas locales. Los datos obtenidos de las entrevistas semi estructuradas fueron analizadas dentro de una base de datos para obtener el porcentaje de uso de las especies vegetales utilizadas como materia prima en la comunidad de San Pablito, Pahuatlán, Puebla. De manera complementaria, se empleó el método de observación participante, mediante estancias en campo en las que se acompañó a los actores locales en sus actividades cotidianas, esta técnica permitió registrar información cualitativa de carácter etnográfico, incluyendo prácticas, saberes tradicionales y dinámicas socioculturales (Fernández, 2009), asociadas al uso y manejo de los cafetales bajo

sombra como agrosistemas que proporcionan la materia prima para la producción de papel amate en la Sierra Norte de Puebla.

Resultados

En la actualidad la extracción y recolección de grandes cantidades de corteza (fibra), para la elaboración de papel amate en la región de la Sierra Norte de Puebla recae en dos especies principalmente, debido a su disponibilidad durante todo el año y a su rápido crecimiento dentro de los cafetales bajo sombra. Según con las observaciones en campo y a través de la información recibida por parte de los entrevistados la fibra más utilizada por todos los artesanos de la comunidad es

Trema micranthum (L.) Blume, que es la base principal del papel amate tanto en los diseños más sencillos conocido como papel liso, así como la base de diferentes productos debido a su rigidez y durabilidad, dicha corteza es la que se extrae durante todo el año y la que más adquieren los artesanos, el color de su corteza es café y es la más abundante dentro de los sistemas agroforestales de la región ya que forma parte de la sombra de los cafetales (Figuras 2 y 3).

La segunda especie mayormente utilizada es *Morus celtidifolia* Kunth, conocida comúnmente por los artesanos como mora, este tipo de materia prima da como resultado un papel más fino (delgado) y con una alta flexibilidad, lo cual lo hace predilecto para la realización de los recortes (papel picado) de diferentes figuras sagradas y nuevos diseños que plasman la diversidad tanto de plantas como animales, el color de la corteza es blanco y solamente se extrae en algunas épocas del año, por lo que los artesanos compran grandes cantidades y la almacenan dentro de sus talleres para poder tener disponibilidad de este material a lo largo del año, los productos que se obtienen con este tipo de fibra adornan los diversos diseños de cuadros y otros productos innovadores en donde la base más rígida se elabora con *Trema micranthum* (L.) Blume, como se mencionó anteriormente y que es conocido por los pobladores como jonote colorado (Figuras 4 y 5).

Figura 2. Corteza de *Trema micranthum* conocido como jonote colorado.

Figura 3. Cuadro de papel amate elaborado con fibras de *T. micranthum* conocida como jonote colorado.

Figura 4. Corteza de *M. celtidifolia* conocida como mora.

Figura 5. Recorte de papel amate elaborados con fibras de *M. celtidifolia* y base blanca de *T. micranthum*.

De acuerdo con los relatos de los entrevistados se obtuvo que para la elaboración de papel amate utilizado dentro de las ceremonias tradicionales o curaciones de sanación aún se siguen extrayendo y utilizando algunas cortezas de otras especies como lo son *S. glandulosum*. (Palo brujo, chilamate) (Figuras 6 y 7), y *U. caracasana* (Chichiclaxtle) está ultima solamente la extraen los médicos tradicionales (curanderos) ya que para poder obtener la materia prima de esta especie se requiere una práctica muy meticulosa debido a que es una especie urticante que genera reacciones alérgicas al contacto de la piel. La forma de extraer la materia prima es realizando cortes a lo largo y en la base del tallo de la planta con una navaja de afeitar o un cuchillo muy delgado, con el cual también se va despegando la corteza del tallo cuidadosamente hasta obtener tiras delgadas de la corteza.

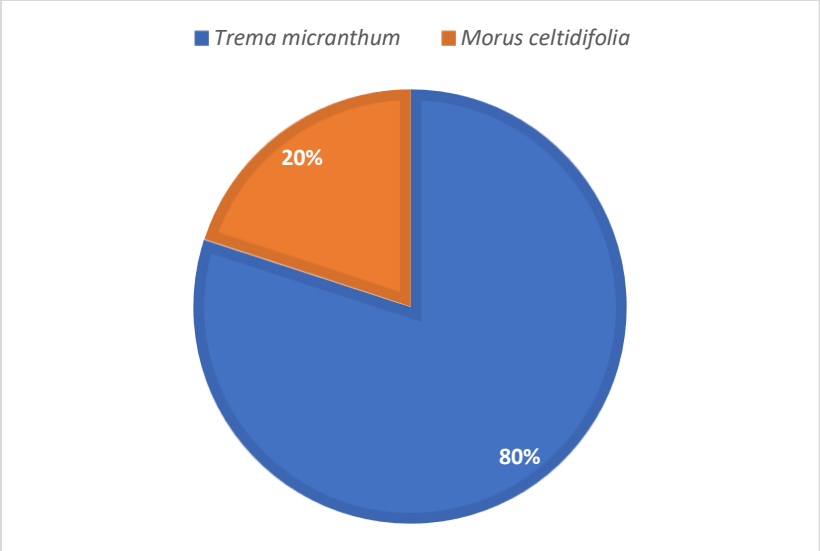
Figura 6. Corteza de *S. glandulosum*. Conocida común mente como palo brujo o chilamate.

Cabe mencionar que estas especies de uso ritual y ceremonial no se recolectan de manera masiva dado su uso ritual, así también cabe hacer mención que muchas veces las personas que compran y adquieren las artesanías de papel amate siguen creyendo que este producto artesanal se realiza con cortezas de árboles del género *Ficus*, pero en la actualidad no se han encontrado indicios de artesanos o de recolectores que demuestren la extracción de cortezas de dichos árboles y solamente ha quedado

como especies documentadas de su uso en la historia de la elaboración de papel amate (Rebolledo-Morales y López,2024).

Figura 7. Papel amate liso de color verde natural elaborado con fibras de *S. glandulosum.*

El motivo de la nula extracción de corteza de las especies de la familia de los *Ficus*, se ha debido a que en la región ya no son tan abundantes, así como se ha demostrado que son árboles de crecimiento lento por lo que no pueden ser aprovechados de manera continua y de manera sustentable por los artesanos. Los entrevistados mencionan que esto mismo se ha presentado recientemente con otras especies que se han identificado a lo largo de la historia de manufactura del papel amate, pero a diferencia de las especies del género *Ficus,* las cortezas de otras especies ya no se recolectan debido a que el conocimiento y reconocimiento de las plantas en campo se está perdiendo. Se identifico que un 80% de los recolectores llamados jonoteros son personas jóvenes y se han especializado en la recolección y extracción de corteza del jonote colorado (*T. micrantum*) y corteza de mora (*M. celtidifolia*), que son las fibras que mayormente se comercializan en los distintos talleres de papel amate en la comunidad de San Pablito, Pahuatlán Puebla (Grafica 1).



Grafica 1. Porcentaje de extracción de tipos de cortezas por parte de jonoteros en la Sierra Norte de Puebla.

Las prácticas de manejo para la extracción de la corteza utilizada como materia prima en la elaboración de papel amate han sido documentadas previamente por López (2003) y Rebolledo-Morales (2012). De acuerdo con la información proporcionada por los recolectores y artesanos entrevistados durante el presente estudio, estas técnicas de extracción continúan realizándose de manera similar a las descritas por dichos autores. El proceso inicia con la identificación de los árboles dentro del bosque o de los cafetales. Posteriormente, con ayuda de un machete, se realizan cortes circulares alrededor del tronco, a una altura aproximada de 20 a 40 cm del suelo. Después se efectúan dos cortes longitudinales, separados entre sí por un ancho de entre 20 y 25 cm. Una vez realizados estos cortes, la corteza se desprende cuidadosamente con el machete y posteriormente se jala con fuerza hacia arriba hasta separarla del tronco. Este procedimiento se repite a lo largo de todo el árbol; cuando los individuos presentan mayor altura, los jonoteros trepan para extraer la mayor cantidad de corteza posible, incluyendo la de las ramas principales.

Los entrevistados señalaron que los árboles aprovechados no deben superar aproximadamente los cinco años de edad, ya que en individuos más maduros la corteza se encuentra más adherida al tronco, lo que dificulta considerablemente su extracción.

Asimismo, mencionaron que la recolección resulta más sencilla durante las noches de luna llena, debido a que, según su conocimiento tradicional, esta fase lunar reduce la adherencia de la corteza al tronco y facilita su desprendimiento. Cabe señalar que los árboles de *Trema micranthum* (L.) Blume son podados o talados antes de alcanzar los seis años de edad. De acuerdo con los entrevistados, a partir de esa etapa de crecimiento la especie comienza a competir por luz, agua y nutrientes con las plantas de café, lo que repercute negativamente en el rendimiento de los cafetales. En este sentido, la extracción de la corteza se integra a las prácticas de manejo del cafetal, ya que el aprovechamiento de los árboles coincide con las labores destinadas a reducir la competencia y mantener la productividad del cultivo.

Durante la última década las zonas de recolección de las fibras vegetales (corteza) para la elaboración de papel amate se ha extendido, esto se ha debido al incremento en la demanda de los productos elaborados de papel amate, que en la actualidad se sigue comercializando de manera, local, nacional y últimamente ha tenido un gran auge a nivel internacional. Por lo que los recolectores (jonoteros), realizan recorridos cada vez más extensos, paro poder cubrir la demanda de los artesanos, llegando a traspasar las fronteras de los estados de vecinos de Hidalgo y Veracruz, en donde también se hace presente el tipo de vegetación y agro sistemas de café bajo sombra, que es donde crecen los árboles de donde se extraen las fibras que son la materia prima para la elaboración de papel amate.

Discusión

La utilización de fibras vegetales como materia prima para la elaboración de papel amate constituye una evidencia de la profundidad del conocimiento ecológico tradicional desarrollado por las comunidades indígenas de la Sierra Norte de Puebla. Durante varias generaciones, los habitantes de esta región han construido un conjunto de saberes y prácticas de manejo que les ha permitido identificar, seleccionar y aprovechar distintas especies arbóreas presentes tanto en los bosques como en los cafetales bajo sombra. Este conocimiento ha sido documentado desde los primeros trabajos botánicos y etnográficos de Standley (1923) y Christensen (1942), así como en investigaciones más recientes (Arroyo, 1993; López, 2003; Rebolledo-Morales, 2012; Rebolledo-Morales y

López, 2024), las cuales han registrado la diversidad de especies utilizadas históricamente para la elaboración de papel amate en la comunidad de San Pablito, Pahuatlán. Los resultados obtenidos en el presente estudio confirman la permanencia de este conocimiento, aunque también actualizan el inventario de especies empleadas a partir de las modificaciones derivadas de la revisión taxonómica y de las sinonimias actualmente aceptadas. Más que representar un simple ajuste nomenclatural, esta actualización pone de manifiesto la importancia de mantener un diálogo permanente entre el conocimiento botánico científico y el conocimiento ecológico local para comprender los procesos históricos de aprovechamiento de los recursos vegetales (Tabla 1).

Tabla 1. Identificación de especies botánicas utilizadas como materia prima a lo largo de la historia que crecen dentro de los cafetales bajo sombra.

Familia, Género y Especie	**Nombre en Hñahñú (N)** **Nombre en Náhuatl (A)**	**Nombre en español**
Euphorbiaceae *Sapium alandulosum* Jacq.	Koni pa̲thi (N)	Palo brujo, chilamate
Moraceae *Brosimum alicastrum* Sw.	Payu koni, Uini koni (N)	Ojite, ramón, uje
Moraceae *Ficus calyculata* Mill.	Xalama (A) Buo popotza (N)	Amate hoja redonda, higuera, matapalo
Moraceae *Ficus cotinifolia* Kunth.	Xalama (A) Tshax popotza (N)	Amate de hoja gruesa
Moraceae *Ficus crocata* (Mig.) Mart. Ex Mig.	Xalama (A) Popotza xibahua (N)	Amate hoja pahua, amate prieto, salate
Moraceae *Ficus padifolia* Kunth aff. *Ficus pertusa* L.f.	Xalama (A) Tshax moushi (N)	Amate limón blanco, palo blanco, camichin, higuera blanca
Moraceae *Morus celtidifolia* Kunth.	Tzatzu̲kü (N)	Mora, mora de lo frío, moral, palo moral
Typhaceae *Typha domingensis* Pers.		Tule
Cannabaceae *Trema micranthum* (L.) Blume	Koni (N)	Jonote colorado, chaca, capulín, capulín macho
Ulmaceae *Ulmus mexicana* (Liebm.) Planch.	Sxifi-tza (N)	Tortocal, jonote cuerudo, olmo, cuerillo
Urticaceae *Urera caracasana* (Jacq.) Gaudich. ex Griseb.	Chichicaxtle (A) Ntzanä (N)	Chichicaxtle
Urticaceae *Myriocarpa cordifolia* Liebm.	Hu̲snä (N)	Hortiga

Fuente: Rebolledo-Morales y López, 2024 (nombres actualizados por Rebolledo-Morales y Santos, 2026).

No obstante, los resultados también evidencian que este conocimiento se encuentra inmerso en un proceso gradual de erosión cultural. El reconocimiento e identificación de las especies en campo fue significativamente menor entre los recolectores y artesanos más jóvenes, quienes concentran su conocimiento en las especies de mayor demanda comercial. Esta tendencia ya había sido señalada por Rebolledo-Morales (2012), lo que indica que la pérdida del conocimiento tradicional continúa profundizándose.

Desde la perspectiva del conocimiento ecológico tradicional, diversos autores han señalado que la transmisión intergeneracional depende de la práctica cotidiana, la participación directa en las actividades productivas y la diversidad de experiencias con el entorno. Cuando estos procesos se restringen a un número reducido de especies o responden principalmente a las exigencias del mercado, el conocimiento asociado a especies menos utilizadas deja de transmitirse y corre el riesgo de desaparecer. En consecuencia, la pérdida no solo afecta el conocimiento taxonómico sobre la flora local, sino también las prácticas de manejo, los criterios de selección, los calendarios de aprovechamiento y los valores culturales que históricamente han sustentado la elaboración del papel amate. Este proceso representa una disminución del patrimonio biocultural de la región, al reducir la diversidad de conocimientos que permiten a las comunidades adaptarse a cambios ambientales y sociales.

Por otra parte, los resultados confirman que los cafetales bajo sombra continúan desempeñando un papel estratégico en la conservación de las especies utilizadas para la elaboración de papel amate. Estos agroecosistemas funcionan como reservorios de biodiversidad donde persisten numerosas especies arbóreas que anteriormente formaban parte de la vegetación original y que actualmente constituyen la principal fuente de materia prima para los artesanos. En este sentido, la permanencia de la cafeticultura tradicional no solo posee importancia económica, sino también ecológica y cultural, ya que contribuye simultáneamente a la conservación de la diversidad vegetal y a la continuidad de las prácticas de aprovechamiento tradicional. Los resultados sugieren que la producción de café y la elaboración de papel amate conforman un sistema biocultural

estrechamente interdependiente: mientras los cafetales proporcionan el hábitat y la disponibilidad de las especies utilizadas para la obtención de corteza, el aprovechamiento de estos árboles forma parte de las prácticas de manejo que realizan los productores para mantener la productividad del cafetal. De esta manera, ambas actividades no deben entenderse como procesos independientes, sino como componentes complementarios de una misma estrategia de manejo del paisaje, donde la conservación de la biodiversidad, la producción agrícola y la permanencia del conocimiento tradicional se encuentran estrechamente vinculadas.

Estos hallazgos refuerzan la necesidad de considerar a los cafetales bajo sombra como sistemas bioculturales cuya conservación resulta indispensable no solo para mantener la producción de café, sino también para preservar el conocimiento ecológico tradicional y la disponibilidad de las especies vegetales que sustentan una de las manifestaciones artesanales más representativas del patrimonio cultural de la Sierra Norte de Puebla.

Conclusiones

Los cafetales bajo sombra son considerados agrosistemas que albergan una alta diversidad de especies. Desde la adopción del cultivo de café por parte de los pueblos indígenas de la Sierra Norte de Puebla, estos sistemas han constituido espacios clave para la obtención de diversas materias primas destinadas a la elaboración de manifestaciones bioculturales, particularmente artesanías de uso cotidiano. Que, con el tiempo, dichos productos han trascendido su función utilitaria original y han sido incorporados a circuitos de comercialización, configurándose como una estrategia económica relevante para las comunidades de la región.

A medida que se vayan perdiendo los cafetales bajo sombra en la región, se van a ir reduciendo las poblaciones de las especies vegetales utilizadas en la elaboración de papel amate, lo cual puede dar paso a la búsqueda de nuevas estrategias para la obtención de materia prima en sitios más alejados, o a la experimentación con nuevas fibras vegetales que se distribuyan dentro de estos sistemas productivos con tal de satisfacer la demanda del mercado del papel amate. Cualquiera de estos escenarios a futuro nos hace reflexionar sobre la forma de obtención de la materia prima dentro de los

cafetales bajo sombra, así como en la implementación de estrategias locales para la regularización en la extracción de las especies a nivel regional.

Por tal motivo es necesario realizar nuevos estudios sobre la abundancia de las especies utilizadas como materia prima para la elaboración del papel amate, dentro de los cafetales. Esto nos brindará la información necesaria para poder establecer estrategias de reproducción, reforestación y manejo de dichas especies dentro de los cafetales, impulsando un manejo controlado en la extracción de la corteza, así como en la generación de planes de manejo dentro de los sitios de extracción que ayuden a la regeneración natural o inducida de las poblaciones de todas las especies que se han documentado que sirven como materia prima para la elaboración de papel amate.

Por otro lado el trabajo con los cafeticultores es imprescindible, debido a que son ellos quienes aún conservan el manejo bajo sombra de la producción del café, y tomar en cuentan que la producción de este grano también se encuentra en riesgo debido a los precios bajos que se les paga por su producto, por lo que hacer trabajo comunitario para la conservación de este sistema productivo es prioritario en esta región ya que en las últimas décadas se ha fragmentado mucho tanto por el abandonó de las huertas de café así como la tala inmoderada en la región. De tal manera que la integración de proyectos o estrategias que involucren la participación y el uso sustentable de los ecosistemas cafetaleros ayudaran a la preservación de la biodiversidad en la región.

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REPORT OF INVASION BY *LISSACHATINA FULICA* (EUPULMONATA, ACHATINOIDEA, ACHATINIDAE) IN A RESIDENTIAL COMMUNITY IN THE SEMIARID REGION OF BRAZIL

INFORME DE INVASIÓN POR *LISSACHATINA FULICA* (EUPULMONATA, ACHATINOIDEA, ACHATINIDAE) EN UNA COMUNIDAD RESIDENCIAL DE LA REGIÓN SEMIÁRIDA DE BRASIL

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Abstract

The giant African snail, *Lissachatina fulica* (Bowdich, 1822), is considered one of the most worrisome invasive invertebrates throughout the world. The present study reports the presence of *L. fulica* in a semiarid region in the western portion of the state of Paraíba in northeastern Brazil and describes body size variation among individuals as well as preferences for different plant substrates. A total of 128 individuals of *L. fulica* were studied in a gated residential community located in a highly urbanized area of the municipality of Cajazeiras associated with 11 plant species. Eighty-five (63%) of these individuals belonged to size class 1. Adult individuals prevailed over subadults associated with cultivated plant species. The snails were mainly associated with the following shrubs/trees: *Musa* sp., *S. trifasciata*, and *C. indicum*. Smaller individuals were mainly associated with *Ixora* sp., whereas larger individuals were associated with *Musa* sp., *C. indicum*, and *A. altilis*. The ultimate control of *L. fulica* should be enforced at nurseries before plants are placed in communities.

Key words: Gastropoda, giant African snail, invasive species, northeastern Brazil.

Resumen

El caracol gigante africano, *Lissachatina fulica* (Bowdich, 1822), se considera uno de los invertebrados invasores más preocupantes del mundo. El presente estudio informa sobre la presencia de *L. fulica* en una región semiárida de la parte occidental del estado

de Paraíba, en el noreste de Brasil, y describe la variación del tamaño corporal entre los individuos, así como las preferencias por diferentes sustratos vegetales. Se estudió un total de 128 individuos de *L. fulica* en una comunidad residencial cerrada ubicada en una zona altamente urbanizada del municipio de Cajazeiras, asociados a 11 especies de plantas. Ochenta y cinco (63%) de estos individuos pertenecían a la clase de tamaño 1. Los individuos adultos prevalecieron sobre los subadultos asociados a especies de plantas cultivadas. Los caracoles se asociaron principalmente con los siguientes arbustos/árboles: *Musa* sp., *S. trifasciata* y *C. indicum*. Los individuos más pequeños se asociaron principalmente con *Ixora* sp., mientras que los más grandes con *Musa* sp., *C. indicum* y *A. altilis*. El control definitivo de *L. fulica* debe implementarse en los viveros antes de colocar las plantas en las comunidades.

Palabras clave: Caracol gigante africano, especie invasora del noreste de Brasil, Gastropoda.

Introduction

The giant African snail – *Lissachatina fulica* (Bowdich, 1822) – is an invasive land snail widely distributed in tropical and subtropical ecosystems throughout the world, well adapted to urban and rural areas (Eston et al., 2006; Raut & Backer, 2008; Albuquerque et al., 2008; Fontanilla et al., 2014). This snail has typically nocturnal habits, a highly voracious generalist diet, a prolific hermaphroditic reproductive strategy, and is tolerant to a broad range of environmental conditions (Eston et al., 2006; Aquino, 2010).

L. fulica is considered one of the most worrisome invasive invertebrates (Lowe et al., 2004; Prasad, 2004; GISD, 2020) due to its ability to adapt to both preserved and anthropic environments, often reaching high population densities (Fischer & Colley, 2005; Silva & Aleluia, 2010; Alves et al., 2017; Eduvirgem & Ferreira, 2019). It is a devastating agricultural pest (Albuquerque et al., 2008; Silva & Aleluia, 2010; Valim & Bim, 2017) and voracious competitor for food resources, exerting negative impacts on native fauna and flora (Silva & Aleluia, 2010; Alves et al., 2017; Valim & Bim, 2017).

This achatinid is distributed throughout the Brazil (Thiengo et al., 2007; Arruda & Santos, 2022), with records from coastal (Albuquerque et al., 2008; Fischer et al., 2008;

Fischer & Costa, 2010) to inland regions of the country and also is spread throughout the semiarid region of Brazil (Leão et al., 2011; Madella & Auricchio, 2014), mainly associated with urban areas (Madella & Auricchio, 2014; Silva et al., 2020). Evidence of invasion and harm has also been found in conservation areas, placing native biota at risk (Fischer & Colley, 2005; Eston et al., 2006; Pivello et al., 2024).

The invasion route is probably due to the accidental human transport of food and ornamental plants containing eggs and/or individuals from other regions (Thiengo et al., 2007; Arruda & Santos, 2022). However, knowledge from scientific studies on the impact caused by this species in the *Caatinga* (xeric forest) biome and adjacent ecosystems remains scarce.

This study aims to report the presence of *L. fulica* in the municipality of Cajazeiras (state of Paraíba, northeastern Brazil) and describe the shell size variation among individuals based on preferences for different plant substrates at the study site.

Material and Methods

Study area

The municipality of Cajazeiras (06°53'24" S, 38°33'43" W) is located in the semiarid region of the state of Paraíba in northeastern Brazil, 475 km from the state capital, João Pessoa. The municipality has an area of 563 km² (11.741 km² of urban area) and a population of 62.576 residents, corresponding to the eighth most populous municipality in the state (IBGE, 2022-2024) (Figure 1).

Cajazeiras has a predominantly warm, dry, tropical climate, with temperatures ranging from 12° to 30°C and annual rainfall ranging from 227.1 to 1961 mm. The dry season typically spans from August to December, whereas the rainy season spans from January to June, with an average annual rainfall of 880.6 mm (Saraiva & Caracristi, 2022). Typical vegetation of the Caatinga biome includes cacti, bromeliads, and Mimosa spp. (xerophytic and deciduous) (Beltrão et al., 2005; Leal et al., 2005; Gariglio et al., 2010; Brito, 2012; Saraiva & Caracristi, 2022).

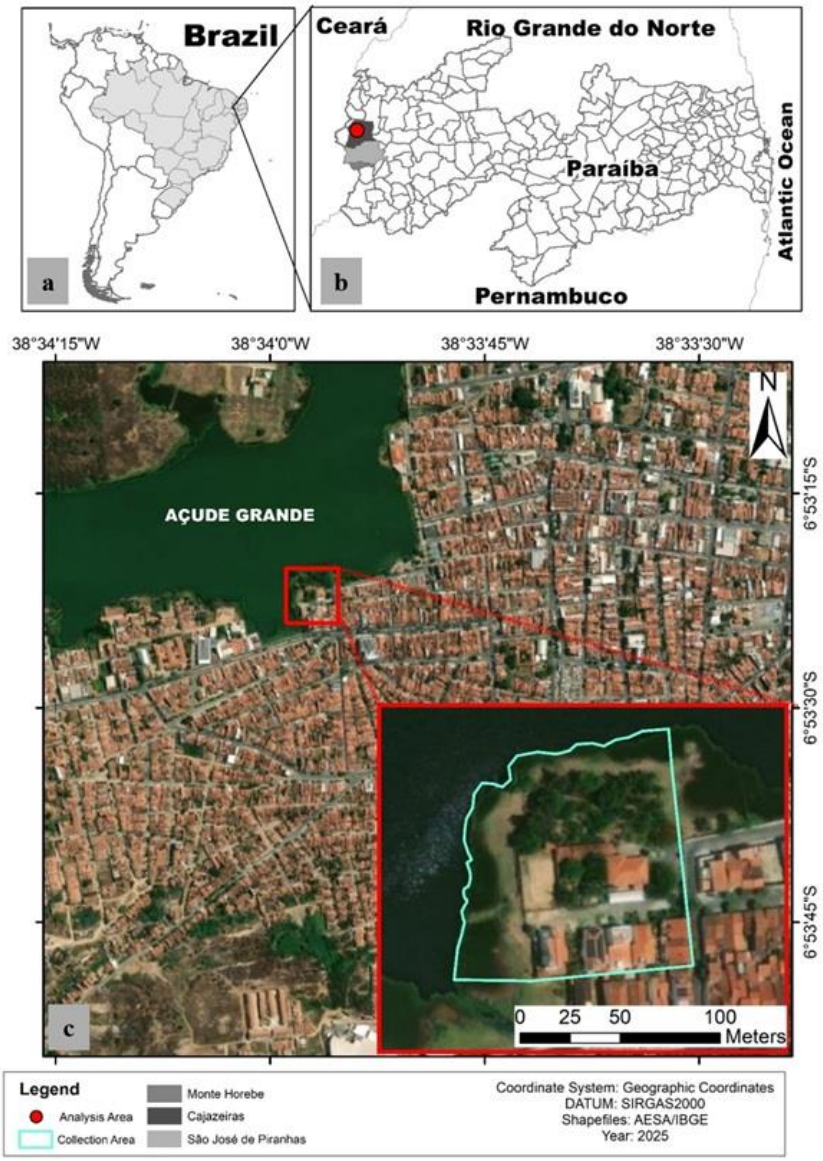

Figure 1. Map of study area: **a)** South America highlighting Brazil, **b)** State of Paraíba highlighting municipality of Cajazeiras (point in red - approximate location of study area), **c)** Study area highlighted in red (residential gated community highlighted in blue).

The area of record is a gated residential community of five houses located in the highly urbanized area (06°53'21"S, 38°33'57"W) of the municipality, bordered to the north by the reservoir denominated “Açude Grande” (Figure 1c). Each of the five houses has a planned outdoor garden area for displaying and cultivating ornamental plants. There is also a large collective area predominantly composed of fruit trees. The seedlings of

shrubs and trees cultivated within the community come from inland regions of the state of Paraíba and are mainly brought from the municipalities of João Pessoa and Bananeiras, both in the state of Paraíba.

The following shrubs and trees are among the species cultivated in the study area: pineapple plant (*Ananas comosus*), Barbados cherry shrub (*Malpighia emarginata*), tuberose plant (*Polianthes tuberosa*), strawberry guava shrub (*Psidium cattleyanum*), banana plant (*Musa* sp.), sugarcane (*Saccharum* sp.), spider plant (*Chlorophytum comosum*), snake plant (*Sansevieria trifasciata*), orange shrub (*C. maxima* × *C. reticulata*), lime shrub (*Citrus limonum*), oxeye daisy (*Leucanthemum vulgare*), "mini lacre" (*Ixora* sp.), Surinam cherry shrub (*Eugenia uniflora*), pomegranate shrub (*Punica granatum*), rose plant (*Rosa odorata*), seriguela plant (*Spondias purpurea*), and sorriso de maria plant (*Chrysanthellum indicum*), herbaceous and shrubby plants; coconut tree (*Cocos nucifera*), African tulip tree (*Spathodea campanulata*), weeping fig tree (*Ficus benjamina*), Royal poinciana (*Delonix regia*), arboreal plants: breadfruit tree (*Artocarpus altilis*), guava tree (*Psidium guajava*), pink trumpet tree (*Handroanthus heptaphyllus*), jabuticaba tree (*Plinia cauliflora*), mango tree (*Mangifera indica*), nim tree (*Azadirachta indica*), olive tree (*Olea europaea*), pitomba tree (*Talisia esculenta*), and tamarindo tree (*Tamarindus indica*) (annex 1 a-f).

Methodological approach and data analysis

On June 25, 2019, the study area was visited to verify the existence of snails associated with vegetation. Hundreds of *L. fulica* individuals were found among the plants even after massive extermination of the snails conducted by the residents, who collected specimens, which were then deposited in a container and incinerated. On June 29 and 30, 2019, and on April 20 and 21, 2020, a careful active search was carried out throughout the area of the gated community beginning at 3:30 pm (2 h effort by two researchers), recording the location and behavior of individuals associated with different types of substrates. Living individuals were quantified and measured with a ruler to determine life stages by size classes of shell length, according to Silva & Aleluia (2010): class 1 [≤ 40 mm: young]; class 2 [41–60 mm: subadult]; and class 3 [≥ 61 mm: adult].

Living individuals were photographed *in situ* on different substrates and associated with the vegetation. The plants used by *L. fulica* individuals as resting sites and, likely, as food sources were studied.

Abundance (N) [number of individuals by size class and by type of substrate (plant species)] and relative frequency [ratio between the abundance of the species (n) in each size class and total sum of individuals (T), expressed as percentage] were calculated using the formula: $Fr = \frac{n}{T} x100$. Subsequently, the variations among the three body size classes (Class 1: ≤ 40 mm; Class 2: 41-60 mm; Class 3: ≥ 61 mm), the relationship between the size of the snails and the plant species, and the interaction between size classes *vs.* plant species were investigated.

Results

A total of 128 individuals of *L. fulica* (measuring 11 to 84 mm) were found at the study site associated with 11 plant species (annex 1–2). Eighty-five (63%) of these individuals belonged to size class 1 (≤ 40 mm; young) (annex 2 a-d, f) (figure 2). Adult individuals (class 3: ≥ 61 mm, (annex 2 g–k) (figure 2) prevailed over subadults (class 2: 41-60 mm, (annex 2e) (figure 2)

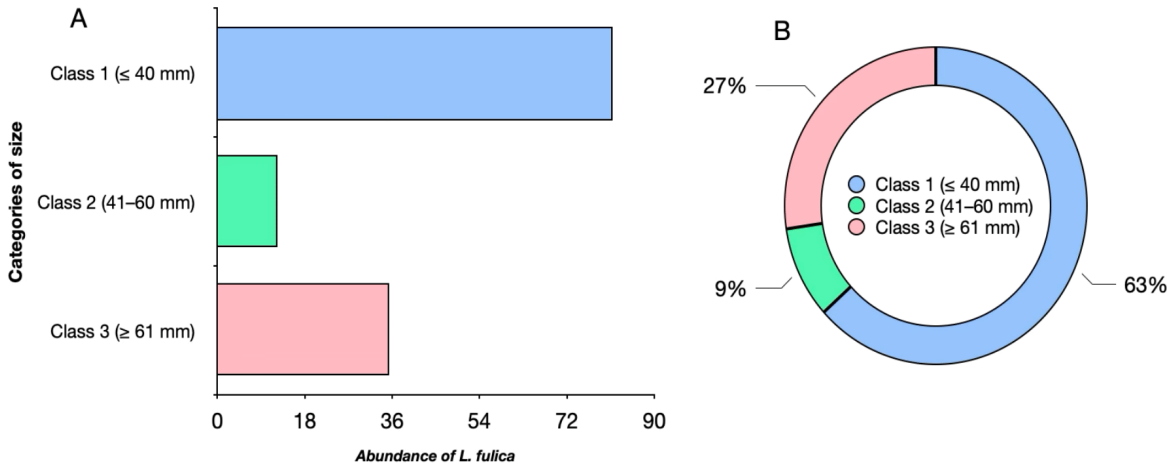

Figure 2. Abundance (A) and relative frequency (B) of *Lissachatina fulica* based on size classes of individuals collected in Crispim residential community, Cajazeiras, Paraíba, northeastern Brazil.

The snails were mainly associated with the following shrub/tree plants: *Musa* sp. (N = 19, Fr = 15%, annex 2 j–k), *S. trifasciata* (N = 18; Fr = 14%, annex 2 b–c), and *C. indicum* (N = 17; Fr = 13%) (Figures 3–5). A smaller number of individuals (N < 5) were found on the arboreal plants *M. indica*, *C. nucifera*, and *A. indica* (annex 2a).

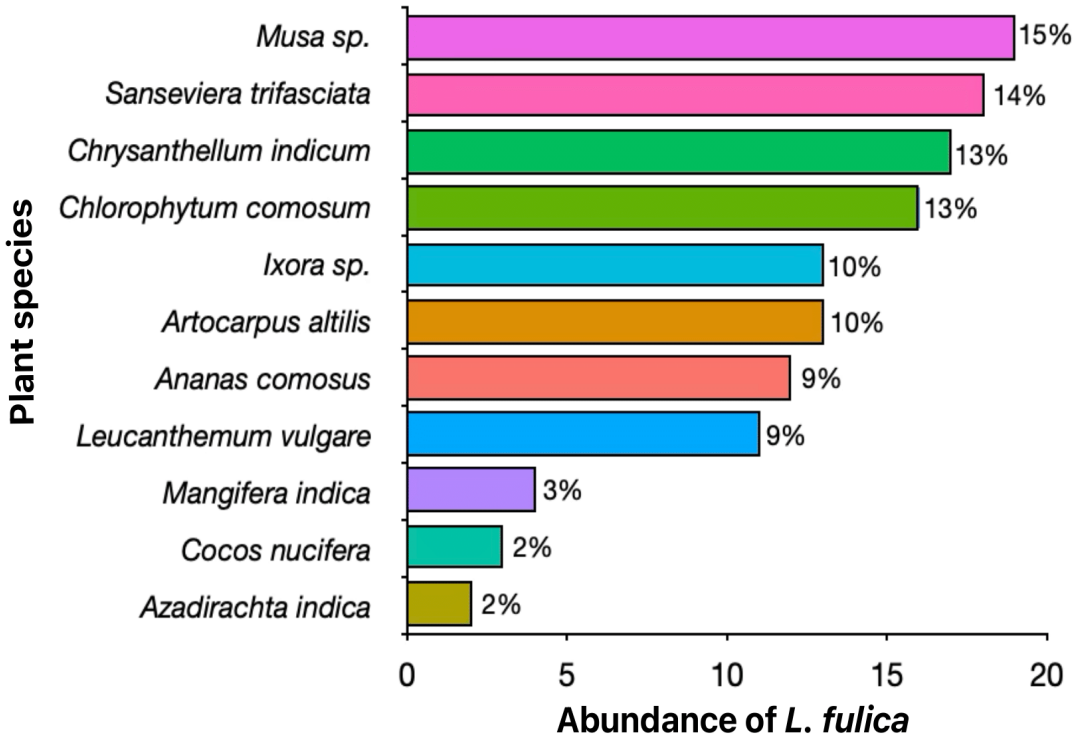

Figure 3. Abundance and relative frequency (%) of *Lissachatina fulica* associated with plant species in Crispim residential community, Cajazeiras, Paraíba, northeastern Brazil.

The analysis of *L. fulica* by body size class revealed that the largest number of individuals were in class 1 on virtually all plant species, accounting for more than 60% of the total abundance. Individuals in class 2 were the least abundant, corresponding to 6-23% of the sample. This class also had a more restricted distribution pattern, being associated with few plant species (*Musa* sp., *C. indicum*, *S. trifasciata*, and *A. altilis*) (Figures 4–5).

Discussion

In sync with other studies, we show that different growth stages have been found mainly in gardens (Fischer et al., 2006; Oliveira et al., 2008; Madella & Auricchio, 2014; Arruda & Santos, 2022), causing severe harm to ornamental and food plants (Fischer & Costa, 2010; Fischer & Nering, 2010; Fischer et al., 2010), even with no trace of the species in the surrounding habitats in certain cases (Arruda & Santos, 2022).

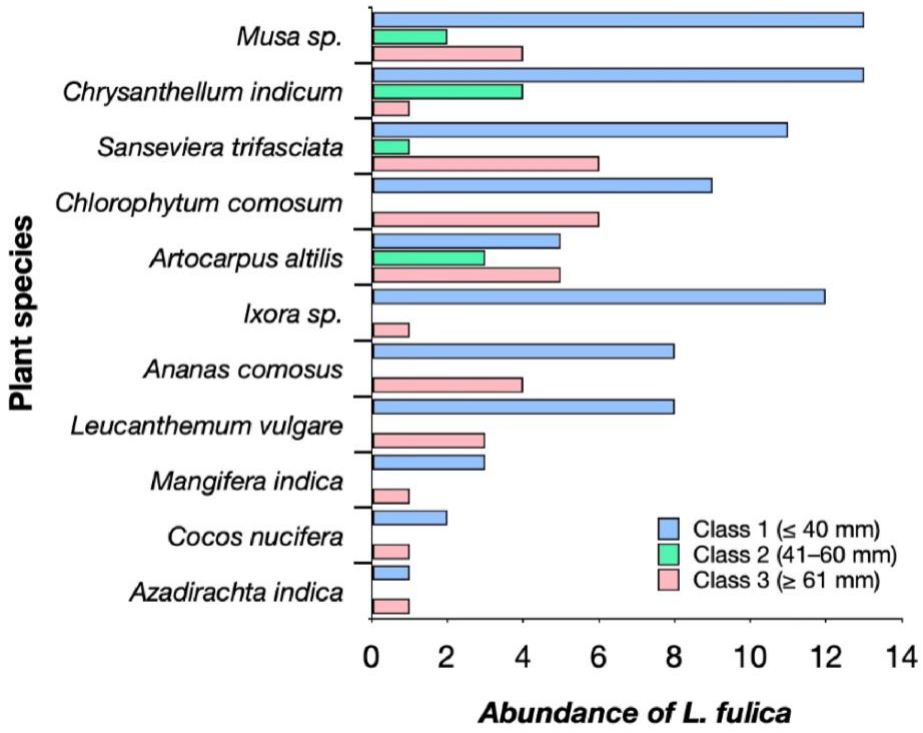

Figure 4. Abundance of *Lissachatina fulica* among body size classes associated with plant species in Crispim residential community, Cajazeiras, Paraíba, northeastern Brazil.

L. fulica was actively sought and not observed outside the study site. This lends strength to the hypothesis that the species arrived at the gated residential community through multiple passive transports associated with the seedlings of ornamental and food plants, which are feeding, resting, and sheltering sites for snails and their eggs. The residents at the study site carried out an intense, urgent collection of individuals, which were then burned. The manual control (collection) of individuals is recognized as the most common and efficient method for eliminating infestations of *L. fulica* (Simião & Fischer, 2004; Colley, 2010). Grassy areas in the gated residential community containing

numerous individuals were burned to reduce the number of animals and prevent the dispersal of snails into the environment. Otherwise, the snails in the gated community would have rapidly spread to the surrounding environment. The species has accelerated population growth that directly affects landscapes due to its voracity for green biomass (Eston et al., 2006; Zenni & Ziller, 2010).

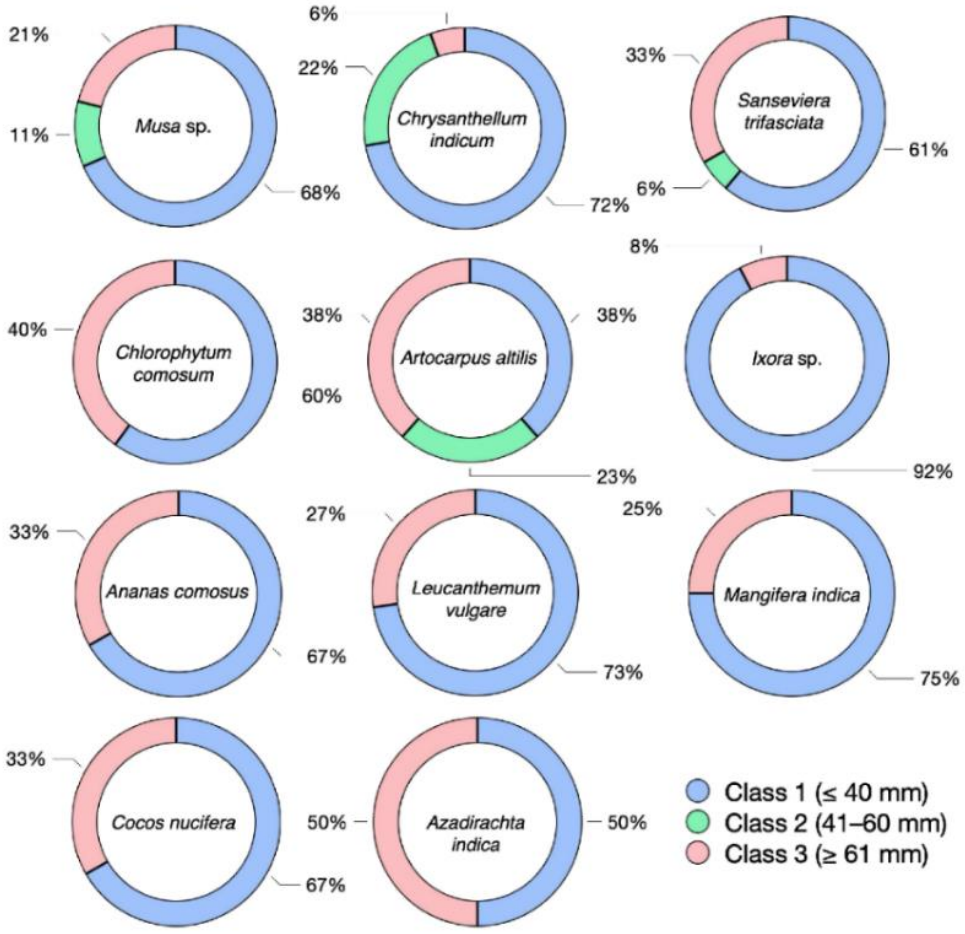

Figure 5. Relative abundance by size class of *Lissachatina fulica* associated with plant species in Crispim residential community, Cajazeiras, Paraíba, northeastern Brazil.

Lissachatina fulica is recorded here for the first time associated with the following plant species: *A. indica*, *C. comosum*, *C. indicum*, *L. vulgare*, and *M. indica.* These species are not on the list of vegetable or ornamental garden plants most seriously attacked by *A. fulica* in Brazil (Thiengo et al., 2007). On the other hand, *A. comosus*, *A. altilis*, *C. nucifera*, *Ixora* sp., *Musa* sp., and *S. trifasciata* are among the plant species

previously recognized as having suffered damage from the giant African snail (Fischer & Colley, 2005; Albuquerque et al., 2008; Raut & Backer, 2008). Annex 2(a) shows one of the few *L. fulica* individuals found on the trunk of the toxic plant *A. indica*, with no evidence of consumption of parts of the plant. Fischer & Colley (2005) also recorded *L. fulica* using *S. trifasciata* (another toxic plant) as a resting site in the state of Paraná (southeastern Brazil). In contrast, this same toxic plant was recorded as being susceptible to feeding damage by the African snail in regions outside Africa (Raut & Backer, 2008). Individuals can either die or tolerate the ingestion of phytotoxic compounds without mortality (Fischer & Nering, 2010).

In this study, individuals were found in the resting period on the leaves, stems, and the base of plants (annex 2a-i), with the exception of a few individuals that began to crawl away after handling (annex2 c, f, j, k). According to Fischer & Nering (2010), these mollusks remain buried or suspended motionless on plants during the day, although young individuals wander over different substrates. *Lissachatina fulica* exhibited voracity for native/non-native, ornamental/edible vascular plants (Teles et al., 1997; Eston et al., 2006; Fischer et al., 2006; Colley, 2010; Fischer & Nering, 2010) [e.g., *A. comosus*, *C. comosum*, *C. indicum*, *Ixora* sp. and *Musa* sp. (annex 1 b, c-e, annex 2 j, k), mainly those that also served as resting sites in the gated residential community. This species can feed on a large number of plants, mainly sprouts and young plants (Eston et al., 2006; Valim & Bim, 2017). Some studies have indicated that *L. fulica* has a feeding preference for exotic succulent plants (Fischer & Colley, 2005) and organic plant matter in different stages of decomposition (Fischer et al., 2006; Oliveira et al., 2008).

Musa spp. is recognized as one of the most susceptible crop plants to feeding damage by *L. fulica* (Fischer & Colley, 2005; Thiengo et al., 2007; Albuquerque et al., 2008; Colley, 2010; Fischer & Nering, 2010; Present Study: Figures 19-20) as well as other achatinids (Raut & Backer, 2008). Fischer & Colley (2005) also recorded *L. fulica* associated with a number of plant species, mainly exotic species on Rasa Island in the municipality of Guaraqueçaba in the state of Paraná, southeastern Brazil, many of which were in a resting state on the base of plants and leaves, especially *Musa* sp. Previous studies have reported the feeding preference of the giant African snail for vascular plants belonging to the genera *Ixora* and *Musa* (Fischer & Colley, 2005; Albuquerque et al., 2008;

Colley, 2010). The latter is also recognized for providing an important resting place due to the accumulation of plant parts in the soil (Fischer & Colley, 2005; Colley, 2010) and for having been devastated by the pest in agricultural areas (Teles et al., 1997).

The population structure of *L. fulica* has been studied in a few municipalities in Northern and northeastern Brazil based on the biometric determination of shell length classes, which reflect the young, subadult, and adult life stages (Oliveira et al., 2008; Silva & Aleluia, 2010; Santos et al., 2022). Similar to our findings, Oliveira et al. (2008) and Santos et al. (2022) also reported the predominance of juvenile snails (shell length ≤ 40 mm) in regions of the states of Macapá (northern Brazil) and Alagoas (northeastern Brazil), respectively. Oliveira et al. (2008) found no adult individuals (shell length ≥ 61 mm) at the study sites investigated, whereas Silva & Aleluia (2010) found a predominance of individuals with shell lengths ranging from 41 to 60 mm in neighborhoods of the city of Salvador in Bahia state (northeastern Brazil).

Lissachatina fulica is an invasive agricultural pest that has caused serious harm throughout the world, particularly in tropical regions. Despite its wide distribution in different phytogeographic domains in Brazil, this snail continues to expand its occurrence due to passive anthropogenic transport, causing devastating impacts in gardens and agricultural regions. Even under semi-arid climate conditions, the individuals who entered the gated residential community successfully occupied the gardens due to the existence of favorable microclimate and ecological conditions. According to the residents, individuals of *L. fulica* declined substantially due to the control method. The remaining individuals still need to be vigilantly combatted to effectively eradicate the species from the study area as soon as possible. Contacting those responsible for nurseries that supply plant seedlings to the study site and explaining the problem of the passive transport of snails is a fundamental aspect in the primary line of defense to prevent *L. fulica* from reaching community gardens.

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Annexes

Annex 1. Main food and ornamental plants from Crispim residential community in which individuals of *L. fulica* were found in association with soil, and on leaves or stalks: a) General view of garden containing *Artocarpus altilis*, *Cocos nucifera*, and *Musa* sp. trees, b) *Ananas comosus*, c) *Sanseviera trifasciata* and *Ixora* sp., d) *Chlorophytum comosum*, e) *Chrysanthellum indicum*, f) *Leucanthemum vulgare*.

Annex 2. Individuals of *Lissachatina fulica* associated with different substrates: a) *Azadirachta indica*, b) and c) – *Sanseviera trifasciata*; d) – h) *Leucanthemum vulgare*, i) Ground, j) and k) *Musa sp.*

THE SECOND INHERITANCE: CULTURAL EVOLUTION

LA SEGUNDA HERENCIA: EVOLUCIÓN CULTURAL

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THE SECOND INHERITANCE: CULTURAL EVOLUTION

LA SEGUNDA HERENCIA: EVOLUCIÓN CULTURAL

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Abstract

Social learning allows individuals to acquire information from others, facilitating the spread of behaviors that can form stable traditions and animal cultures. This review examines the mechanisms and evolutionary consequences of cultural transmission in non-human animals, focusing primarily on primates, cetaceans, and birds. We analyze evidence across diverse biological contexts, including foraging strategies in orcas, migratory routes in cranes and whales, and vocal learning in songbirds and parrots. These examples demonstrate that behaviors previously attributed solely to instinct are often shaped by social inheritance. Furthermore, we explore how cultural evolution interacts with genetic evolution. Case studies, such as genomic adaptations in distinct orca ecotypes and accelerated speciation rates in vocal-learning bird lineages, suggest that culture can act as a selective pressure driving morphological and genetic divergence. We conclude that cultural transmission constitutes a secondary inheritance system complementary to genetics. Recognizing this dual inheritance model is essential for a comprehensive understanding of animal behavior, adaptation, and speciation.

Keywords: Animal culture, cultural evolution, cultural transmission, non-genetic inheritance, gene-culture coevolution, social learning.

Resumen

El aprendizaje social permite a los individuos adquirir información de otros, lo que facilita la propagación de comportamientos que pueden formar tradiciones estables y culturas animales. Esta revisión examina los mecanismos y las consecuencias evolutivas de la transmisión cultural en animales no humanos, con énfasis en primates, cetáceos y

aves. Analizamos evidencia en diversos contextos biológicos, incluidas las estrategias de forrajeo en orcas, las rutas migratorias de grullas y ballenas y el aprendizaje vocal en aves cantoras y loros. Estos ejemplos demuestran que comportamientos previamente atribuidos únicamente al instinto con frecuencia se moldean por la herencia social. Además, exploramos cómo la evolución cultural interactúa con la evolución genética. Estudios de caso, como las adaptaciones genómicas en distintos ecotipos de orcas y las tasas de especiación aceleradas en linajes de aves con aprendizaje vocal, sugieren que la cultura puede actuar como una presión selectiva que impulsa la divergencia morfológica y genética. Concluimos que la transmisión cultural constituye un sistema de herencia secundario complementario a la genética. Reconocer este modelo de herencia dual es esencial para una comprensión integral del comportamiento animal, la adaptación y la especiación.

Palabras clave: Aprendizaje social, coevolución gen-cultura, cultura animal, evolución cultural, herencia no genética, transmisión cultural.

Introduction

Social learning is a process in which individuals learn from the actions and consequences of others (Heyes, 1994) and transmit behaviors across individuals, populations, and even generations (Heyes & Galef, 1996). This allows organisms to expand their behavioral repertoire by introducing new information (Dukas, 2013), helping them adapt to local environmental conditions (Snell-Rood, 2013). By sharing information and skills, social learning enables individuals to draw on others' prior experiences to improve their biological fitness (Slagsvold & Wiebe, 2011). This contrasts with individual learning, which relies on personal trial and error (Whiten, 2019). Studies suggest that innovations, such as specific whale songs (Garland et al., 2011) or foraging techniques in primates, birds, and cetaceans (Kawai, 1965; Allen et al., 2013; Aplin et al., 2014) can spread rapidly through populations. Furthermore, sharing this information over long periods may lead to the formation of animal culture (Laland & Hoppitt, 2003; Whiten, 2011; Aplin, 2016), which acts as an inheritance system complementary to genetics (Whiten, 2005, 2017a; Mesoudi, 2015).

But how is culture defined? Some authors define it simply as the existence of a tradition, while others describe culture as socially transmitted information, whether it be beliefs, skills, thoughts, or knowledge (Mesoudi, 2015; Whiten, 2019). However, Mundinger (1980) proposed a consensus definition based on definitions used in various disciplines: “culture is a set of populations that, through learning, are replicated generation after generation: an open population of functionally related, shared and imitable behavioral patterns (and any material products), and, simultaneously, a closed population of acquired neural codes for these behaviors.” In this definition, the concept of population follows the framework suggested by White (1959) regarding non-genetic inheritance. Therefore, it refers not to groups of living organisms but rather to a population of ideas or neural codes, and the associated motor patterns that operate as behavioral models (Mundinger, 1980). In addition, Mundinger (1980) proposed a specific definition for tradition: “a tradition is a complex of learned behaviors shared by individuals within a population of organisms, appearing and persisting in their behavioral repertoire generation after generation”.

Therefore, "cultural transmission" can be defined as the various social learning processes through which individuals acquire traditions. These traditions can be highly stable; for instance, Pipek et al. (2016) suggest that the Yellowhammer (*Emberiza citrinella*) -a bird- has maintained its song for centuries. Similarly, Haslam et al. (2009) highlight a behavior in chimpanzees that has persisted for thousands of years: the use of stone tools. However, if an individual modifies a behavior while learning it, and these changes are subsequently passed on to others via cultural transmission, a second form of evolution can emerge (Whiten, 2019).

Cultural evolution can be categorized into two main processes: cultural evolutionary drift and Darwinian cultural evolution (Whiten, 2019). Cultural evolutionary drift is analogous to genetic drift in organic evolution, involving changes that are selectively neutral (Futuyma, 2013). Conversely, some culturally transmitted behaviors may be subject to selection, adapting to specific selective pressures; this process corresponds to Darwinian cultural evolution (Boyd & Richerson, 1985; Mesoudi et al., 2006). Darwinian cultural evolution can stabilize beneficial traits or be directional, actively

driving evolutionary change. These changes may accumulate or disappear over long periods, potentially increasing the complexity and efficiency of the behaviors involved (Whiten, 2019). Therefore, cultures are not static; their components can change over time, altering their form, function, or frequency. Notably, this wide range of cultural practices can significantly influence the life, survival, and biological fitness of organisms (Galef & Whiten, 2017; Whiten, 2017b).

It is widely established that cultural transmission and social learning occur across a diverse array of behaviors and animal species, spanning from insects and birds to mammals (Mundinger, 1980; Heyes, 2012; Aplin, 2016; Whiten, 2019). However, given the volume of existing evidence, three primary groups have emerged as the focus of animal culture research: primates (Whiten, 2017c), cetaceans (Rendell & Whitehead, 2001), and birds (Podos & Warren, 2007). In the following sections, we will examine specific taxa for which social learning and cultural inheritance have been suggested, as well as the specific contexts in which these inherited behaviors occur.

Cultural inheritance across diverse contexts and species

As previously noted, social learning is widespread across various taxa of the animal kingdom and occurs in a variety of contexts. In primates, examples include tool use and grooming practices (Biro et al., 2003; Whiten et al., 1999), while in whales, there is evidence of migratory routes learning (Baker et al., 1990; Valenzuela et al., 2009). Similarly, birds exhibit behaviors such as predator recognition (Curio et al., 1978), courtship (White, 2004), and foraging (Norton-Griffiths, 1967).

Foraging

Orcas (*Orcinus orca*), also known as killer whales, have a wide distribution range, extending from the Antarctic to the Arctic, and a diet that includes birds, fish, mammals, and reptiles. However, they form groups or "ecotypes" with specialized diets and distinct hunting traditions (Beans, 2017). Some groups specialize in salmon, others in mammals, and others in penguins. Furthermore, even among groups that feed on seals, hunting practices differ significantly: some generate waves to wash seals off ice floes, whereas

others intentionally beach themselves to grab seals and drag them back into the water (Foote et al., 2016).

Riesch et al. (2012) present an example of cultural limitation in orcas; they describe three orcas from a mammal-eating specialist group that, after being captured and held in captivity, refused fish when offered as food. However, this fish was known to be nutritious for the species, as it constitutes the primary food source for other orca populations. Because of refusing the fish, one individual died of starvation. In contrast, within just 24 hours, the other two individuals adapted to the established culture of the group into which they were integrated and began feeding on fish. This suggests that culture can drastically influence orca behavior, potentially leading to disastrous consequences.

Migration

Both birds and cetaceans are taxonomic groups well known for their migratory behaviors. Among birds, approximately 2,000 species are migratory, and for some, evidence suggests that migratory routes may be transmitted via social learning. For instance, in the Great Bustard (*Otis tarda*), one of the heaviest flying birds, research indicates that juveniles undertake their first migration (and occasionally subsequent ones) alongside their parents or members of their local community. They subsequently follow the routes acquired during these initial journeys (Palacín et al., 2011). Such findings suggest that collective migration provides evidence that these acquired routes are culturally transmitted.

Further evidence supporting the social learning of migratory routes comes from experimental studies. For example, Sladen et al. (2002) successfully taught a migratory route to Canada Geese (*Branta canadensis*) by leading them with an ultralight aircraft. Remarkably, 83% of these birds returned independently to the training site the following spring, whereas individuals transported by ground in enclosed trucks failed to return. Similar results were reported by Lishman et al. (1997), who used the same method to teach a migratory route to Sandhill Cranes (*Grus canadensis*); the majority of these birds also successfully returned to their training grounds.

Mueller et al. (2013) offer another example involving the Whooping Crane (*Grus americana*). Their results suggest that young birds learning migratory routes by flying with "expert" individuals deviate 34% less from the route than juveniles that do not travel with such guides. These findings indicate that migratory skills in this species develop over several years and that cultural transmission via experienced birds yields progressive improvements in the migratory performance of younger individuals.

Similarly, evidence supports the social learning of migratory routes in cetaceans. These highly conserved movements between breeding and feeding grounds are typically transmitted from mother to calves. Such migratory behaviors have been documented in Southern Right Whales (*Eubalaena australis*, Valenzuela et al., 2009), Humpback Whales (*Megaptera novaeangliae*, Whitehead, 2010), and Belugas (*Delphinapterus leucas*, Colbeck et al., 2013). This transmission of information is critical, as locating novel feeding and breeding grounds without prior knowledge can be extremely costly and lead to high mortality rates (Whitehead, 2007, 2010). Conversely, these ingrained traditions may prevent whales from exploring new areas in response to habitat degradation caused by climate change. This cultural conservatism can lead to maladaptive behavioral choices within their established ranges, potentially driving populations toward collapse (Whitehead & Richerson, 2009).

Vocalization

Bird songs are often used for mate identification as well as for territorial defense (Searcy & Andersson, 1986). In birds of the suborder Passeri (songbirds), vocal development is influenced by imitative learning, allowing for wide variation in learning patterns (Beecher & Brenowitz, 2005). One of the primary advantages of song learning may be the formation of dialects, which has been suggested to promote genetic adaptation to local environmental conditions (Nottebohm, 1972). Nottebohm (1972) proposes that males learn the dialect of their natal area because local females develop a preference for these dialects; consequently, females select males capable of singing the local dialect.

Female preference for more elaborate songs is another proposed advantage, driving males to incorporate acoustic elements from other individuals into their vocal

repertoire. For instance, in Zebra Finches (*Taeniopygia guttata*), it has been suggested that female preference for complex songs correlates with higher male quality (Woodgate et al., 2012).

Humpback Whales (*Megaptera novaeangliae*) learn their vocalizations, which are often highly elaborate. Much like bird songs, these calls have been suggested to serve the functions of attracting mates and repelling rivals (Tyack, 1981). In contrast, Bottlenose Dolphins (*Tursiops truncatus*) possess simple, yet unique vocalizations known as "signature whistles." These are typically emitted when individuals become separated from close group members, suggesting they facilitate social cohesion by enabling the identification and localization of distant individuals (Caldwell & Caldwell, 1965; Janik & Slater, 1998; King & Janik, 2013).

Strikingly, a similar strategy is found in some parrots. These birds also utilize short, simple, yet individual-specific vocalizations to promote social cohesion, serving primarily to attract individuals to foraging flocks and to identify mates (Balsby & Adams, 2011; Berg et al., 2011; Farabaugh et al., 1994). Some parrots, such as the Australian Cockatoo (*Cacatua galerita*), modify their contact calls to match diverse groups, suggesting an advantage in mediating the fission-fusion dynamics characteristic of many parrot species (Scarl & Bradbury, 2009).

Primates

Primates have been extensively studied in both field and laboratory settings, providing comprehensive evidence of their culture and behaviors. Consequently, more than 39 traditions have been identified in Chimpanzees (*Pan troglodytes*) across Africa, ranging from foraging techniques and tool use to social behaviors and sexual habits (Whiten et al., 1999). A wide variety of traditions has also been reported for other primates, including 24 for Orangutans (genus *Pongo*; van Schaik et al., 2003) and 22 for gorillas (genus *Gorilla*; Robbins et al., 2016).

Chimpanzees demonstrate distinct preferences in nut-cracking tools; some populations prefer wooden tools, while others utilize stone tools (Luncz & Boesch, 2014). Furthermore, archaeological excavations have revealed that this behaviour dates back at

least 4,300 years, indicating that this tradition has persisted for a significant period (Mercader et al., 2007).

Additionally, McGrew and Tutin (1978) reported the first social custom observed in a non-human animal: the "grooming handclasp". This behavior is performed exclusively by a chimpanzee population in a national park in Tanzania, and was not observed even in a nearby group inhabiting a different national park within the same country.

Can cultural inheritance drive genetic divergence?

Currently, animal populations are recognized as possessing two distinct streams of information: genetic and cultural. Cultural information is inherited as individuals learn behaviors from mothers, fathers, mates, or unrelated individuals. But how do these two information streams interact? A prominent example in humans is the production of lactase in adulthood within European populations. This trait co-evolved with the cultural practice of dairy farming, selecting individuals with the LP allele, which allows for the continuous production of the enzyme throughout adult life (Itan et al., 2009).

Furthermore, current research suggests that culture can directly influence trait evolution and the divergence of populations toward speciation. Just as variations in morphological traits allow some individuals to survive or reproduce more effectively than others, cultural innovations — such as tools or predator avoidance tactics — can also enhance an individual's survival and reproductive success (Beans, 2017). Consequently, culture can drive selection for adapted morphology to these behaviors, such as arms better suited for tool manipulation, or selection for cognitive traits, like the ability to acquire tool use through imitation (Galef & Whiten, 2017).

Although obtaining evidence for these phenomena is challenging, the research on orcas provides substantial support for this theory of cultural selection. Foote et al. (2016) examined the genomic consequences of specialized hunting cultures in 48 orcas across five distinct ecotypes. They aimed to determine if these groups were truly isolated and if their cultures were linked to unique genomic changes. The results revealed genetically distinct groups, even among those inhabiting the same geographic areas with overlapping distribution ranges. Furthermore, they identified genetic variants associated with

adaptations to the specific hunting traditions of each ecotype. For instance, mammal-eating ecotypes were associated with variants in the metabolism of the methionine-regulating gene, an essential amino acid found in high concentrations in their prey. Conversely, groups inhabiting the extreme cold of the Antarctic showed variants in genes related to adipose tissue development, providing necessary thermal protection. Despite these significant findings, the authors note that not all groups will necessarily diverge into separate species, suggesting that full speciation has not occurred in the past, given that their common ancestor is relatively recent.

Further evidence can be found in bird songs, which are innate in some species but require social learning in others. In both cases, the song evolves over time and across generations. Mason et al. (2017) suggest that culture plays a crucial role in this evolutionary process. They analyzed the songs of nearly 600 bird species from two families: *Thraupidae* (Tanagers), which learn their songs, and *Furnariidae* (Ovenbirds), which possess innate vocalizations. The researchers estimated how quickly songs evolved within different branches of the family tree; high rates of evolution were inferred where songs differed significantly between closely related species. Subsequently, they combined this acoustic dataset with genetic data indicating speciation rates to identify relationships between acoustic change and species divergence. When the rate of song evolution increased in a phylogenetic branch, the rate of speciation also increased. Notably, songs evolved 1.4 times faster in *Thraupidae* — the song-learning family — compared to *Furnariidae*, which relies on innate vocalizations. The authors suggest that while song may diverge before the species in some instances, and vice versa in others, a clear pattern emerges: the faster the song evolves, the faster the species diverges. This leads to the conclusion that rapid song evolution — facilitated by cultural transmission — can contribute to speciation.

Conclusions

The discussion of the existence of culture in non-human animals dates to the 1950s, yet lacks the attention it merits, and few studies attempt to link the influence of cultural phenomena to genetic, morphological, and even ecological research. Nevertheless, the studies reviewed in this article highlight the importance of social

learning and culture in behaviors previously attributed to the simplest explanation: instinct. Key examples include the learning of migratory routes in birds and cetaceans, and individual recognition in dolphins and parrots.

On the other hand, few studies conclusively demonstrate genetic, morphological, or ecological changes resulting from cultural evolution. Even in humans — the most studied species — examples remain scarce, with lactase persistence in European populations standing out as a classic case. Consequently, a primary objective for researchers should be to determine whether cultural evolution influences the genetic, morphological, and perhaps ecological variations observed across taxa.

In an era of accelerated scientific discovery, we can no longer afford to ignore cultural evolution as a potential explanation for these phenomena. It must be recognized that, alongside genetics, a secondary form of inheritance plays a substantial role in the lives of many organisms: cultural inheritance.

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APLICACIÓN DE FITOSOMAS EN LA INDUSTRIA FARMACÉUTICA: OPORTUNIDADES Y RETOS PARA SU DESARROLLO EN MÉXICO

APPLICATION OF PHYTOSOMES IN THE PHARMACEUTICAL INDUSTRY: OPPORTUNITIES AND CHALLENGES FOR THEIR DEVELOPMENT IN MEXICO

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Abstract

Medicinal plants contain various bioactive compounds such as alkaloids, flavonoids, among others, which possess therapeutic activities, mainly exhibiting antibacterial, antioxidant, anti-inflammatory, anticancer, and immunomodulatory effects. However, their application is restricted due to their low solubility, limited bioavailability, poor stability, as well as their high toxicity at elevated doses. To overcome these limitations, compound delivery systems have been developed, among which phytosomes stand out because of their ability to form phyto-phospholipid complexes that improve the permeability, solubility, and stability of plant extracts. Phytosomes have emerged as a novel method for phytochemical encapsulation, as these compounds are encapsulated within the hydrophilic head of the phospholipid, thereby increasing their bioavailability. However, in Mexico, their implementation in the pharmaceutical field remains limited due to the lack of extract standardization, scaling challenges, and the limited collaboration between research and industry. This research note describes a perspective on the potential of phytosomes as delivery systems for therapeutic compounds and the need to promote their development, with the aim of contributing to the discussion regarding their standardization and strengthening within the national context.
Keywords: Encapsulation, Pharmaceutical science, Phytosomes, Plant extracts.

Resumen

Las plantas medicinales contienen distintos compuestos bioactivos como alcaloides, flavonoides, entre otros, los cuales poseen actividades terapéuticas

destacando principales efectos de tipo antibacteriano, antioxidante, antiinflamatorio, anticancerígeno e inmunomodulador, pero su aplicación se ve restringida debido a su baja solubilidad, limitada biodisponibilidad, poca estabilidad, así como a su toxicidad a dosis altas. Para superar estas limitaciones, se han desarrollado sistemas de liberación de compuestos, entre los cuales se destacan los fitosomas, debido a su capacidad para formar complejos fito-fosfolípido que mejoran la permeabilidad, solubilidad y estabilidad de los extractos vegetales. Los fitosomas surgen como un novedoso método de encapsulación de fitoquímicos ya que estos quedan encapsulados dentro de la cabeza hidrofílica del fosfolípido, lo cual aumenta su biodisponibilidad. Sin embargo, en México su implementación en el área farmacéutica aún es limitada debido a la escasa estandarización de extractos, los retos de escalamiento y la limitada vinculación entre investigación e industria. En la presente nota, se describe una perspectiva sobre el potencial de los fitosomas como sistemas de administración de compuestos terapéuticos y la necesidad de impulsar su desarrollo, con el propósito de contribuir a la discusión sobre su estandarización y fortalecimiento en el contexto nacional.
Palabras clave: Encapsulación, Extractos vegetales, Farmacéutica, Fitosoma.

Introducción

Existe una gran biodiversidad de plantas medicinales las cuales poseen una amplia cantidad de componentes químicos que ofrecen posibles beneficios para el sector salud. Los componentes bioactivos que se encuentran en las plantas incluyen alcaloides, flavonoides, terpenoides, fenólicos y aceites esenciales. En este sentido, se han reportado los efectos farmacológicos de estas sustancias, como su potencial antibacteriano, antioxidante, antiinflamatorio, anticancerígeno e inmunomodulador (Dar et al., 2023). No obstante, el uso de extractos vegetales cuenta con diversas limitantes como lo es susceptibilidad a la oxidación, baja solubilidad, reducida biodisponibilidad, inestabilidad y toxicidad inducida por dosis altas (Sogut et al., 2020). Asimismo, en México el desarrollo de tecnologías avanzadas para el sector biofarmacéutico enfrenta limitantes relacionadas con el escalamiento tecnológico y la insuficiencia de políticas en

ciencia, tecnología e innovación dirigidas al sector biotecnológico y biofarmacéutico a diferencia de países como Argentina y Brasil (Gligo et al., 2023). En este contexto, resulta necesaria la implementación de sistemas avanzados de administración de fármacos que permitan una liberación más controlada y dirigida. Estos sistemas presentan propiedades físicas, químicas y morfológicas que influyen en su velocidad y mecanismo de liberación, así como en su afinidad por diversas sustancias farmacológicas (Ezike et al., 2023).

Dentro de estos sistemas, se encuentran los fitosomas, liposomas, nanopartículas, emulsiones, niosomas, hidrogeles, los cuales han sido estudiados como sistemas de administración de extractos vegetales (Sogut et al., 2020). Uno de los sistemas que ha tomado mayor interés son los fitosomas, los cuales consisten en nanopartículas constituidas por fosfolípidos de monocapa o doble capa que forman vesículas.

La importancia de estos coloides se basa en su uso dirigido al sitio objetivo, lo cual mejora la eficacia terapéutica de los compuestos farmacéuticos (Susilawati et al., 2021). Además, la cantidad de fosfolípidos en este sistema regula el incremento de la solubilidad lo que favorece a la permeabilidad de compuestos activos e incrementa la estabilidad del sistema (Susilawati et al., 2021). Por otro lado, las cadenas alifáticas de los fosfolípidos permanecen sin cambios tanto en su forma libre como en el complejo, lo que indica que no participan directamente en la interacción, sino que actúan como recubrimiento del compuesto activo (Chandran et al., 2023).

Los fitosomas presentan una estructura micelar, la cual se encuentra diseñada para imitar las propiedades estructurales de las membranas celulares, protegiendo a los fitoquímicos de las condiciones enzimáticas del sistema digestivo y aumenta la eficacia del transporte hacia tejidos específicos (Mardiana et al., 2025). También, presentan aplicaciones en diferentes áreas, principalmente en el campo farmacéutico, donde se destacan por incrementar la biodisponibilidad y favorecer la absorción de extractos vegetales con baja solubilidad (Bhakat et al., 2024).

En el área cosmética, estos sistemas son utilizados en productos para el cuidado de la piel debido a su capacidad para liberar extractos vegetales con actividad antioxidante y antiinflamatoria (Bhakat et al., 2024). Por otro lado, también son

empleados en la formulación de cremas, lociones y sueros tópicos para mejorar la penetración cutánea y garantizar una liberación más eficiente de extractos vegetales bioactivos (Bhakat et al., 2024).

En comparación con otros vehículos de liberación, como los liposomas, los fitosomas presentan ciertas similitudes, sin embargo, también muestran diferencias estructurales fundamentales. En los liposomas, los fitoquímicos se disuelven en el núcleo acuoso interno o en la membrana lipídica. En contraste, en los fitosomas el principio activo se entrelaza en la cabeza hidrofílica de los fosfolípidos, interacción que no ocurre en los liposomas (Karpuz et al., 2020) (Figura 1).

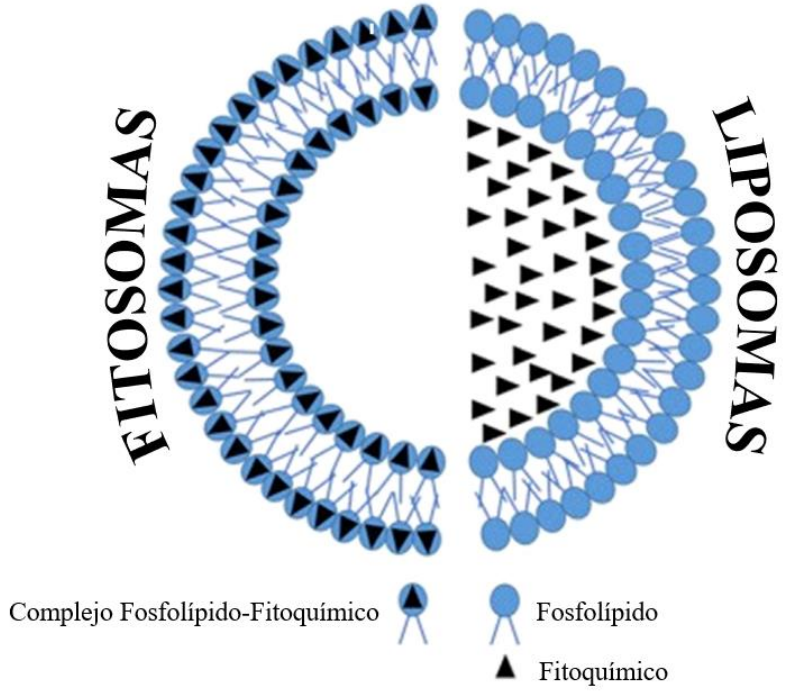

Figura 1: Diferencias estructurales entre fitosomas y liposomas. Adaptado de Ghanbarzadeh et al. (2016).

Asimismo, la cantidad de fosfolípidos en la formulación de liposomas es aproximadamente cinco veces mayor que en los fitosomas, lo cual representa una

desventaja para los liposomas en aplicaciones orales (Karpuz et al., 2020). A pesar de las ventajas terapéuticas que presentan, su desarrollo e implementación en México aún son limitados.

Gran parte de las empresas farmacéuticas nacionales presentan una reducida participación en la innovación de terapias dirigidas a enfermedades prioritarias para la salud nacional. No obstante, las empresas con mayor capacidad productiva y tecnológica podrían diversificar sus bases mediante el desarrollo de conocimientos biotecnológicos en sus departamentos e implementar colaboraciones con el sector científico nacional, lo cual abre un panorama para el fortalecimiento del sector farmacéutico nacional (Gligo et al., 2023).

CONCLUSIONES

Los fitosomas representan uno de los sistemas de liberación más prometedores en el sector farmacéutico debido a su capacidad para mejorar la solubilidad, estabilidad y biodisponibilidad de compuestos de origen vegetal. Sin embargo, su implementación en México aún es limitada. Esta situación no se relacionada con la falta de biodiversidad, ya que México posee una de las floras medicinales más extensas a nivel mundial, sino con las limitaciones en infraestructura, la escasa estandarización de extractos herbales y la reducida vinculación entre el sector científico y la industria farmacéutica.

Por ello, es necesario robustecer la investigación en sistemas avanzados de administración, así como impulsar políticas de innovación, colaboración académica-industrial y desarrollo tecnológico que favorezcan la producción de formulaciones basadas en fitosomas. Esta propuesta podría ayudar al aprovechamiento del potencial terapéutico de los recursos naturales presentes en México y el fortalecimiento del sector biofarmacéutico nacional.

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