Agricultura, Sociedad y Desarrollo

EDIBLE INSECTS: SOCIOECONOMIC AND ENVIRONMENTAL PERSPECTIVE IN NORTH-CENTRAL MEXICO

H. **Romero-Jiménez**[1], J. **Cadena-Íñiguez**[1], L. A. **Tarango-Arámbula**[1]*, S. Ugalde-Lezama[2], G. **Olmos-Oropeza**[1], E. **Hernández-Roldan**[3]

[1]Colegio de Postgraduados, Campus San Luis Potosí, Iturbide 73, 78600, Salinas de Hidalgo, S.L.P., México.
[2]Área de Recursos Naturales renovables. Departamento de Suelos. Universidad Autónoma Chapingo. km 38.5 Carretera México-Texcoco, 56230, Chapingo, Estado de México. México.
[3]Facultad de Ciencias Biológicas y Agropecuarias, Región Orizaba-Cordoba, Universidad Veracruzana. Josefa Ortiz de Domínguez s/n, Camino Peñuela-Amatlán, Peñuela s/n, 94945, Amatlán de los Reyes, Veracruz, México.
*Corresponding author: ltarango@colpos.mx

Citation: Romero-Jiménez H, Cadena-Íñiguez J, Tarango-Arámbula LA, Ugalde-Lezama S, Olmos-Oropeza G, Hernández-Roldan, E. 2025. Edible insects: socioeconomic and environmental perspective in north-central Mexico. Agricultura, Sociedad y Desarrollo https://doi.org/10.22231/asyd.v22i2.1752

ASyD(22): 278-300

Editor in Chief:
Dr. Benito Ramírez Valverde

Received: October 21, 2024.
Approved: November 20, 2024.

Estimated publication date:
April 10, 2025.

ABSTRACT

Escamolera ant (*Liometopum apiculatum*), red worm (*Comadia redtenbacheri*) and white worm (*Aegiale hesperiaris*) have suffered from significant extraction by inhabitants of rural communities, decreasing their populations due to poor management of their habitats. These species are economically and nutritionally important resources for rural communities in arid and semi-arid areas of Mexico. However, these insects face lack of regulation regarding their use. Therefore, the objective of this research was to identify the socioeconomic and environmental perspective of key actors involved in the harvest of edible insects (escamol, white worm and red maguey worm). For this, interviews were applied to key actors and the results were rendered on graphs, according to observation frequencies and basic statistics. A principal component analysis (PCA) was conducted to identify the most important indicators related to the key actors. A cluster analysis was also carried out to determine differences or dissimilarities among the variables considered. The collection of edible insects in central-northern Mexico faces a challenge to the sustainable management of its populations and habitats. This study revealed the need for initiatives promoting sustainable rural development, attributing cultural and economic value to this activity and contributing to its viability.

Key words: invertebrates, nutrition, rural communities, semi-desert, sustainability.

INTRODUCTION

In central and northern Mexico, there are natural resources of great ecological and socioeconomic value (Pedroza *et al*., 2014). In the state of Zacatecas, edible insects have been continuously extracted since 30 years, specifically the escamolera ant (*Liometopum apiculatum* M.), a hymenopteran; the red worm (*Comadia redtenbacheri* H.) and the white maguey worm (*Aegiale hesperiaris* W.), both lepidopterans (Briones *et al*., 2022). Currently, these species are economically important; however, they are exploited in an unsustainable manner (De Luna *et al*., 2013).

The escamolera ant and the red and white maguey worm are over-exploited by rural communities in central Mexico, which has reduced their populations. Nest destruction resulting from extraction has also been recorded, in addition to habitat change due to human activities (Dinwiddie *et al*., 2013). Besides this, it has been documented that the rural population in the Potosino-Zacatecano Highlands has limited information regarding the rational management of extraction, concerning the ecological behavior of the species, and gaps in the implementation of environmental regulations (Ramos *et al*., 2006). Some variables of climate change, such as drought, increased temperature, and reduction of the plant canopy necessary for the foraging activity of the species *Liometopum apiculatum* M., *Aegiale hesperiaris* W., and *Comadia redtenbacheri* H., are impacting the survival of these species.

Colonies of the escamolera ant are over-exploited due to the economic importance derived from the sale of their larvae (Briones *et al*., 2022). Likewise, the habitat it shares with the white and red maguey worm is under intensive grazing pressure and studies on these species are lacking. The larvae of *L. apiculatum, C. redtenbacheri* and *A. hesperiaris* have an agro-industrial potential due to their nutritional value, in addition to being well accepted by the consumer; however, this potential is limited by their seasonal availability. Even though these species are an important economic and nutritional resource for rural inhabitants of arid and semi-arid areas of Mexico, they are threatened by overgrazing (Hernández *et al*., 2017), so that an attenuating factor to reduce these impacts may be the implementation of outreach, awareness-raising and training for key actors, which would contribute to the conservation of wildlife (Rosas *et al*., 2015), as well as promoting projects for diversification, such as productive reforestation projects with local species that accommodate insect species.

In this context, it is essential to establish collaborative links with ejidatarios, commissioners, intermediaries, and particularly collectors. Therefore, the objective of this research was to identify the socioeconomic and environmental perspective of the key actors in the activity-collection of edible insects (escamol, white worm, and red maguey worm), through a social intervention model.

THEORETICAL FRAMEWORK

The main species of edible insects that are exploited in north-central Mexico are: *Liometopum apiculatum* M. (escamolera ant), *Comadia redtenbacheri* H. (red worm) and *Aegiale hesperiaris* W. (white worm). In this region, the escamolera ant has been the most studied. This species inhabits a wide variety of climates and soils, representing a thermophilic, monogynous and polyandrous species in its reproduction, with an omnivorous diet and low biological vulnerability

(Berumen *et al*., 2021). Some of the studies focus on foraging and nesting substrates, where the ant forages on *Yucca spp*., *Agave salmiana* and *Opuntia rastrera* and built its nest under *A. salmiana, Yucca* spp., *O. rastrera* and *Dalea bicolor* (Rafael *et al*., 2017). Regarding habitat use, it does not make use of habitat components according to their availability, avoids bare soil, sites at low elevation and selects slopes with southwest exposure (Cruz *et al*., 2014). Likewise, the escamolera ant forages in a territorial area of about 1 565.65 ± 535.63 m^2, where the main nesting substrates consist of *Agave salmiana, Yucca spp., Prosopis spp., Acacia farnesiana*, bare soil, woody material and shrub cover (Rafael *et al*., 2019). The highest nest density has been recorded in the crasicaule scrub (3.8 nests/ha) (Hernández *et al*., 2017) and 4.8 nests/ha (Cruz *et al*., 2023). The ant larvae (escamoles) are rich in proteins, amino acids, lipids, vitamins and minerals but the composition of these nutrients varies depending on the type of vegetation (Cruz *et al*., 2018). It has been proposed that this species should be included in the NOM-059, in the category of Subject to Special Protection (SSP) (Berumen *et al*., 2021). Additionally, the productive characteristics have been studied, indicating that the length and width of the larvae (N = 1,100) were similar in all nesting substrates, and that their weight varies from 0.09 g, in the *Prosopis laevigata* substrate to 0.16 g, in the dry palm substrate (*Yucca* spp.); therefore, to complete one kg, between 11,111 and 6,250 larvae respectively, are required (Romero *et al*., 2024).

The red worm (*Comadia redtenbacheri*) or chinicuil, is associated with the maguey and feeds mainly on its roots, where it completes its larval development (Granados *et al*., 1993). Its size ranges between 3 and 4 cm in length, and it is consumed in its larval phase (Quintero and Ramos, 2018). It is collected in the states of Hidalgo, Puebla, Tlaxcala, Querétaro, San Luis Potosí, Oaxaca, Chiapas, Jalisco and Mexico City (Llanderal *et al*., 2010). In recent years, its exploitation has intensified in Zacatecas, Coahuila, Nuevo León, and Jalisco. The white maguey worm (*Aegiale hesperiaris*), also known as the butter worm, is the larvae of a jumping butterfly that lives in the maguey leaves. This worm is abundant in the states of Hidalgo, State of Mexico, Tlaxcala, and Puebla (Quintero and Ramos, 2018) and is currently marketed in Zacatecas and San Luis Potosí. These species of maguey worms contain between 28% and 81% of protein (Ramos and Pino, 2001; Esparza *et al*., 2008).

Collection of larvae from the escamolera ant begins during the second half of February and when adequately exploited, this collection can extend until June. However, poor nest management shortens this period to May (Briones *et al*., 2022). The white worm is collected between May and August, extracted from agave leaves (Ramos *et al*., 2006; Briones *et al*., 2022). Collection is carried out among magueys with yellowish or reddish leaves, which have lost turgor, coinciding with the rainy season, from August to October (Briones *et al*., 2022). Extraction of the red worm implies the destruction of the plant, but if not collected, the insect would end up killing the plant anyway, so its exploitation can be considered beneficial (Ramos *et al*., 2006).

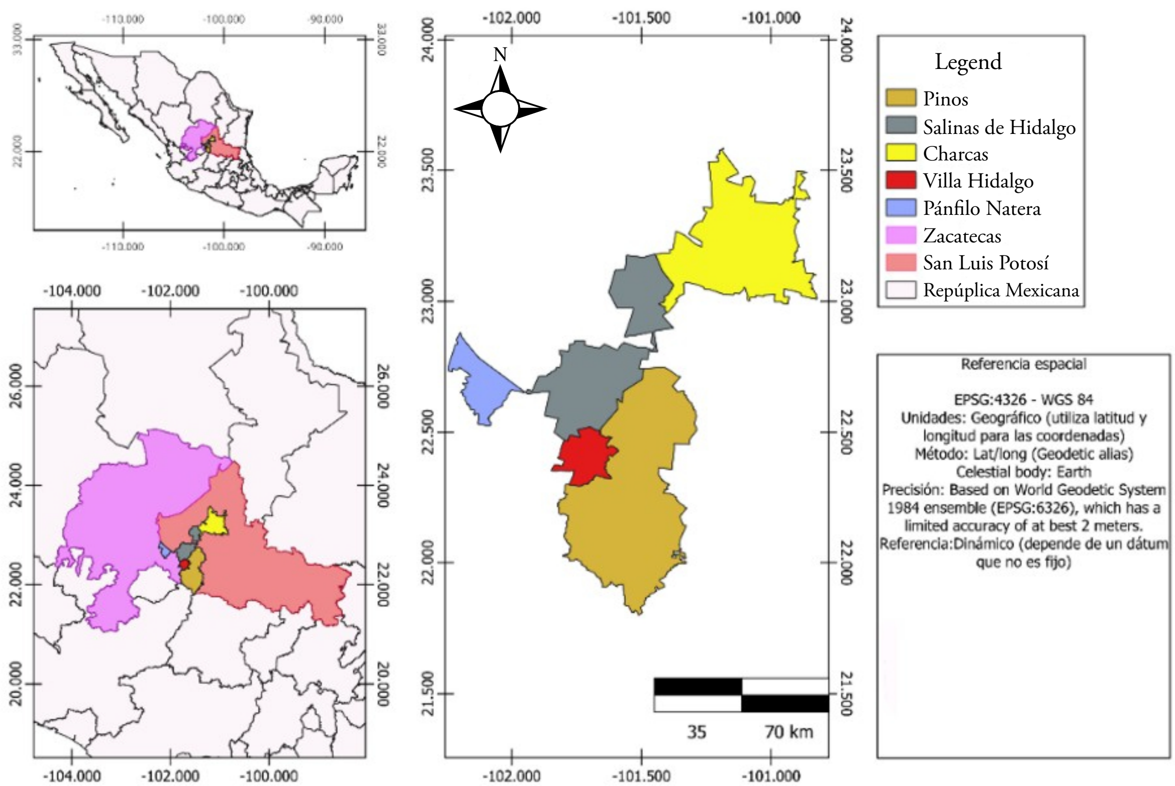
METHODOLOGY

Study area

This research was carried out in the municipalities of Pinos, General Pánfilo Natera and Villa Hidalgo in Zacatecas, as well as in Salinas de Hidalgo and Charcas, San Luis Potosí. The rural communities included La Pendencia, Santiago, El Zacatal, Pámanes, Guadalupe Victoria, Guadalupe de los Pozos, El Salto, El Tecomate, Trinidad, and San Juan Sin Agua (Figure 1).

Social Intervention Model

The Social Intervention Model (SIM) was applied; a comprehensive methodology based on a dialogue format with rural inhabitants (Castro *et al*.,



Source: self-elaborated.

Figure 1. Macro -location of the rural communities in the territory where social intervention was implemented.

2018). The SIM facilitated the active participation of key agents, ensuring that the data collected reflected the realities and perspectives of the actors involved, as accurately as possible (Greenwood and Levin, 2007).

A qualitative approach was applied through directed interviews, which allowed for an in-depth exploration of the experiences, practices and perceptions of key stakeholders. This qualitative method was essential to capture complex details and specific aspects that could not have been addressed through quantitative techniques. Building relationships of trust was fundamental to the success of the intervention. Deliberate efforts were made to establish open and transparent communication with participants, explaining the objectives of the study and ensuring confidentiality (McKnight and Chervany, 2006). The selection of key stakeholders was undertaken by consulting with local experts and peasant organizations. Invitations were made to explain the purpose of the study and the role of participants. In addition, pilot interviews were conducted in order to fine-tune the questions and validate their relevance.

The final selection of key stakeholders was made, based on the results from the pilot interviews and the availability of participants, ensuring adequate representation of all groups involved.

Regarding ethical considerations, prior informed consent was obtained from participants, ensuring that they understood the purpose of the research and their right to privacy, and codes were used instead of names (American Psychological Association, 2020). Each key agent represented a larger sample of people who are involved in collecting edible insects.

Elaboration of interviews

The interviews were designed to include a combination of open-ended and multiple-choice questions to provide both flexibility in responses and specific, quantifiable data. Open-ended questions allowed participants to express their experiences, perceptions, and knowledge in their own words, which facilitated the collection of contextualized information (Strauss and Corbin, 1998). Multiple-choice questions helped to obtain more structured and comparable data on specific aspects of insect collection and management.

The interview script included three sections, each focused on a type of edible insect: ant, white worm, and red maguey worm. Each section addressed particular aspects related to the insect in question. This structure allowed the interview to comprehensively cover the various aspects of edible insect collection, ensuring an overall perspective.

Interviews were conducted considering four thematic strata: social, economic, technical, and environmental. This stratified approach enabled addressing the topic from multiple points of view, providing an integrated view of the harvesting activity. The social stratum explored aspects of the specific information of the key agents, while the economic stratum focused on the income generated and market dynamics. The technical stratum addressed the productive figures in the harvest, and the environmental stratum examined the impact of the harvest on the ecosystem. Strategies of coexistence and dynamism were applied, to help maintain the interest of the interviewees (Greenwood and Levin, 2007).

STATISTICAL ANALYSIS

Observation frequency analysis

Data from individual interviews were used to determine and graphically compare the social, technical, economic, and environmental situation of edible insect collectors. The information used to determine social circumstances included: gender, age, education, productive activity, and location; this information was analyzed using the Observation Frequency Index (Fo) (Curts, 1993) and basic statistics. Current product prices and economic spillover by season were analyzed to determine the economic situation. Likewise, to determine the technical (productive) situation, data such as insect harvest per day and per season were analyzed, and this information was also used to identify variations in production in recent years. To determine the relationship between the yield and production of edible insects with particular characteristics of their environment, the key actors were questioned about the effect of precipitation, overgrazing and deforestation on the activity of collecting edible insects.

Principal Component Analysis

A multivariate analysis by Principal Components PCA (Pearson, 1901; Rentería *et al*., 2011) was applied to reduce the variance of the variables describing the responses of key agents, in three axes that explained the greatest variance in variables (questions) that reflected the current situation of the use of escamoles, white and red worm, submitting 18; 15 and 12 variables respectively for each insect, in order to identify the association between variables using Xlstat v.2021.4 (Bald *et al*., 1999; Navarro *et al*., 2010).

Hierarchical Agglomerative Clustering Analysis (HAC)

Differences between variables in the responses of key actors by location were performed using a Hierarchical Agglomerative Clustering (HAC) analysis. This multivariate statistical analysis minimizes a large and complex data set into a small number of data groups called clusters, where members of some of the groups share characteristics (similarity) (Lin and Chen, 2006). This analysis was undertaken using Xlstat v.2021.4. Figure 2 shows images of edible insects and their habitat in the study area.

RESULTS

Social situation

A total of 31 key agents were interviewed. 38.7% of the collectors were older adults (52 to 84 years), 45.1% were adults (32 to 50 years) and 16.1% were young people (16 to 27 years). Age distribution indicates a critical situation regarding generational differences among collectors which may signify the abandonment of traditional practices.

The interviewees' education levels vary, which affects their ability to adapt to innovations in the sustainable exploitation of edible insects. Of the 31 interviewees, 48.4% completed secondary school, which is the most common level of education among key agents. 35.5% completed primary school, 9.7% completed high school, and 6.4% have no formal education (S/E).

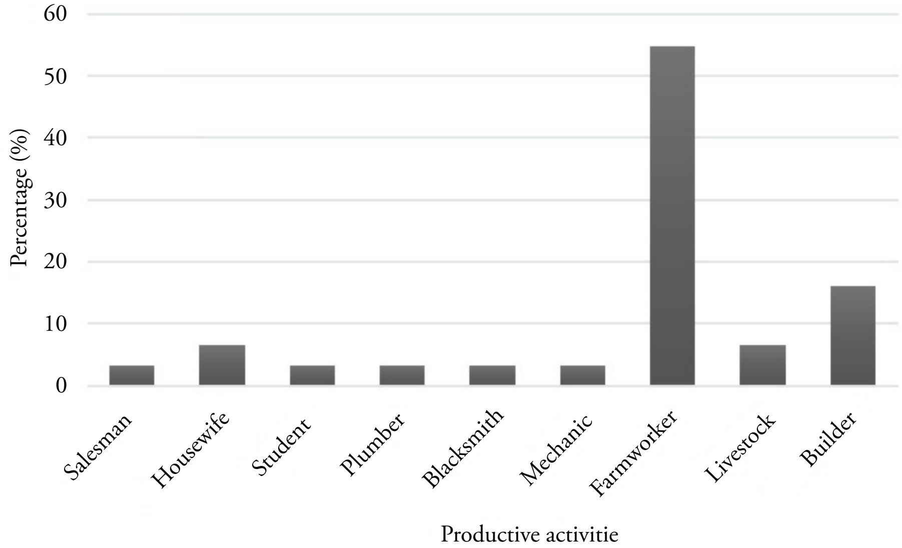
Regarding productive activity, most key agents (54.8%) are farm-workers and 16.1% work in construction (Figure 3).

Notably, none of the key actors considers insect collection as their main principal productive activity; however, due to economic importance of this activity, they engage in it annually as an alternative source of income. Regarding location and gender, the communities of El Tecomate and Charcas were outstanding for the participation of key actors at 19.3%, followed by San Juan Sin Agua (16.1%), Guadalupe de los Pozos, El Patrocinio and Zacatal, each with a participation of 9.6%, whereas Pámanes only had 6.4%. Other locations such as La Pendencia, La Trinidad and Santiago had a lower value (3.2%). The collectors are mainly men (90.3%) and women (9.7%); generally, this relationship is maintained for other productive activities.

Habitat of edible insects   *L. apiculatum* larvae   *C. redtenbacheri* larvae

Source: self-elaborated.

Figure 2. Edible insects in their habitat.



Source: self-elaborated with data from interviews, 2024.
Figure 3. Main productive activities of key actors involved in edible insect collection activity in central-northern Mexico.

Economic situation

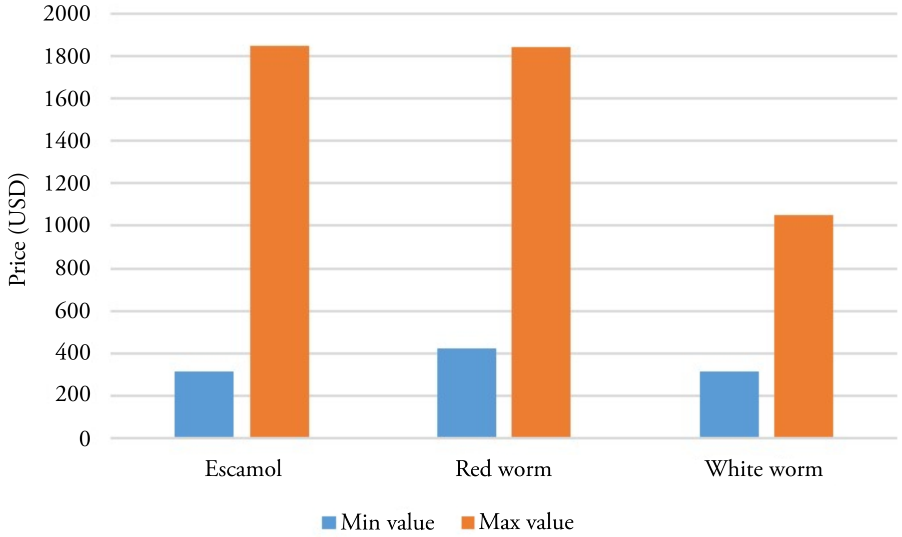
The prices of escamol and red and white worms show notable differences, usually depending on demand, availability, cultural perception, and time of year. For example, according to those interviewed, the price of escamol varied between USD$16.00 and USD$42.00 per kilogram (Figure 4).

The minimum price of red worm was USD$47.00 and the maximum was USD$53.00. This insect is generally the most expensive of the three. The prices of white worm show a similar behavior to that of escamol (USD$21.00 to USD$42.00) (Figure 5).

Maximum per capita incomes derived from the collection of escamol and red worm were similar. In contrast, minimum incomes for escamol and white worm were similar (Figure 4), reflecting annual income from the three insects of USD$351.00 and USD$1,580.00 as minimum and maximum, respectively.

Technical/productive situation

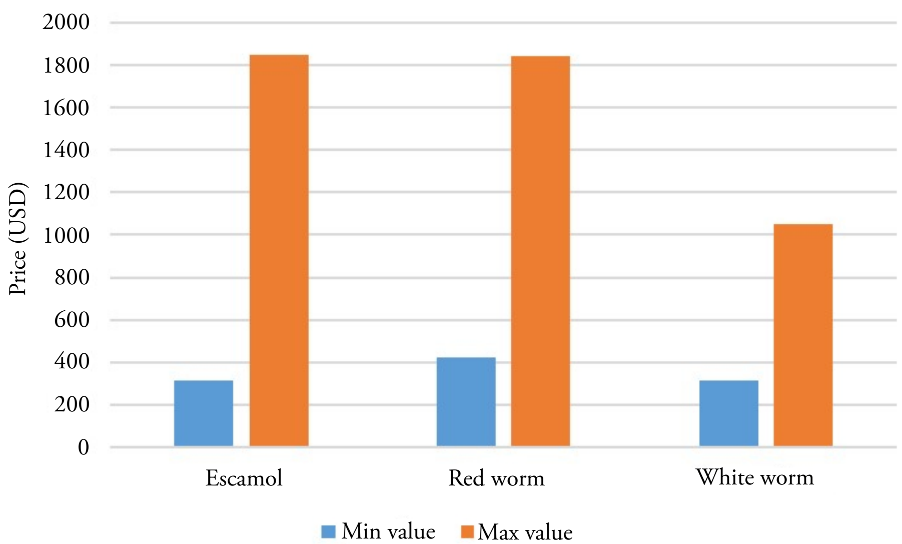
The amount of insects collected per person per day fluctuates between 1.0 and 10.0 kg of escamol and between 0.5 and 2.0 kg of white and red worms (Figure 6), resulting in 200 kg of escamol, 30 kg of red worms and 20 kg of white worms per year (Figure 7). This indicates an annual income of USD$4,390.00 for individual collectors. According to the information provided,100% of the key agents agreed that insect collection has decreased considerably in recent years.



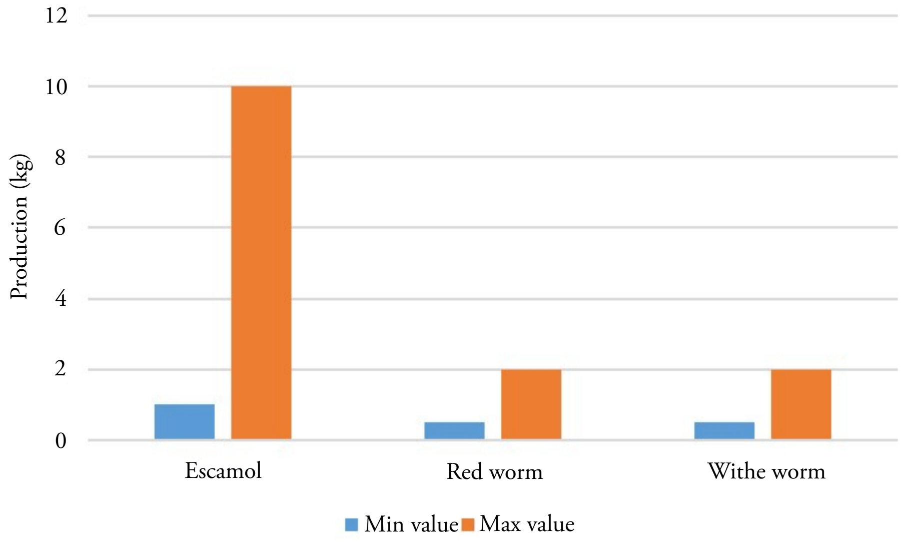
Source: self-elaborated with data from interviews, 2024.
Figure 4. Prices for edible insects in dollars per kilogram.

Environmental Situation

Most key stakeholders perceive significant environmental deterioration in the exploitation areas. 95% of those interviewed mentioned that droughts have severely modified the ecosystem and hindered natural regeneration. Similarly,

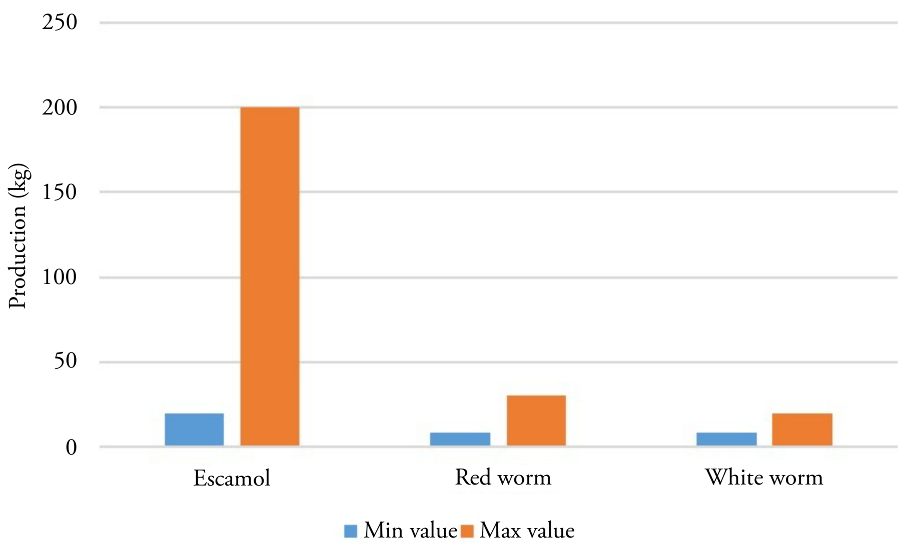


Source: self-elaborated with data from interviews, 2024.
Figure 5. *Per capita* income of key actors, from annual insect collection in central-northern Mexico.

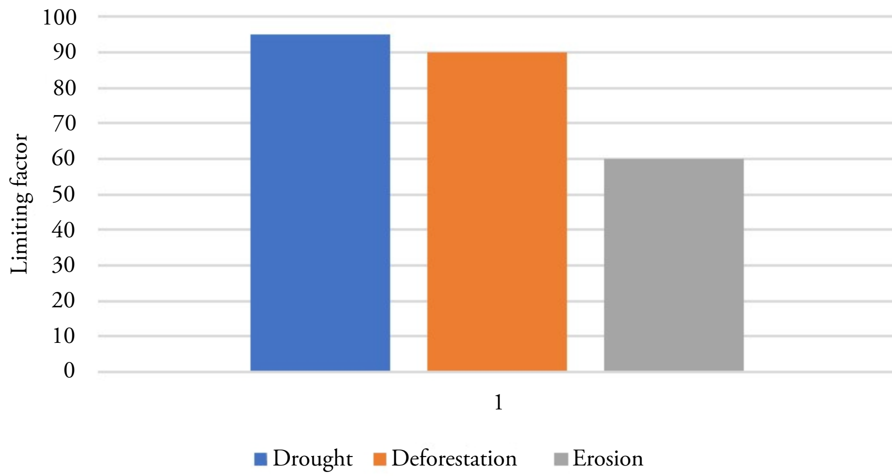


Source: self-elaborated with data from interviews, 2024.
Figure 6. Collection of edible insects by key actors per person, per day.

90% consider that deforestation caused by expanding the mezcal and cattle industry has negatively impacted local biodiversity. 60% of participants also relate this environmental deterioration to soil erosion, further aggravating environmental problems (Figure 8).



Source: self-elaborated with data from interviews, 2024.
Figure 7. Collection of edible insects by key actors *per capita*/year.



Source: self-elaborated with data from interviews, 2024.
Figure 8. Environmental limitations to the collection of edible insects.

Principal component analysis

Results from the PCAs showed that the first three components explained 52% of the accumulated variance for escamol, 66% for red worm and 60% for white worm, related to the variables (questions) that describe the perception of key agents assessing edible insect collection. The most important variables in Component 1 (PC1) were collection per season (0.793), number of nests (0.582) and income per season (0.537), indicating that this component is linked to the use of escamol based on collection season and production. PC2 relates to nest and livestock management practices and PC3 to demographic and experience characteristics (Table 1).

In the case of the red worm, the outstanding variables of PC1 were income per season (0.834), harvest per day (0.780) and per season (0.701). These variables are mainly related to production and income derived from the use of this insect. PC2 reflects a relationship between experience and adequate management of the resource and PC3 describes the sociodemographic characteristics (Table 2).

Regarding the white worm, the PC1 was related to physical and biological aspects, as the most important variables consisted of the number of worms per maguey leaf (0.654), size of the worm (0.531), number of leaves per maguey (0.433) and the leaves containing the worm (0.365). PC2 includes the economic importance of use, and PC3 includes experience and demographic characteristics, as was the case with the escamol (Table 3).

Hierarchical Agglomerative Clustering (HAC) Analysis

Hierarchical Agglomerative Clustering (HAC), for the data concerning the perception of key agents by location related to edible insect harvest, formed

Table 1. Accumulated variance reflected in the variables integrated into the first three principal components that reduce dimensionality in the exploitation of escamol.

Variable	PC1	PC2	PC3
Ag	0.037	0.124	0.109
Ge	0.256	0.033	0.050
Sc	0.010	0.016	**0.418**
Em	**0.383**	0.185	0.011
NuMe	0.024	0.000	**0.453**
Hy	0.239	0.217	**0.281**
LvHe	0.000	**0.453**	0.169
CoNu	**0.582**	0.028	0.002
FoPh	0.196	0.104	0.001
HarNu	**0.252**	0.131	0.235
NeRe	0.273	**0.353**	0.194
ReTi	**0.314**	0.301	0.155
Wa	0.027	**0.282**	0.025
ClTi	**0.097**	0.051	0.010
HaperDay	0.266	**0.279**	0.009
HarPerSea	**0.793**	0.001	0.001
Wor	0.094	**0.316**	0.027
ProPerSEs	**0.537**	0.009	0.004

Note: PCA loading factors performed on the correlation matrix of 18 descriptive variables related to the use of escamol in north-central Mexico. (Ag: age, Ge: gender, Sc: education level, Em: employment, NuMe: Number of members, Hy: years of harvest, LvHe: heads of Livestock, ConNu: number of nests, FoPh: foraging paths, HarNu: number of harvests, NeRe: nest rest, ReTi: rest time, Wa: water, ClTi: cleaning, HaperDay: harvest per day, Har-PerSea: harvest per season, Wor: prices, ProPerSEs: income per season.

two clusters for escamol; suggesting that these groups are based on harvesting experience, geographical location, management practices and perception of sustainability (Figure 9).

Table 2. Accumulated variance reflected in the variables integrated into the first three principal components that reduce dimensionality in the exploitation of the red worm.

Variable	CP1	CP2	CP3
Gen	0.238	0.050	0.207
Ag	0.130	**0.631**	0.064
Sc	0.000	0.077	0.161
Em	0.113	0.035	**0.677**
HarYea	**0.386**	0.377	0.074
LivStHe	0.002	**0.538**	0.165
AgMag	0.011	**0.594**	0.024

Table 2. Continuation.

Variable	CP1	CP2	CP3
WorWid	0.032	0.272	**0.288**
HarvPerDay	**0.780**	0.106	0.002
HarvPerSea	**0.701**	0.140	0.065
Wor	0.080	0.023	0.001
WorPerSea	**0.834**	0.039	0.012

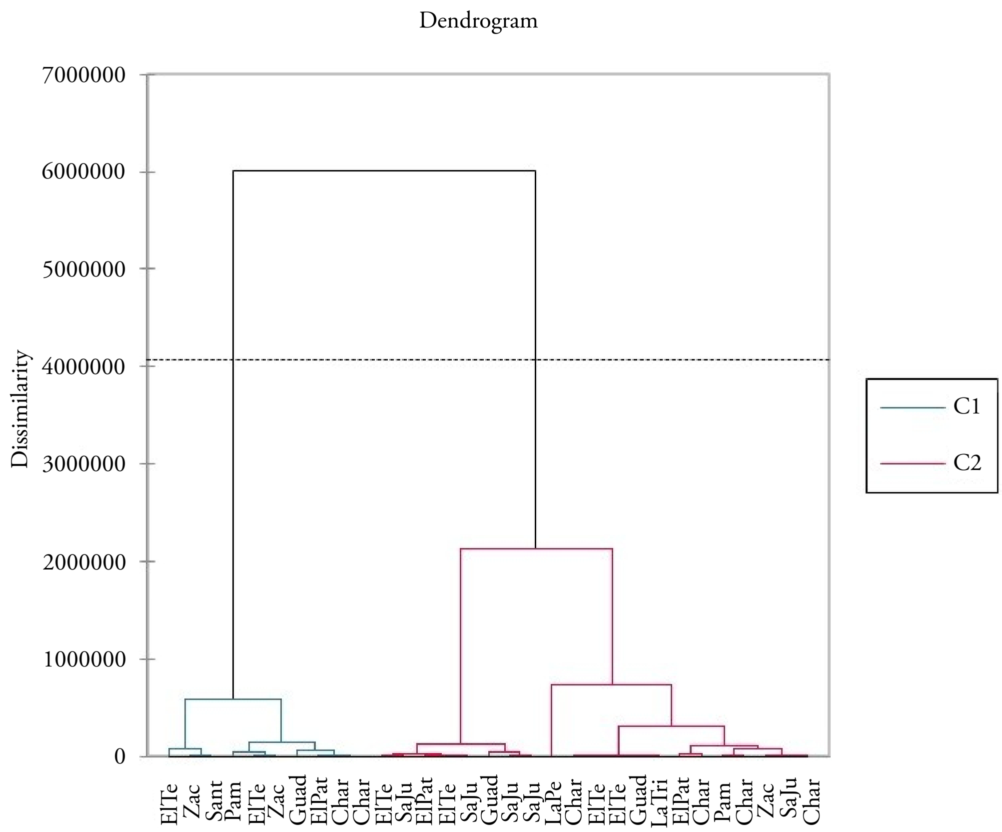
English: Note: PCA loading factors performed on the correlation matrix of 12 descriptive variables related to the use of red worm in north-central Mexico. Gen: gender, Ag: age, Sc: education level, Em: employment, HarYea: years of harvest, LivStHe: heads of livestock, AgMag: agave maturity, WorWid: worm price, HarvPerDay: harvest per day, HarvPerSea: harvest per season, Wor: prices, WorPerSea: income per season.

Three clusters were identified regarding the collection of the red worm: those who are concerned about overexploitation, those who depend economically on the red worm, and those who manage sustainable collection strategies (Figure 10).

Table 3. Accumulated variance reflected in the variables integrated into the first three principal components that reduce dimensionality in the exploitation of the white worm.

Variable	PC1	PC2	PC3
Ag	0.035	0.009	**0.525**
Ge	0.272	0.216	0.036
Sc	0.035	0.089	0.000
Em	0.095	0.078	0.003
HaYe	0.349	0.002	**0.541**
LivSHe	**0.374**	0.019	0.286
AgA	0.096	**0.330**	0.306
LeaMa	**0.365**	0.036	0.209
LeaWo	**0.433**	0.004	0.233
WorLea	**0.654**	0.001	0.036
WorWid	**0.531**	0.053	0.029
HarvPDay	0.349	**0.421**	0.007
HarvPSea	0.003	**0.334**	0.226
Wor	0.116	**0.544**	0.010
WorPerSea	0.072	**0.686**	0.095

Note: PCA loading factors performed on the correlation matrix of 15 descriptive variables related to the use of white worm in north-central Mexico. Ag: age, Ge: gender, Sc: education level, Em: employment, HaYe: harvest years, LivSHe: heads of livestock, AgA: Agave stage, LeaMa: maguey leaves, LeaWo: leaves with worm, WorLea: worm per leaf, WorWid: worm size, Har-vPDay: harvest per day, HarvPSea: Harvest per season, Wor: price, WorPerSea: income per season.



ElTe: El Tecomate, Zac: Zacatal, Sant: Santiago, Pam: Pámanes, Guad: Guadalupe de los Pozos, ElPat: El Patrocinio, Char: Charcas, SaJu: San Juan sin Agua, LaTri: La Trinidad, LaPe: La Pendencia.

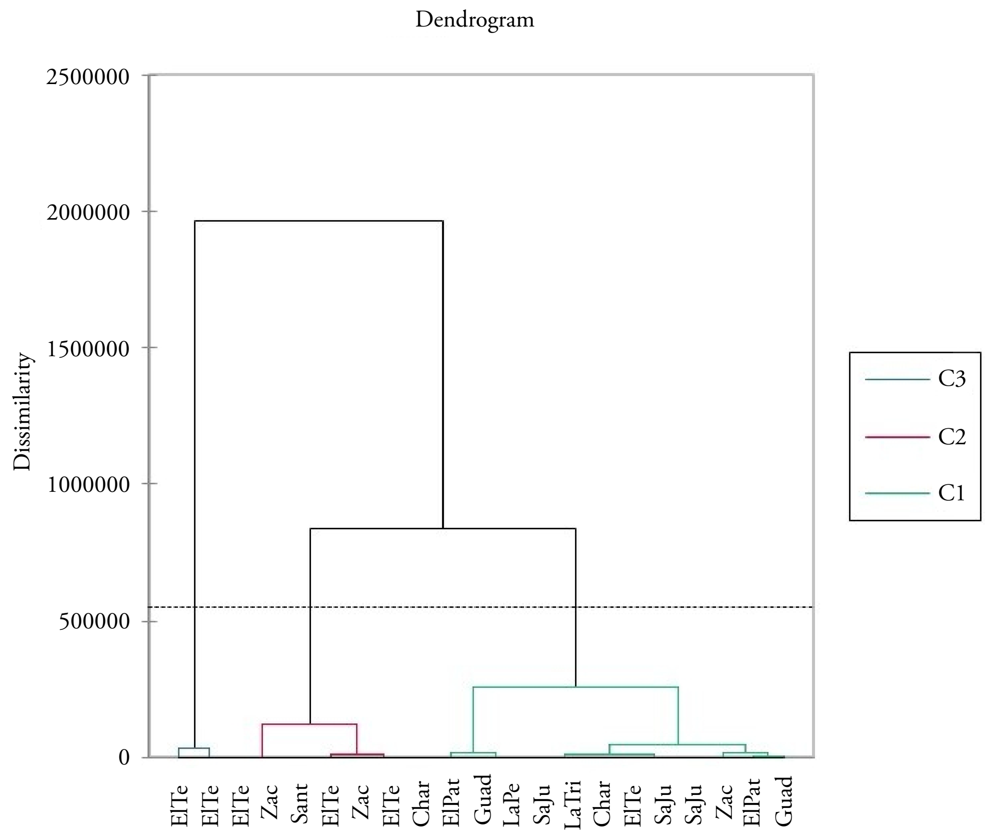
Figure 9. Hierarchical Agglomerative Clustering (HAC), for variables recorded from key stakeholders in the escamol harvesting activity by location.

Concerning the collection of white worms, two clusters were identified, which are related to perceptions about the harvest's economic viability or environmental impacts (Figure 11).

DISCUSSION

This study identified that the main problems included the low participation of young people in the activity, the lack of formal education among collectors, and the impacts of climate change and human activities such as deforestation and intensive grazing. Likewise, the need for strategies that integrate training, modernization of practices and gender equity was emphasized to promote sustainable management and ensure the economic and cultural viability of this activity.

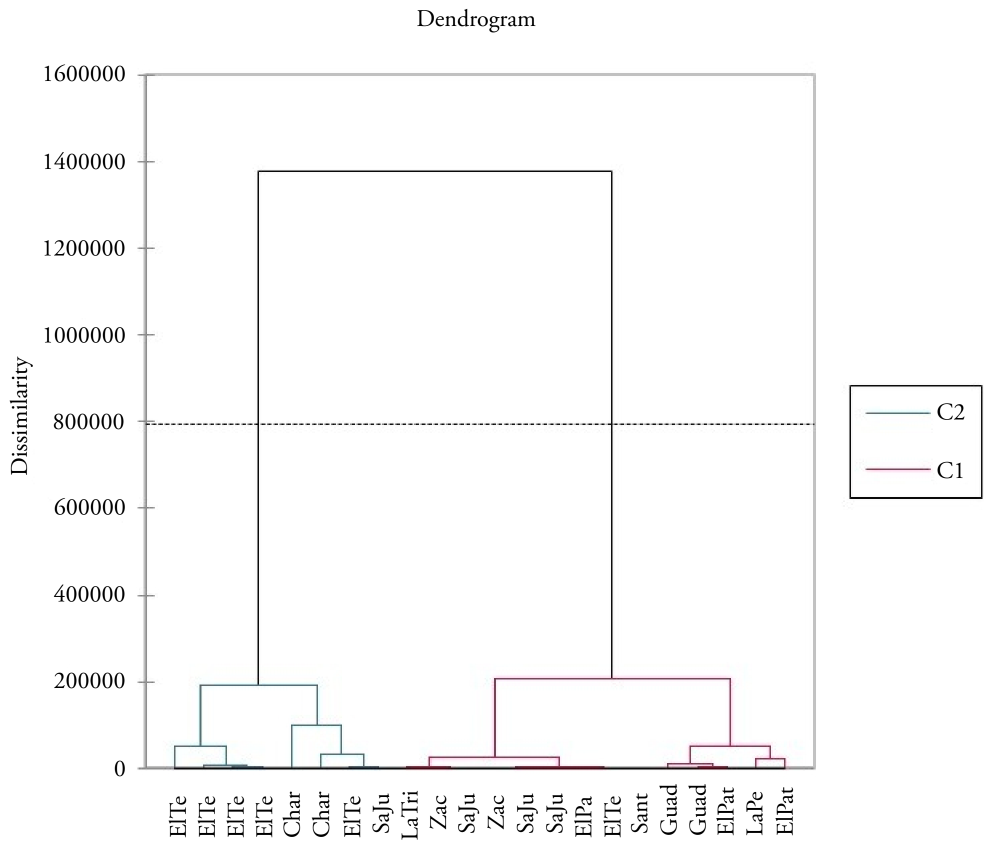
Based on analysis of age distribution, there is a low average of young key actors involved in the edible insect harvest. This coincides with previous studies on the



ElTe: El Tecomate, Zac: Zacatal, Sant: Santiago, Pam: Pámanes, Guad: Guadalupe de los Pozos, ElPat: El Patrocinio, Char: Charcas, SaJu: San Juan sin Agua, LaTri: La Trinidad, LaPe: La Pendencia.

Figure 10. Hierarchical Agglomerative Clustering Analysis (HAC), for the variables recorded from key stakeholders in the red worm harvesting activity by location.

abandonment of rural activities by these people, who tend to migrate to urban areas in search of better job opportunities (Mercado and Nava, 2013). Various authors have pointed out that the modernization of rural practices and the implementation of value-added projects could revitalize this sector, making it more attractive to young people (Guerrero *et al*., 2022). Integrating innovative research, technologies and business strategies could change this phenomenon, but a joint effort by government and community actors is necessary to promote this transition (Dallin *et al*., 2021). The aging of the collecting population poses a risk to the continuity of this activity, as traditional knowledge associated with the location, extraction and conservation of insects may be lost if it is not transmitted to younger generations (Chiswell *et al.,* 2018). It is essential to create programs that train and motivate young people to get involved in this practice, which would help preserve biodiversity and rural sources of income, as younger people are usually involved in more efficient and innovative



ElTe: El Tecomate, Zac: Zacatal, Sant: Santiago, Pam: Pámanes, Guad: Guadalupe de los Pozos, ElPat: El Patrocinio, Char: Charcas, SaJu: San Juan sin Agua, LaTri: La Trinidad, LaPe: La Pendencia.

Figure 11. Hierarchical Agglomerative Clustering Analysis (HAC), for the variables recorded from key stakeholders in the white worm harvesting activity by location.

production practices (Zagata and Sutherland, 2015).

The educational level of collectors significantly influences their ability to adopt innovative techniques when exploiting edible insects, as those with secondary or high school education have greater analytical and problem-solving skills (Góngora *et al*., 2020). This facilitates the integration of advanced practices; those with primary or no formal studies face significant barriers to implementing more complex innovations, related to the high dropout rates from basic education in Mexico (Solís, 2018). This underscores the need to diversify and strengthen educational programs in rural areas, as suggested by Castellanos and Carrasco (2021), in order to encourage the adoption of more efficient and sustainable techniques.

The analysis of the productive activity of key actors shows that a significant proportion is dedicated to agriculture, suggesting that harvesters have solid experience in natural resource management and practical knowledge that can facilitate the implementation of appropriate practices for insect exploitation (Tarango, 2005); however, benefits from trade represents the other main economic activity (Dinwiddie *et al*., 2013). Familiarity with agriculture can influence the way in which these actors integrate insect collection and management techniques into their existing agricultural practices.

Community location can result in variations concerning the availability of natural resources, the cultural tradition related to insect collection or the degree of development of sustainable practices when dealing with these species (Hernández *et al*., 2017).

Regarding the analysis of gender participation in insect collection, apparently cultural tradition and access to economic resources tend to favor greater male participation, limiting women's access to key roles in insect collection (Juárez *et al*., 2012). However, recent studies suggest that the inclusion of more women in this work would enrich the diversity of approaches and techniques in collection, promoting more timely and equitable practices (Suárez, 2005). The incorporation of women would not only diversify perspectives, but also promote innovation in the production-collection chain of edible insects. Likewise, reducing the gender gap in these activities is crucial for promoting the adoption of technologies that improve the management and conservation of these natural resources (Torcuato *et al*., 2017).

Variability in the price of escamol suggests that it is an accessible product, but with a niche willing to pay more, probably driven by its increasing use in haute cuisine. The price fluctuation could be linked to its seasonality and the exclusivity of certain harvesting areas (Ramos *et al*., 2006; Briones *et al*., 2022). The use of the maguey worm in traditional dishes reinforces its value in the market, consolidating its prestige in local and international commerce (Ramos *et al*, 2012).

Price range among edible insects is related to their regional popularity and the ability of producers to adjust supply to demand (Ramos *et al*., 2006). Although the use of the white worm in gastronomy is less frequent than that of the red worm, in certain areas it still has significance, ensuring its competitive value in the market (Van Huis *et al*., 2013). While the red worm stands out for its stability and high value, the escamol and the white worm show greater variation in price, indicating a more dynamic and segmented market. These findings coincide with studies that highlight the revaluation of edible insects as a sustainable and nutritious source, with a growing interest on the part of specialized markets (Barrios *et al*., 2022).

Seasonal range in income received from the escamol collection suggests that collectors in areas with high demand or access to premium markets can obtain substantial income, whereas those in less favored areas receive modest amounts; likewise, Briones *et al*. (2022) indicate that collectors disagree with the amounts they receive. Variation in income may relate to a less diversified market, where demand and supply are more homogenous (Van Huis *et al*., 2013).

Collectively, these revenues not only provide a livelihood for rural communities, but also underscore the importance of preserving and sustainably managing these natural resources (Rafael *et al*., 2019). The importance of these insects in generating significant economic spillover highlights their value as a food source and economic driver, in regions with limited employment opportunities. If properly managed, this natural capital can contribute to local economic development and promote sustainable practices and thus the conservation of associated biodiversity.

Wide variability in the amount of edible insects collected per day can be explained by factors such as geographical location, collector experience, and seasonal availability (Ortiz *et al*., 2023). This high yield, coupled with high market prices, underscores the economic potential of the escamol as a key resource for rural communities (Esparza *et al*., 2008). Despite the low daily production of the red worm, the market value, which exceeds that of other insects, compensates for its limited extraction, positioning it as a major luxury product in specialized markets (García *et al.*, 2023).

Variations in the production of these species reveal an inverse relationship between the amount collected and the market price. The insect with the lowest daily collection, such as the red worm, tends to reach higher prices, due to its relative scarcity, greater demand, and food stability (García *et al*., 2023). This highlights the importance of carefully managing natural resources to maintain the sustainability of the edible insect market, promoting species conservation and the economic capacity of collectors (Van Huis *et al*., 2013). Competition for land use between livestock activities, the mezcal industry, and agriculture is limiting suitable spaces for the collection of edible insects (Romero *et al.*, 2024). According to the widespread perception that edible insect production is declining, coinciding with that documented by Briones *et al*. (2022); this reflects a significant risk for this harvest to continue, as current policies fail to mitigate the negative impact of human activities on ecosystems.

Principal Component Analysis revealed that insect use is interrelated and offers a comprehensive view of the collection process. For example, considering the information on the collection of the three insects, PC1 results emphasize the importance of maximizing collection during critical seasons to obtain higher income. However, this component cannot work in isolation without including the Sustainable Management and Resource Management Component (PC2).

The Sociodemographic Component (PC3) highlights the importance of experience and human capital for success concerning insect use. Collectors with more experience and family support enjoy an advantage in terms of collection, which, together with good resource management practices, may result in a more efficient activity. This is significant, as few studies explore the holistic vision of edible insect collectors.

Likewise, the Hierarchical Clustering Analysis show clustering patterns that vary depending on the type of insect. It seems that the red worm generates diversity in perceptions, probably due to greater variability in its extraction or handling, whereas key actors in the collection of the escamol and white worm, divide into two more specific and homogeneous groups, in terms of their collection and handling.

It is crucial to implement sustainable management strategies and design management policies that ensure balanced and profitable extraction in the long term (Berumen *et al*., 2021). This approach would contribute to ecosystem preservation and local economic development, as suggested by previous research on the management of edible insects in rural communities (De Luna *et al*., 2013).

CONCLUSIONS

Collection of edible insects faces a challenge in terms of sustainable use. The results indicate that implementing initiatives that promote sustainable rural development, combined with the cultural and economic valorization of this activity, are essential to ensure its viability.

The use of edible insects in central-northern Mexico depends on a combination of efficient harvesting, adequate management of natural resources and harvest experience. Undertaken in a balanced manner, these factors could guarantee the economic development of collectors in the short term and the sustainability of the activity and resources in the long term.

ACKNOWLEDGMENTS

We would like to thank Fernando Montoya Frausto, José Antonio Briones Santoyo, Miguel Morales Huerta, Miguel Morales García, Margarito Alfaro Briones and the collectors from El Tecomate, Pinos and Colonia Pámanes, Zacatecas; as well as the collectors from San Juan sin Agua and Charcas, San Luis Potosí for their collaboration in this research.

REFERENCES

American Psychological Association. 2020. Publication manual of the American Psychological Association (7.ª ed.).

Bald J, Borja, A Franco J, Castro R, Puig J. 1999. El análisis de Componentes Principales (ACP) como Herramienta de Cálculo Cuantitativo del Impacto Ambiental en Medio Marino. U.P.V, editor. V Jornadas Españolas de Ingeniería de Costas y Puertos, A Coruña (Spain), pp: 1001-1014.

Barrios ML, Peralta XP, Salazar R, Maldonado YI. 2022. Análisis físico y químico proximal, de tres especies de insectos comestibles en Guerrero, México. Acta Agrícola y Pecuaria. 8(1). 1-8. https://aap.uaem.mx/index.php/aap/article/view/472.

Berumen M, Valdez RD, Méndez SJ, Cadena J, Esparza A, Tarango LA. 2021. Determinación del estado de conservación de la hormiga "escamolera" (*Liometopum apiculatum* Mayr) en México por el método de evaluación de riesgo – MER. Agrociencia. 55(6). 539-535. https://agrociencia-colpos.org/index.php/agrociencia/article/view/2558.

Briones JA, Tarango LA, Velázquez A, Reyes VJ, Salazar MA. 2022. Edible insect harvest in Pinos, Zacatecas, Mexico. Agro Productividad. 15(6). 37-49. https://doi.org/10.32854/agrop.v14i6.2275.

Castellanos JC, Carrasco SAN. 2021. Educación Superior en México: las consecuencias del gobierno presidencial en el periodo 2018-2024 en la cobertura. Ensayo: Evaluación y Políticas Públicas en Educación. 30(115). 394-413. https://doi.org/10.1590/S0104-403620210002902288.

Castro M, Chávez JC, Arellano AV. 2018. Modelos de intervención en trabajo social: Una propuesta metodológica para su construcción. Editorial ACANITS. Yucatán, México. https://www.ojs.acanits.org/index.php/catalogo-libros-acanits/article/view/12/12. 11 p.

Chiswell HM. 2018. From Generation to Generation: Changing Dimensions of Intergenerational Farm Transfer. Sociologia Ruralis, 58(1). 104-125. https://doi.org/10.1111/soru.12138.

Cruz JD, Crosby MM, Delgado A, Alcántara JL, Cuca JM, Tarango LA. 2018. Nutritional content of Liometopum apiculatum Mayr larvae ("escamoles") by vegetation type in north-central Mexico. Journal of Asia-Pacific Entomology. 21(4). 1239-1245. https://doi.org/10.1016/j.aspen.2018.09.008.

Cruz JD, Tarango LA, Alcántara JL, Pimentel J, Ugalde S, Ramírez G, Méndez SJ. 2014. Habitat use by the "Escamolera" ant (*Liometopum apiculatum* Mayr) in central Mexico. Agrociencia. 48(6). 569-582. https://www.agrociencia-colpos.org/index.php/agrociencia/article/view/1103/1103.

Cruz JD, Tarango LA, Alcántara JL, Ugalde S, Delgado A, Crosby MM. 2023. Densidad de nidos de la hormiga escamolera (*Liometopum apiculatum* Mayr) y su asociación con el hábitat en vegetación de matorral. Revista Chapingo Serie Ciencias Forestales y del Ambiente. 29(3). 31-45. https://doi.org/10.5154/r.rchscfa.2022.08.056.

Curts J. 1993. Análisis exploratorio de datos. Las aves de la Sierra Purépecha del estado de Michoacán. SARH División Forestal Coyoacán, México, DF. 1-14.

Dallin J, Hadfield J, Garcia MD, Larsen R. 2021. Utah State University Extension Farm and Ranch Succession Program. Outcomes and Impact Quarterly, 1(1). https://doi.org/10.26077/a087-63bf .

De Luna B, Macías FJ, Esparza G, León E, Tarango LA, Méndez SJ. 2013. Recolección de insectos comestibles en pinos Zacatecas: descripción y análisis de la actividad. Agroproductividad. 6(5). 35-45. https://link.gale.com/apps/doc/A382430306/IFME?u=anon~a80cbfceysid=googleScholaryxid=09fb5745.

Dinwiddie ML, Jones RW, Roitman P, Tarango LA, Malda GX. 2013. Estudio etnoentomologico de la hormiga escamolera (*Liometopum apiculatum*) en dos localidades del Estado de Querétaro. Agroproductividad. 6(5). 27-32. https://link.gale.com/apps/doc/A382430305/IFME?u=anon~1b95b1efysid=googleScholaryxid=10797799

Esparza G, Macías FJ, Martínez M, Jiménez MA, Méndez SJ. 2008. Insectos comestibles asociados a las magueyeras en el ejido Tolosa, Pinos, Zacatecas, México. Agrociencia, 42(2). 243-252. https://www.agrociencia-colpos.org/index.php/agrociencia/article/view/624.

García MA, Figueredo CJ, Bucio R, Leonel AL. 2023. Los Chinicuiles o gusanos rojos del maguey: Alimento de origen prehispánico amenazado por su sobreexplotación. Biología Sociedad. 6(12). 41–47. https://doi.org/10.29105/bys6.12-90.

Góngora RD, Milán MJ, López F. 2020. Strategies and drivers determining the incorporation of young farmers into the livestock sector. Journal of Rural Studies. 78. 131-148. https://doi.org/10.1016/j.jrurstud.2020.06.028.

Granados DS. 1993. Los Agaves en México. Universidad Autónoma Chapingo. Chapingo, México. 252 p.

Greenwood DJ, Levin M. 2007. Introduction to action research: Social research for social change (2.ª ed.). Sage Publications. 110 p.

Guerrero JE, Lara P, Maroto F, Ortiz L. 2022. El relevo generacional y su importancia para el desarrollo de los territorios rurales. Mediterráneo económico. (35). 219-235. https://publicacionescajamar.es/wp-content/uploads/2022/03/me-35-el-relevo-generacional-y-su-importancia-para-el-desarrollo-de-los-territorios-rurales.pdf

Hernández E, Tarango LA, Ugalde S, Hernández A, Cortez C, Cruz Y y Morales FJ. 2017. Hábitat y densidad de nidos de la hormiga escamolera (*Liometopum apiculatum* M.) en una UMA de Zacatecas, México. Agroproductividad. 10(5). 10-17. https://revista-agroproductividad.org/index.php/agroproductividad/article/view/1012/866.

Llanderal C, De los Santos HM, Almanza I, Nieto R, Castillejos C. 2010. Establecimiento del gusano rojo en plantas de maguey en invernadero. Acta Zoológica Mexicana. (26). 1-6. https://doi.org/10.21829/azm.2010.261677.

Lin GF, Chen LH. 2006. Identification of homogeneous regions for regional frequency analysis using the self-organizing map. Journal of Hydrology. 324(1-4). 1-9. https://doi.org/10.1016/j.jhydrol.2005.09.009.

McKnight DH, Chervany NL. 2006. The role of trust in e-commerce. *In*: Proceedings of the International Conference on E-Commerce. Springer. pp: 154-191.

Mercado P, Nava RM. 2013. Calidad de vida y expectativas de migración en jóvenes de zonas rurales del Estado de México. Población y Salud en Mesoamérica. 10(2). 1-19. https://doi.org/10.15517/psm.v10i2.8513

Navarro JM, Casas GM, González E. 2010. Principal Component and Regression Analysis for Categorical Data. Application to Arterial Hypertension. Revista de Matemática: Teoría y Aplicaciones. 17(2). 199-230. https://doi.org/10.15517/rmta.v17i2.2128.

Ortiz A, Pablo E, Pacheco R, López S. 2023. Entomofagia: seguridad alimentaria (disponibilidad y estabilidad) en una zona rural de Oaxaca, México. Revista Española de Nutrición Comunitaria. 29(2). https://www.renc.es/imagenes/auxiliar/files/RENC-D-23-0019._Final.pdf.

Pearson K. 1901. LIII. On lines and planes of closest fit to systems of points in space. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science. 2(11). 559-572. https://doi.org/10.1080/14786440109462720.

Pedroza A, Sánchez I, Becerra JL, Ramos E, Reyes C, Rosales LV, Vargas G. 2014. Regionalización de zonas con escaso régimen pluvial: Estudio de caso zona Centro-Norte del estado de Durango, México. Revista Chapingo Serie Zonas Áridas. XIII(2). 71-85. https://www.redalyc.org/articulo.oa?id=455545055004.

Quintero B, Ramos B. 2018. Insectos Comestibles, Delicias Ancestrales del Presente: El gusano rojo (*Comadia redtenbacheri* H.) y el blanco del maguey (*Aegiale hesperiaris* W.). El Pasado del Futuro Alimentario: Los alimentos Ancestrales Americanos. Instituto de Investigaciones Dr. José María Luis Mora: México. pp: 311-328.

Rafael J, Tarango LA, Ugalde S, Cruz JD, Clemente F, Cadena J. 2019. Amplitud forrajera de la hormiga escamolera (*Liometopum apiculatum* Mayr, *Hymenoptera: Formicidae*) en una zona semiárida del altiplano zacatecano. Revista Chapingo Serie Zonas Áridas. 18(1). 05–19.

Rafael J, Tarango LA, Ugalde S, Lozano EA, Ruíz VM, Bravo A. 2017. Sustratos forrajeros y de anidación de la hormiga escamolera (*Liometopum apiculatum* Mayr, *Hymenoptera: Formicidae*) en Villa González Ortega, Zacatecas, México. Agrociencia. 51(7). 755-769. https://agrociencia-colpos.org/index.php/agrociencia/article/view/1325.

Ramos J, Pino JM, Conconi M. 2006. Ausencia de una reglamentación y normalización de la explotación y comercialización de insectos comestibles en México. Folia Entomológica Mexicana. 45(3). 291-318. https://www.redalyc.org/pdf/424/42445304.pdf.

Ramos J, Pino JM. 2001. Contenido de vitaminas en algunos insectos comestibles de México. Revista de la Sociedad Química de México. 45(2). 66-76. https://www.redalyc.org/pdf/475/47545206.pdf.

Ramos B, Quintero B, Ramos J, Pino JM, Ángeles SC, García Á, Barrera VD. 2012. Análisis químico y nutricional de tres insectos comestibles de interés comercial en la zona arqueológica del municipio de San Juan Teotihuacán y en Otumba, en el estado de México. Interciencia. 37(12). 914-920. https://www.interciencia.net/wp-content/uploads/2018/01/914-c-PINO-7.pdf.

Rentería L, Cantú C, Estrada E, Marmolejo J, González F. 2011. Representatividad de los tipos de vegetación en las áreas naturales protegidas de Durango. Revista Mexicana de Ciencias Forestales. 2(3). 69-82. https://doi.org/10.29298/rmcf.v2i3.630.

Romero H, Tarango LA, Martínez JF, Briones JA. 2024. Monitoreo del cambio del uso de la tierra como herramienta para el manejo de recursos naturales. Agro-Divulgación, 4(3). https://doi.org/10.54767/ad.v4i3.302.

Romero H, Tarango LA, Peredo E, Del Rosario J, Olmos G, Hernández E, López LA. 2024. Productive Characteristics, Nesting Substrates, and Colonies of the Escamolera Ant (*Liometopum apiculatum* M.) in Zacatecas, Mexico. Agro Productividad. 17(6). 185-195. https://doi.org/10.32854/agrop.v17i6.2933.

Rosas OC, Hernández AD, Olvera JI, Guerrero JD, Aceves E, Tarango LA. 2015. Monitores comunitarios para la conservación e investigación participativa en áreas naturales protegidas. Agroproductividad: 5(8). 56-61. https://revista-agroproductividad.org/index.php/agroproductividad/article/view/684/552.

Solís, P. 2018. La transición de la secundaria a la educación media superior en México: el difícil camino a la cobertura universal. Perfiles Educativos. 40(159). 66–89. https://doi.org/10.22201/iisue.24486167e.2018.159.58412.

Strauss A, Corbin J. 1998. Basics of qualitative research: Techniques and procedures for developing grounded theory (2.ª ed.). Sage Publicación. 182 p.

Suárez B. 2005. La jornada de trabajo de las mujeres campesinas e indígenas en proyectos productivos. La integración económica de las mujeres rurales: Un enfoque de género. Secretaria de la Reforma Agraria. México. 1. 189-223.

Tarango LA. 2005. Problemática y alternativas de desarrollo de las zonas áridas y semiáridas de México. Revista Chapingo Serie Zonas Áridas, 4(2). 17-21. https://www.redalyc.org/pdf/4555/455545052003.pdf.

Van Huis A, Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P. 2013. Edible insects: Future prospects for food and feed security. Food and Agriculture Organization of the United Nations (FAO). https://www.fao.org/4/i3253e/i3253e.pdf. 59 p.

Zagata L, Sutherland LA. 2015. Deconstructing the young farmer problem in Europe: towards a research agenda. Journal of Rural Studies. 38. 39-51. https://doi.org/10.1016/j.jrurstud.2015.01.003.