Fecha de recepción: Abril 3, 2025 Fecha de aceptación: Junio 27, 2025

CURRENT STATUS AND CONSERVATION STRATEGIES OF THE LOCAL VARIETIES OF *CARICA PAPAYA* IN THE YUCATAN PENINSULA

Mónica I. Jiménez-Rojas[1]*, Fátima Duarte-Ake[1], Mauricio Heredia-Pech[2],Carlos David Hernández-Pinto[3]

[1]Tecnológico Nacional de México, Instituto Tecnológico de Mérida, Av. Tecnológico Km. 4.5, 97118 Mérida, Yucatán, México.

[2]Centro de Investigación Científica de Yucatán, Calle 43 No. 130, Colonia Chuburná de Hidalgo, 97205, Mérida, Yucatán, México.

[3]Facultad de ingeniería, Universidad Autónoma de Yucatán. Av. Industrial No Contaminantes por Periférico Norte, S/N. Mérida, Yucatán, México.

*Correo: monica.jr@merida.tecnm.mx

ABSTRACT

The Yucatan Peninsula is a living repository of biodiversity, where Maya communities have historically played a pivotal role in cultivating, preserving, and transmitting deep knowledge about the sustainable management of natural resources, especially fruit species. This research analyzes the current situation of the conservation status, traditional uses, and ecological and economic significance of two local varieties of papaya (*Carica papaya*) *"cera amarilla"* and *"mamey"*. To this end, it conducted semi-structured interviews and complemented with participant observation of 16 producers located in the states of Campeche, Yucatán and Quintana Roo who cultivated these two local varieties in addition to the commercial variety *Maradol*. The results obtained suggest that the producers have a deep knowledge of the varieties, and acknowledge the cultural, medicinal and ecological importance of their conservation. However, the results identified three important challenges that hinder their preservation and cultivation, lack of market, low productivity compared to commercial varieties, and lack of interest of younger generations in getting involved in their cultivation. Therefore, this research suggests that there is a need to establish comprehensive strategies that combine traditional knowledge of agriculture with innovative approaches, promoting the development of adequate markets, strengthening government support, and the participation of local communities to ensure the preservation of the *"cera amarilla"* and *"mamey"* papaya varieties.

KEYWORDS: Agricultures, Biodiversity, Maya Culture, Local varieties, Preserving

ESTADO ACTUAL Y ESTRATEGIAS DE CONSERVACIÓN DE LAS VARIEDADES LOCALES DE *CARICA PAPAYA* EN LA PENÍNSULA DE YUCATÁN

RESUMEN

La Península de Yucatán es un repositorio vivo de biodiversidad, donde las comunidades mayas han desempeñado, históricamente, un papel fundamental en el cultivo, la preservación y la transmisión de conocimientos profundos

sobre el manejo sostenible de los recursos naturales, especialmente de especies frutales. Esta investigación analizó la situación actual del estado de conservación, usos tradicionales e importancia ecológica y económica de dos variedades locales de papaya (*Carica papaya* L.), "*cera amarilla*" y "*mamey*". Para ello, se realizaron entrevistas semiestructuradas y se complementaron con observación participante a 16 productores que contaban con variedades locales además de la variedad comercial Maradol ubicada en los estados de Campeche, Yucatán y Quintana Roo. Los resultados obtenidos mostraron un profundo conocimiento de estas variedades por parte de los productores, quienes reconocen la importancia cultural, medicinal y ecológica de su conservación. Sin embargo, se identificaron varios desafíos importantes que dificultan la preservación y el cultivo de estas variedades, como la falta de mercado, la baja productividad en comparación con las variedades comerciales y la falta de interés de las nuevas generaciones en involucrarse en su cultivo. Por lo tanto, se pudo concluir la importancia de establecer estrategias integrales que combinen el conocimiento tradicional de la agricultura con enfoques innovadores, promoviendo el desarrollo de mercados adecuados, fortaleciendo el apoyo gubernamental y la participación de las comunidades locales para asegurar la preservación de las variedades locales de papaya "*cera amarilla*" y "*mamey*".

PALABRAS CLAVE: Agricultura, Biodiversidad, Cultura Maya, Variedades locales, Preservación

INTRODUCTION

Koleff et al. (2009) have pointed out that The Yucatan Peninsula has exceptional biocultural wealth, characterized by the harmonious coexistence of remarkable biological and cultural diversity. This region serves as a living repository of biodiversity, where Maya communities have historically played a pivotal role in cultivating, preserving, and transmitting deep knowledge about the sustainable management of natural resources, especially fruit species (Jiménez-Rojas et al. 2019; Meyer and Purugganan 2013).

For centuries, Maya communities have sustained a symbiotic relationship with their environment, deeply rooted in their cultural identity and cosmovision. This bond suggests an integrated approach to natural resource management, which includes sustainable agricultural practices, the meticulous harvesting of wild plants, and their application across food, medicine, and cultural rituals (Bellon et al. 2009). This integrated approach to natural resource management and its practices illustrate a harmonious balance between meeting human needs and conserving ecological integrity, ensuring the sustainability of ecosystems for future generations (Heredia-Pech et al. 2025; Ruiz-Gil et al. 2023).

The Mesoamerican agricultural system, the milpa, relies on polycultures and agroforestry techniques that enhance soil fertility, conserve biodiversity, and build resilience against environmental stressors (Swarup et al. 2021). Beyond agriculture, the identification, collection and use of wild plants form a sophisticated ethnobotanical tradition (Syfert et al. 2016). These plants serve not only as nutritional resources but also as integral components of traditional medicine, used in preventing and treating illnesses, while playing a sacred role in rituals that strengthen communal and spiritual bonds (Casas et al. 1997; Caballero et al. 1998; Mokganya et al. 2018).

The Maya traditional ecological knowledge is a testament to the ingenuity and adaptability of Maya communities, offering invaluable insights for modern sustainability and biodiversity conservation efforts (De Carvalho et al.,2016; Lobo and Medina 2009). Integrating these ancestral practices into broader conservation strategies could help address pressing challenges such as climate change, and its relation to food security, and the erosion of cultural heritage (Chávez-Pesqueira and Núñez-Farfán 2017; Barlow et al. 2016).

However, the Maya traditional knowledge system is increasingly vulnerable due to ongoing socioeconomic

and environmental changes that have left the local varieties of papaya (*Carica papaya* L.) at risk. This crop is a fast-growing tropical tree cultivated for its fruit, enzymes such as papain and pectin, in addition to antibacterial compounds (Niklas and Marler 2007). Producers now grow papaya extensively in tropical and subtropical lowlands worldwide—with trade exceeding $200 billion in 2009 (Chávez-Pesqueira & Núñez-Farfán 2017; Evans and Ballen 2012)—the expansion of market-driven economic models and rural depopulation have displaced local varieties in favor of commercial improved varieties like the Maradol papaya.

Cultivation of local varieties of papaya *"cera amarilla"* and *"mamey"* has declined drastically. These varieties possess unique traits, including pest resistance and adaptation to local conditions, which are invaluable for food security and sustainable agriculture (Barlow et al. 2016). Their loss not only reduces genetic diversity but also weakens the cultural identity and ecological resilience of Maya communities. The absence of public policies promoting their preservation, coupled with the impacts of climate change, further exacerbates their vulnerability (Swarup et al. 2021; Barlow et al. 2016).

Notably, consumers prize *"mamey"* papaya for its intensely colored flesh and distinctive flavor, while value *"cera amarilla"* for its waxy skin and robust disease resistance, as well its yellow flesh color and tourists like its great taste on the palate (Hernandez-Salinas et al. 2019; Ávila et al. 2013). Farmers are further favoring improved varieties with these unique characteristics and higher commercial yields, leaving aside traditional indigenous varieties and limiting opportunities for agricultural diversification (Allendorf et al. 2012). This genetic change reduces the adaptability of agricultural systems to environmental changes and weakens their resilience to emerging threats (Wall and Tripathi 2014).

Despite these challenges, the local varieties remain indispensable for their adaptability, potential to diversify crops, and contributions to resilience against disease and environmental stress. Promoting their conservation and sustainable use is critical not only to safeguarding the biocultural wealth of the region but also to supporting rural communities whose livelihoods depend on these crops (Paz and Vázquez-Yanes 1998; Chávez-Pesqueira & Núñez-Farfán, 2017). This study aims to assess the status of two local *Carica papaya* varieties, "*cera amarilla"* and *"mamey",* to know the current status of these local varieties as well as by their conservation status, traditional uses, and ecological and economic significance (Aikpokpodion 2012; Morales-Payán et al. 2017). By analyzing the role of these varieties in local agricultural systems and their cultural importance, the research seeks to emphasize the value of traditional knowledge and advocate for its integration into sustainable management strategies. These efforts aim to contribute to the conservation of biocultural heritage, ensuring the resilience of human communities and biodiversity in a region of unparalleled ecological and cultural significance.

METHODS

STUDY SITE AND SITE SELECTION

This study was conducted in the Yucatán Peninsula, covering the states of Campeche, Yucatán, and Quintana Roo. This region is recognized as the possible center of domestication for papaya (*Carica papaya*) and is home to its wild relatives, which are still observed in naturally disturbed tropical forests (Fig. 1).

The research sites were strategically chosen based on the presence of one or both local papaya varieties, "*cera amarilla*" and "*mamey*," alongside the widely cultivated commercial variety "Maradol" (Fig. 2). This selection criterion ensured a targeted investigation of plantations where traditional varieties are still cultivated, allowing for an in-depth analysis of their ecological adaptability, continued usage, and cultural significance.

A combination of geographic and ecological criteria guided the site selection process, ensuring that study locations represented diverse agricultural landscapes, including small-scale family farms and larger community-managed plots.

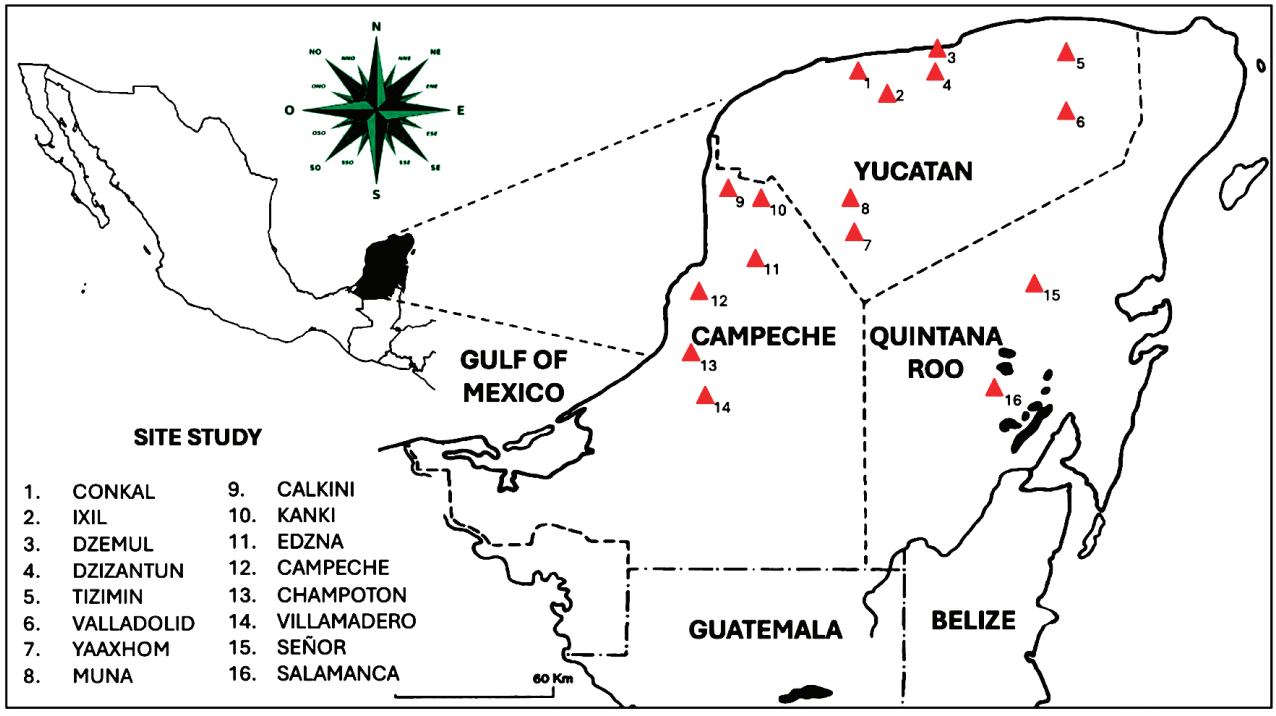

Figure 1. Locations of Crops with the varieties of *Carica papaya* "*cera amarilla*" and "*mamey*" in the Yucatan peninsula.

This section summarizes the demographic composition and indigenous language use across selected communities in the Yucatán Peninsula.

Yucatán

Conkal: Is a municipality of 16,671 inhabitants, conformed for 49% men and 51% women. 1,720 people (10.3% of the total) speak at least one indigenous language. The most spoken indigenous languages were Maya (1,686 speakers), Tseltal (11 speakers), and Ch'ol (11 speakers) (INEGI, 2020).

Ixil: According to INEGI (2020) the total population of Ixil was 4,186 inhabitants, with 49.8% women and 50.2% men. The age groups that concentrated the highest population (25.9% of the total) were 20 to 24 years (381 inhabitants), 15 to 19 years (358 inhabitants), and 40 to 44 years (347 inhabitants). 398 people (9.51% of the total population) speak Maya.

Dzemul: The total population in was 3,622 inhabitants (50.4% women and 49.6% men). The age ranges with the highest population (23.2% of the total) were 15 to 19 years (285 inhabitants), 20 to 24 years (279 inhabitants), and 25 to 29 years (278 inhabitants). 679 people (18.7%) speak at least one indigenous language. The most spoken indigenous languages were Maya (677 inhabitants), Chontal de Tabasco (1 inhabitant), and Ch'ol (1 inhabitant) (INEGI, 2020).

Dzidzantun: In 2020 the total population of Dzidzantun was 8,345 inhabitants, conformed for 49.5% women and 50.5% men. The age ranges that concentrated the largest population (23.1% of the total) were 15 to 19 years (676 inhabitants), 45 to 49 years (627 inhabitants), and 20 to 24 years (621 inhabitants). 414 people (4.96% of the total population) speak an indigenous language. The most spoken indigenous languages were Maya (412 inhabitants) and Mam (2 inhabitants) (INEGI, 2020).

Tizimin: The total population of Tizimin was 80,672 inhabitants, being 50.3% women and 49.7% men. The age ranges that concentrated the highest population (28.1% of the total) were 15 to 19 years (7,677 inhabitants), 10 to 14 years (7,637 inhabitants), and 5 to 9 years (7,316 inhabitants). 26,100 people (32.4% of the total population) speak an indigenous language. The most

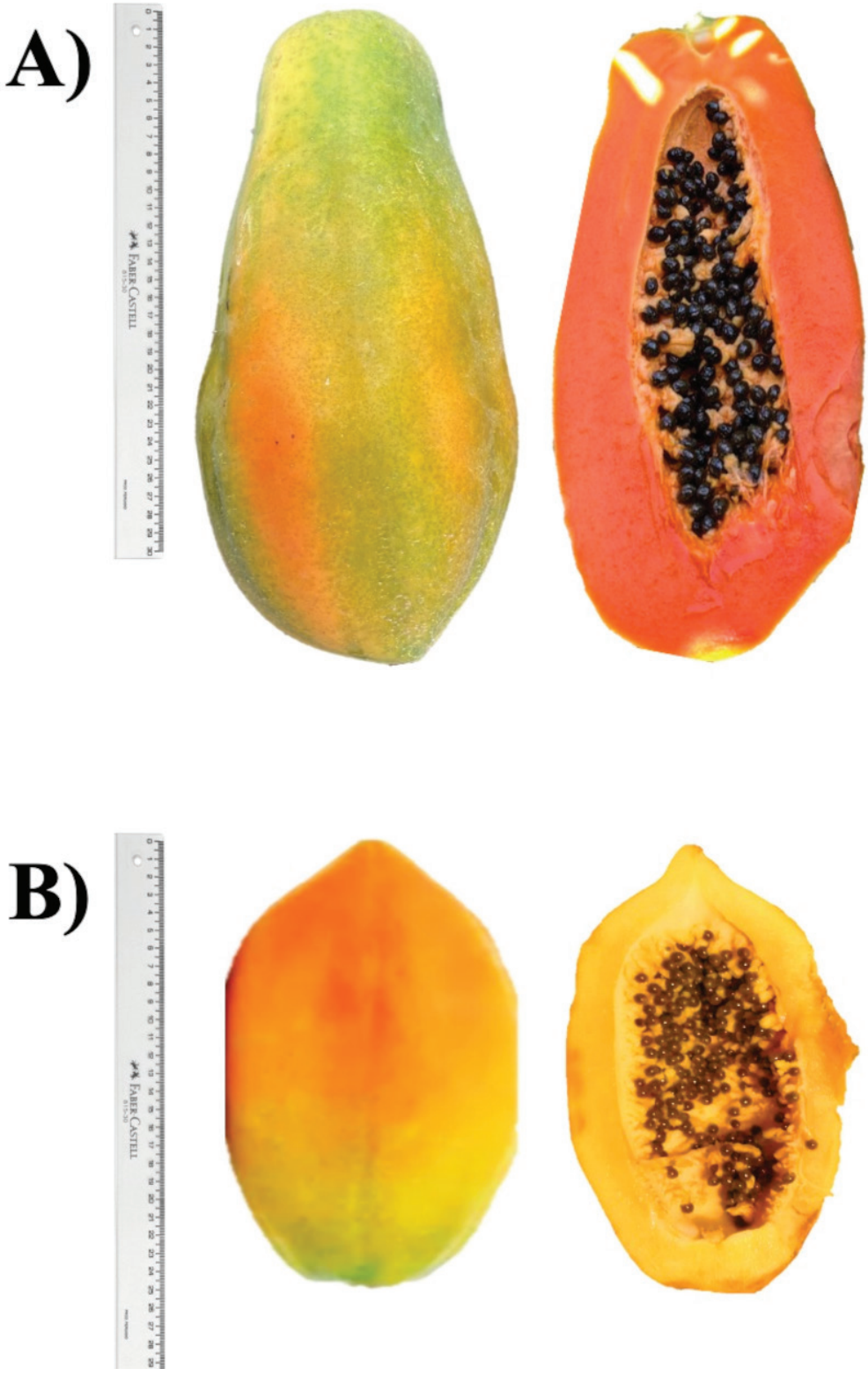

Figure 2. Photo of *Carica papaya* variety A) "*mamey*" and B) "*cera amarilla*".

spoken indigenous languages were Maya (26,028 residents), Tseltal (42 residents), and Ch'ol (19 residents) (INEGI, 2020).

Valladolid: The total population of Valladolid was 85,460 inhabitants, being 50.9% women and 49.1% men. The age ranges that concentrated on the largest population (28.3% of the total) were 15 to 19 years (8,302 inhabitants), 10 to 14 years (8,040 inhabitants), and 20 to 24 years (7,841 inhabitants). 44.8% of the total population (8,300 people) speak an indigenous language. The most spoken indigenous languages are Maya (38,046 speakers), Mixe (162 speakers), and Mixteco (40 speakers) (INEGI, 2020).

Yaaxhom: San Antonio Yaaxhom is a locality in the Municipality of Oxkutzcab, Yucatán, with 156 inhabitants, which 72 are women and 84 are men. 44.2% of the population speaks an indigenous language, with Maya being the most spoken language. 0.64% of Maya speakers do not speak Spanish (INEGI, 2020).

Muna: The total population of Muna was 13,494 inhabitants, with 50% women and 50% men. The age ranges that concentrated on the largest population (25.7% of the total) were 20 to 24 years (1,187 inhabitants), 0 to 4 years (1,148 inhabitants), and 25 to 29 years (1,135 inhabitants). 4,810 people (35.6% of the total population) speak an indigenous language. The most spoken indigenous languages were Maya (4,781 residents), Tsotsil (8 residents), and Ch'ol (7 residents) (INEGI, 2020).

Campeche

Calkiní: The total population of Calkiní was 59,232 inhabitants, with 50.8% women and 49.2% men. The age groups that concentrated on the largest population (26% of the total) were 5 to 9 years (5,268 inhabitants), 10 to 14 years (5,129 inhabitants), and 0 to 4 years (5,026 inhabitants). 24600 people (41.6%) speak an indigenous language. The most spoken indigenous languages were Maya (24,509 speakers), not specified (27 speakers), and Zapotec (25 speakers) (INEGI, 2020).

Kanki: The locality of Kankí belongs to the Municipality of Tenabo. Kankí have 268 inhabitants, and it is at an altitude of 49 meters. 32.84% of the population speaks an indigenous language, the only indigenous language spoken is Maya (INEGI, 2020).

Edzná: The locality of Quetzal Edzná belongs to the Municipality of Campeche. Edzná has 1,032 inhabitants, being 50.6% women and 49.4% men. 16.2% of the population speaks an indigenous language, with Maya being the most spoken language and 0.2% of Maya speakers do not speak Spanish (INEGI, 2020).

Campeche: The total population of Campeche was 294,077 inhabitants, being 51.9% women and 48.1% men. The age ranges that concentrated on the largest population were (24% of total) 20 to 24 years (24,306 inhabitants), 30 to 34 years (23,153 inhabitants), and 15 to 19 years (23,133 inhabitants). 12800 people, which corresponds to 4.35%, speak an indigenous language. The most spoken indigenous languages were Maya (10,007 inhabitants), Ch'ol (676 inhabitants), and Tseltal (605 inhabitants). Mam, Zapotec, Mixtec, and Tsotsil are also spoken among others (INEGI, 2020).

Champotón: The total population of Champotón was 78,170 inhabitants, with 50.1% woman, and 49.9% men. The age ranges that concentrated the largest population (28.6% of the total) were 5 to 9 years (7,809 inhabitants), 10 to 14 years (7,375 inhabitants), and 0 to 4 years (7,171 inhabitants). 4710 inhabitants (6.03% of the total) speak an indigenous language. The most widely spoken indigenous dialects were Maya (2,971 inhabitants), Q'anjob'al (621 inhabitants), and Mam (299 inhabitants) (INEGI, 2020).

Villa Madero: The locality of Villa Madero belongs to the Municipality of Seybaplaya, Campeche. The population of Villa Madero is 4,612 inhabitants, 2,309 women and 2,303 men. 2.7% of the population speak an indigenous language, with Maya being the most spoken language. 0.07% of the inhabitants speak Maya but do not speak Spanish (INEGI, 2020).

Quintana Roo

Señor: The town of Señor belongs to the Municipality of Felipe Carrillo Puerto (State of Quintana Roo). There are 3,785 inhabitants. with 48.8% woman, and 51.2% men. 78% of the population speaks an indigenous language, with Maya being the most spoken language. 8% of the population speaks Maya but does not speak Spanish (INEGI, 2020).

Salamanca: The locality of Salamanca (Quintana Roo) belongs to the Municipality of Bacalar, with 1,175 inhabitants, belong 49.3 % woman, and 50.7% men. In Salamanca, no indigenous language is spoken, and Spanish predominates as the main language (INEGI, 2020).

ETHNOBOTANICAL APPROACH

To assess the ethnobotanical knowledge and conservation practices of local papaya producers, a mixed-methods approach was employed, integrating semi-structured interviews, participatory observation, and qualitative documentation of agricultural practices (Supplementary table 1). This methodological framework follows established ethnobotanical protocols (Martín, 1997) and aligns with previous studies in the region (Heredia-Pech et al., 2025; Ruiz Gil et al., 2023).

PARTICIPANT SELECTION AND RECRUITMENT

Participants were recruited through community outreach in papaya farming regions previously identified in related research. The inclusion criteria specified that participants must be actively engaged in papaya cultivation, grow the native varieties under study ("*cera amarilla*" and "*mamey*"), and reside in the Yucatán Peninsula. However, due to the limited number of producers, information was ultimately collected from all available producers. A total of 16 producers were selected, distributed across the region to capture geographic and agricultural variability.

The final group consisted of 16 men, categorized by age as follows: 25-35 years: 4 participants and 36-50 years: 12 participants. All participants provided free, prior, and informed consent, ensuring ethical compliance in the data collection process. Ethical guidelines aligned with international research standards, emphasizing respect for participants' knowledge and cultural heritage.

DATA COLLECTION METHODS

SEMI-STRUCTURED INTERVIEWS

Semi-structured interviews were conducted at each participant's plantation to provide an in-depth understanding of their knowledge and perspectives on local papaya varieties. Interviews consisted of 35 questions covering six thematic areas: 1) Personal and demographic information, 2) Traditional and agronomic knowledge of *Carica papaya,* 3) Perceived importance of local varieties, 4) Challenges in conservation and cultivation, 5) Institutional and community support and 6) Economic benefits and prospects.

This structured yet flexible approach ensured consistency in data collection while allowing space for additional insights and participant-driven discussions. Interview sessions were recorded with participants' consent, and detailed notes were taken to supplement the audio recordings.

PARTICIPATORY OBSERVATION

To complement the interviews, participatory observation was conducted to document firsthand how producers manage their plantations, select and handle seeds, cultivate local varieties, and market their products. The authors actively engaged with producers in their daily agricultural activities, allowing for an immersive understanding of the cultivation cycle, decision-making processes, and traditional conservation techniques. Key aspects of participatory observation included: 1) Selection and management of local varieties, 2) Traditional seed-saving techniques, 3) Pest and disease management, and 4) Marketing and commercialization strategies.

The plantation owner served as the key informant, providing critical insights into why these local varieties continue to be cultivated despite the increasing dominance of commercial alternatives. This individual played a pivotal role in contextualizing the coexistence of traditional and commercial varieties, discussing economic considerations, cultural significance, and environmental adaptability.

DATA ANALYSIS

Data collected from interviews and participatory observations were transcribed and categorized into thematic codes corresponding to the six key research areas.

Quantitative data, such as participant demographics and response frequencies, were analyzed using descriptive statistics. The integration of qualitative and quantitative analysis provided a comprehensive understanding of the factors influencing the conservation and utilization of local papaya varieties in the Yucatán Peninsula.

RESULTS

KNOWLEDGE OF LOCAL VARIETIES

The ethnobotanical interviews revealed that all surveyed producers were familiar with the local varieties "*cera amarilla*" and "*mamey*." These varieties were praised for their distinct qualities, including their sweet taste, unique texture, vibrant pulp color, and resistance to pests. Furthermore, 87.5% of respondents indicated direct involvement in the production or conservation of these varieties, emphasizing their low agronomic maintenance requirements, which make them particularly valuable within traditional agricultural systems.

Despite widespread knowledge of these varieties, only 6% of interviewees reported having received formal education or specialized training in their cultivation. Instead, knowledge is predominantly acquired through generational transmission, with most learning from their parents and grandparents, who also cultivated these varieties. This traditional knowledge system highlights the importance of preserving indigenous agricultural practices and oral traditions.

IMPORTANCE AND CHALLENGES IN CONSERVATION

All interviewees strongly agreed that conserving local varieties is "very important." The primary reasons cited for their importance include biodiversity preservation (75%) and medicinal applications (25%) (Figure 3). Various parts of the plant have been used to treat digestive conditions, due to the presence of papain, a proteolytic enzyme that facilitates digestion and contributes to the relief of disorders such as dyspepsia, gastritis and constipation. In addition, leaf and seed extracts have shown useful anti-inflammatory properties in the treatment of arthritis and muscle pain (Otsuki et al., 2010). Its antioxidant and hepatoprotective action have also been documented, attributed to the high content of vitamins A, C and E, as well as to bioactive compounds present in its leaves and fruits. Papaya has antimicrobial and antiparasitic activity, effective against bacteria such as *Escherichia coli* and *Salmonella spp.*, as well as intestinal parasites (Dawkins et al., 2003). In preclinical and clinical studies, a hypoglycemic effect has been observed, suggesting a potential use in the management of type 2 diabetes (Dawkins et al., 2003). Particularly relevant are the investigations on the use of leaf extract in patients with dengue, where a significant increase in platelet count has been reported (Subenthiran et al., 2013). Finally, some phytochemical compounds in papaya, such as flavonoids and alkaloids, have been linked to anticancer effects, especially in studies with leaf extracts (Dawkins et al., 2003). Additionally, these papaya varieties play a critical role in cultural heritage, food security, and environmental sustainability. Their cultivation not only preserves ancestral agricultural practices and traditional knowledge but also contributes to the resilience of local food systems by providing a reliable source of nutrition in rural communities. Furthermore, the ecological characteristics of native papaya varieties—such as their adaptation to local soils and climate—reduce the need for intensive agricultural inputs, thereby promoting more sustainable farming practices. By supporting biodiversity

and reinforcing cultural identity, these varieties are integral to the development of agroecological strategies in the Yucatán Peninsula.

However, conservation efforts face several challenges. For example, there are no socioeconomic incentives within the market for these varieties (100%). This would lead farmers to opt for more commercially viable crops, which would further endanger these traditional varieties. Furthermore, their productivity is limited (75%) and they have a short shelf life (25%). These factors limit the competitiveness of local varieties compared to commercial cultivars, which affects the economic viability of their continued cultivation.

CONSERVATION STRATEGIES

When discussing conservation strategies, 75% of participants identified *in-situ* field conservation as the most effective method. Additionally, 12.5% mentioned the potential benefits of seed banks and re-education workshops as alternative approaches. Importantly, 94% of respondents reported using traditional or ancestral methods to preserve genetic diversity, underscoring the importance of indigenous agricultural practices in conservation efforts (Figure 3).

Despite recognizing the value of structured conservation strategies, none of the interviewees reported active participation in formal conservation initiatives such as seed banks or organized exchange programs. This represents a significant opportunity to integrate traditional knowledge with scientific and institutional conservation frameworks, potentially strengthening the resilience of these local varieties.

INSTITUTIONAL AND COMMUNITY SUPPORT

A critical finding from the interviews is that none of the respondents (100%) were aware of existing governmental or institutional support programs for the conservation of local varieties. This lack of awareness and access to support mechanisms presents a major barrier to conservation efforts.

All interviewees highlighted financial assistance as the most urgent need (100%), followed by community participation, which was universally rated as “poor”. Furthermore, 94% of respondents believed that the government should take the lead in conservation initiatives, while 6% suggested that educational and research institutions should play a complementary role in knowledge transfer and technical support. This underscores the need for coordinated efforts between governmental agencies, academic institutions, and local communities to establish effective conservation policies and initiatives.

MARKET OPPORTUNITIES AND FUTURE

All respondents recognized that expanding the market for local varieties could be achieved through valorization and diversification strategies, including the development of niche markets, integration with agrotourism, and the promotion of cultural heritage projects. However, 75% expressed concerns about the future sustainability of these efforts due to market limitations and generational disinterest.

A particularly pressing issue is the lack of interest among younger generations, with 94% of interviewees reporting a decline in enthusiasm for continuing local variety cultivation. This trend was attributed to the limited commercial demand for these crops (Figure 3). To address this challenge, interviewees suggested two primary solutions: increasing awareness of the significance of local varieties (50%) and recognizing their value as part of the region’s agricultural and cultural heritage (50%).

Moreover, all interviewees indicated that *Carica papaya* local varieties are primarily sold in community markets (Figure 3), where the fruit is either consumed fresh or used in traditional desserts like “papaya sweet”. A portion of the production is also marketed to gourmet restaurants in the Mexican Caribbean, where these varieties attract tourists due to their distinct flesh color compared to the commercial Maradol variety. Expanding these niche

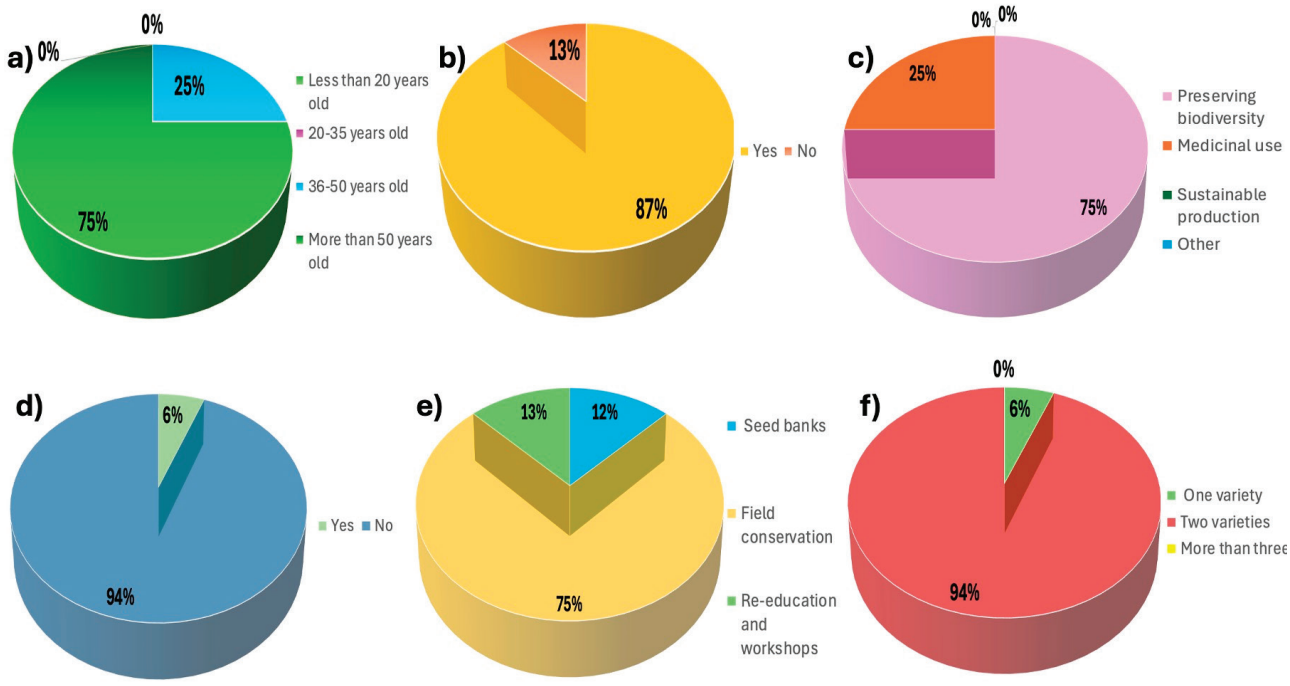

Figure 3. Outstanding results of the ethnobotanical study on the conservation and management of local varieties of *Carica papaya*. The answers are shown to: A) Age range of the owners or plantation managers; B) Direct link with the production or conservation of local varieties; C) Formal training in the management of these varieties; D) Perceptions of the importance of their conservation; E) Practices considered most effective for their conservation; and F) Number of local varieties currently retained by participants. These results allow us to identify the socioeconomic profiles and the level of knowledge about the conservation of *Carica papaya* in the study region.

markets could provide a viable economic incentive for continued conservation and cultivation.

DISCUSSION

The findings of the present ethnobotanical study reflect the importance of local papaya varieties within the agricultural and cultural context of the Yucatan Peninsula. Through traditional knowledge, producers have maintained a valuable biocultural heritage, which faces significant challenges in terms of conservation and economic viability.

Mayan Culture and Traditional Knowledge: The study confirms the relevance of traditional knowledge in the conservation of local varieties. The intergenerational transmission of knowledge about varieties "*cera amarilla*" y "*mamey*" it evidences the continuity of ancestral agricultural practices, a characteristic aspect of the Mayan culture (Caballero, 1992). This transfer of knowledge without formal intervention underscores the need for educational strategies that strengthen conservation and promote the participation of new generations.

The botanical knowledge of the Maya peoples has been documented in various studies, highlighting their ability to domesticate and manage local species in a sustainable way (Gomez-Pompa & Kaus, 1999). The management of diversified agroecosystems, such as milpas and Mayan plots, has allowed the conservation of biodiversity and the adaptation of crops to variable climatic conditions (Altieri et al., 2017) as is the case of the local varieties of papaya that are common in Maya plots. In addition, the Maya worldview closely links agriculture with spirituality and community, which reinforces the preservation of traditional varieties through festivities, rituals, and collective practices (Barrera-Bassols & Toledo, 2005).

However, globalization and agricultural modernization have led to a progressive loss of this knowledge, as young people move away from traditional practices in search of job opportunities in urban sectors (Zizumbo-Villarreal & Colunga-GarcíaMarín, 2010). To mitigate this

Figure 4. Production of local varieties: A) Sale in municipal markets and family consumption; B) Sale of fruits for desserts such as "papaya sweet"; C) and D) Fruits for marketing in tourist areas.

trend, it is essential to implement intercultural educational programs that integrate traditional knowledge with scientific advances in agroecology and conservation (Maffi, 2005).

Variety Management and Selection: The results show that the selection and management of local varieties is based on their adaptability, resistance to pests and organoleptic quality. The absence of sophisticated agronomic requirements suggests that these varieties may have advantages in agroecological production systems. However, the low level of formal training in breeding techniques and management may limit the use of their agronomic and commercial potential (Altieri & Nicholls, 2000). Similar examples have been observed in species such as mamey (*Pouteria sapota*) and black sapote (*Diospyros digyna*), where fruit selection is based on traditional criteria rather than structured breeding programs (Clement et al., 2010).

Conservation of Local Varieties: The consensus on the importance of conservation highlights the need to preserve biodiversity and the ecosystem services associated with these varieties (Brush, 2004). However, lack of market and low productivity represent critical barriers. The reliance on *in situ* conservation reflects the absence of integrated strategies that incorporate gene banks and participatory breeding programs (Clement et al., 2010). Similar cases have been recorded with species such as the chicozapote (*Manilkara zapota*), whose maintenance depends largely on family gardens and indigenous communities (Gomez-Pompa & Kaus, 1999).

Institutional and Community: Lack of Support: A worrying finding is the total lack of knowledge of support programs

for the conservation of local varieties, which suggests deficiencies in the dissemination of agricultural and environmental policies. The negative perception of community participation indicates the need for inclusive strategies that involve both farmers and academic and governmental institutions (Toledo & Barrera-Bassols, 2008). In other contexts, revaluation programs have been successful in crops such as vanilla (*Vanilla planifolia*) in communities in southeastern Mexico, demonstrating the key role of training and community organization in the conservation of endemic species (Maffi, 2005).

Market Perspectives and Future: Despite the challenges, there is widespread recognition of the potential of local varieties in niche markets, agritourism, and gastronomy (Altieri et al., 2017). However, concern about generational disinterest points to the urgency of educational and commercial initiatives that revalue these crops. The case of papaya in gourmet restaurants in the Mexican Caribbean represents a model of valorization that could be replicated in other regions (Lins Neto et al., 2010). Similar success stories have been observed with fruits such as dragon fruit (*Hylocereus* spp.), whose boom in international markets has been driven by differentiation strategies based on their origin and quality (Barrera-Bassols & Toledo, 2005).

CONCLUSION

This study reaffirms the importance of local varieties papaya as part of the biocultural heritage of the Yucatan Peninsula. However, to guarantee their conservation and sustainable use, it is essential to implement market strategies, formal training and institutional strengthening that facilitate their integration into resilient agri-food systems. In addition, it is crucial to encourage the participation of local communities in the design of agricultural policies, promote the creation of gene banks and revalue traditional knowledge as a key strategy for climate change adaptation and food security in the region.

AUTHOR CONTRIBUTION

Mónica I. Jiménez-Rojas and Fatima Duarte Ake conceptualized and designed the study; David Hernández Pinto, Mauricio Heredia-Pech, Fatima Duarte Ake and Mónica I. Jiménez-Rojas fieldwork and ethnobotanical data collection. Mónica I. Jiménez-Rojas performed data analysis and wrote the first draft of the manuscript. Fatima Duarte Ake, Carlos David Hernández Pinto and Mauricio Heredia-Pech edited and finalized the final draft of the manuscript. All authors read and approved the final version manuscript.

DATA AVAILABILITY

All data has been included in the main text.

DECLARATIONS

The study adhered to ethical research standards, ensuring the protection of participant rights, confidentiality, and informed consent. All participants were informed about the study's objectives, their voluntary participation, and their right to withdraw at any time without consequences. Anonymity was maintained in data presentation to respect participants' privacy. All papaya producers consent to participate in the study prior to the performance of semi-structured interviews including audio recording. Only producers who consented to participate in the study as volunteers were interviewed and their voices were recorded.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The authors declare that there are no conflicts of interest.

Funding. This study was supported by SECRETARIA DE CIENCIA, HUMANIDADES TECNOLOGÍA E INNOVACIÓN (SECIHTI), scholarship 568022 to MIJR.

REFERENCES

Aikpokpodion, P. O. (2012). Assessment of genetic diversity in horticultural and morphological traits among papaya (*Carica papaya*) accessions in Nigeria. *Fruits*. 67:173-187. https://doi.org/10.1051/fruits/2012011

Allendorf, F. W., Luikart, G. H., & Aitken, S. N. (2012). *Conservation and the genetics of populations* (2nd ed.). Wiley-Blackwell.

Altieri, M.A., C.I. Nicholls and R. Montalba. (2017). Technological Approaches to

Sustainable Agriculture at a Crossroads: An agroecological perspective, *Sustainability*,

9: 349.

Altieri, M. A., & Nicholls, C. I. (2000). Agroecología: Teoría y práctica para una agricultura sustentable. *Serie Textos Básicos Para La Formación Ambiental*. PNUMA-MARENA-UNESCO.

Ávila, R. C., Hernández, G., García, E., Hernández, E., Palemón, F., Hernández, J. L., & Jobo, J. (2013). Directed collection of the plant genetic resources of *Carica papaya* L. In *Executive Abstracts. Fiscal Year 2010*. National Seed Inspection and Certification Service.

Barlow, J., Lennox, G. D., Ferreira, J., Berenguer, E., Lees, A. C., Mac Nally, R., ... & Gardner, T. A. (2016). Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. *Nature*, 535, 144–147. https://doi.org/10.1038/nature18326

Barrera-Bassols, N., & Toledo, V. M. (2005). Ethnoecology of the Yucatec Maya: Symbolism, knowledge and management of natural resources. *Journal of Latin American Geography*, 4(1), 9–41.

Bellon, M. R., Barrientos-Priego, A. F., Colunga-GarcíaMarín, P., Perales, H., Reyes Agüero, J. A., Rosales-Serna, R., & Zizumbo-Villarreal, D. (2009). Diversity and conservation of genetic resources in cultivated plants. In CONABIO (Ed.), *Natural capital of Mexico: State of conservation and trends of change* (Vol. 2, pp. 355–382). CONABIO.

Brush, S. B. (2004). *Farmers' bounty: Locating crop diversity in the contemporary world*. Yale University Press.

Caballero, J. (1992). Maya homegardens: Past, present and future. *Etnoecológica*, 1, 35–54.

Caballero, J., A. Casas, L. Cortés, andC. Mapes. (1998). Patterns in the knowledge, use and management of plants in indigenous peoples of Mexico. *Atacameño Studies* 16: 181-195.

Chávez-Pesqueira, M., and Núñez-Farfán, J. (2017). Domestication and genetics of papaya: A review. *Frontiers in Ecology and Evolution*, 5, 155. https://doi.org/10.3389/fevo.2017.00155

Clement, A., Nathan, N., Epaud, R., Fauroux, B., and Corvol, H. (2010). Interstitial lung diseases in children. *Orphanet journal of rare diseases*, *5*, 22. https://doi.org/10.1186/1750-1172-5-22

Casas, A., J. Caballero, C. Mapes, and S. Zárate. (1997). Vegetation management, plant domestication and origin of agriculture in Mesoamerica. *Bulletin of the Botanical Society of Mexico* 61: 31-47.

De Carvalho, M. Â., Bebeli, P. J., da Silva, A. M., Bettencourt, E., Slaski, J. J., & Dias, S. (2016). Agrobiodiversity: The importance of inventories. In M. R. Ahuja & S. M. Jain (Eds.), *Genetic diversity and erosion in plants* (pp. 307–335). Springer. https://doi.org/10.1007/978-3-319-25954-3_10

Dawkins, G., Hewitt, H., Wint, Y., Obiefuna, P. C., & Wint, B. (2003). Antibacterial effects of *Carica papaya* fruit on common wound organisms. *The West Indian Medical Journal*, 52(4), 290–292.

Evans, E. A., & Ballen, F. H. (2012). *An overview of global papaya production, trade, and consumption*. University of Florida.

Gómez-Pompa, A., & Kaus, A. (1999). From pre-Hispanic to future conservation alternatives: Lessons from Mexico. *Proceedings of the National Academy of Sciences*, 96(11), 5982–5986. https://doi.org/10.1073/pnas.96.11.5982

Heredia-Pech, M., Martínez-Castillo, J., Martínez-Natarén, D. A., Ruiz-Gil, P., Jiménez-Rojas, M. I., Ortiz-García, M. M., & Chávez-Pesqueira, M. (2025). Effects of domesticated to wild gene flow on wild papaya in Mesoamerica. *Genetics*, 153(7). https://doi.org/10.1007/s10709-024-00223-2

Hernandez-Salinas, G., A. Soto-Estrada, E. García-Pérez, A. Pérez-Vazquez, M. Rocandio-Rodríguez, and L. Córdova-Téllez. (2019). Variación morfológica *in situ* de *Carica papaya* L. nativa de México. *Revista Fitotecnia Mexicana* 42(1): 47-55.

Instituto Nacional de Estadística Geografía e Información. (2020). Censo de Población y Vivienda 2020. Recuperado de: Censo de Población y Vivienda 2020

Jiménez-Rojas, M. I., Andueza-Noh, R. H., Martínez-Castillo, J., & Potter, D. (2019). Management and cultivation of the Huaya India (*Melicoccus oliviformis*) on the Yucatan Peninsula. *Economic Botany*, 73, 429–442. https://doi.org/10.1007/s12231-019-09470-3

Koleff, P., Tambutti, M., March, I. J., Esquivel, R., Cantú, C., & Lira-Noriega, A. (2009). Identification of priorities and analysis of gaps in the conservation of Mexico's biodiversity. In CONABIO (Ed.), *Natural Capital of Mexico: State of conservation and trends of change* (Vol. 2, pp. 651–718). CONABIO.

Lins Neto, E.M., Peroni, N. & de Albuquerque, U.P. (2010). Traditional Knowledge and Management of Umbu (Spondias tuberosa, Anacardiaceae): An Endemic Species from the Semi–Arid Region of Northeastern Brazil. Economy Botany 64, 11–21 https://doi.org/10.1007/s12231-009-9106-3

Lobo, M., & Medina, C. I. (2009). Conservation of agrobiodiversity genetic resources to support sustainable systems. *Ciencia y Tecnología Agropecuaria*, 10(1), 33–42.

Maffi, L. (2005). Linguistic, cultural, and biological diversity. *Annual Review of Anthropology*, 34, 599–617. https://doi.org/10.1146/annurev.anthro.34.081804.120437

Martín, G. J. (1997). *Ethnobotany: Principles and applications*. Chapman & Hall.

Meyer, R. S., & Purugganan, M. D. (2013). Evolution of crop species: Genetics of domestication and diversification. *Nature Reviews Genetics*, 14(12), 840–852. https://doi.org/10.1038/nrg3605

Mokganya, M. G., Tshisikhawe, M. P., Swelankomo, N., Tshivhandekano, T. R., Ramovha, L. I., Masevhe, N. A., Ligavha-Mbelengwa, M. H., & Mocheki, T. A. (2018). Additional uses of wild edible fruit plants in Limpopo, South Africa. *Indian Journal of Traditional Knowledge*, 17, 276–281.

Morales-Payán, J. P., J. Ortiz, and N. Guzmán. (2017). Resilience of local crop varieties in traditional agricultural systems. Agricultural Systems 15:774-81.

Niklas, K. J., & Marler, T. E. (2007). *Carica papaya*: A case study into effects of domestication. *American Journal of Botany*, 94(6), 999–1002. https://doi.org/10.3732/ajb.94.6.999

Otsuki, N., Dang, N. H., & Morita, H. (2010). *Carica papaya* leaf extract shows anti-tumor activity. *Journal of Ethnopharmacology*, 127(3), 760–767. https://doi.org/10.1016/j.jep.2009.11.024

Paz, L., & C. Vázquez-Yanes. (1998). Comparative seed ecophysiology of wild and cultivated Carica papaya trees from a tropical rain forest region in Mexico. Tree Physiology 18: 277–280. https://doi.org/10.1093/treephys/18.4.277

Ruiz Gil, P. J., Wegier, A., Alavez, V., Rosas Plaza, S., Núñez Farfán, J., & Chávez Pesqueira, M. (2023). Gene flow from domesticated papaya into wild populations. *Genetic Resources and Crop Evolution*, 70(8), 2391–2410. https://doi.org/10.1007/s10722-023-01568-x

Subenthiran, S., Choon, T. C., Cheong, K. C., Thayan, R., Teck, M. B., Muniandy, P. K., Afzan, A., Abdullah, N. R., & Ismail, Z. (2013). *Carica papaya* juice increases platelet count in dengue. *Evidence-Based Complementary and Alternative Medicine*, 2013, 616737. https://doi.org/10.1155/2013/616737

Swarup, S., Cargill, E. J., Crosby, K., Flagel, L., Kniskern, J., & Glenn, K. C. (2021). Genetic diversity is indispensable for plant breeding. *Crop Science*, 61(2), 839–852. https://doi.org/10.1002/csc2.20377

Syfert, M. M., Castañeda-Álvarez, N. P., Khoury, C. K., Särkinen, T., Sosa, C. C., Achicanoy, H. A., Bernau, V., Prohens, J., Daunay, M. C., & Knapp, S. (2016). *Solanum melongena* wild relatives under threat. *American Journal of Botany*, 103(4), 785–795. https://doi.org/10.3732/ajb.1500539

Toledo, V. M., & Barrera-Bassols, N. (2008). *La memoria biocultural: La importancia ecológica de las sabidurías tradicionales*. Icaria Editorial.

Wall, M. M., & Tripathi, S. (2014). Papaya nutritional analysis. In R. Ming & P. H. Moore (Eds.), *Genetics and genomics of papaya* (pp. 377–390). Springer. https://doi.org/10.1007/978-1-4614-8087-3_16

Zizumbo-Villarreal, D., & Colunga-GarcíaMarín, P. (2010). Origin of agriculture and plant domestication in West Mesoamerica. *Genetic Resources and Crop Evolution*, 57, 813–825. https://doi.org/10.1007/s10722-009-9521-4