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# Ecological knowledge, use and management of *maax ik* (*Capsicum annuum* var. *glabriusculum* (Dunal) Heiser & Pickersgill) in a rural Mayan community

# Conocimiento ecológico, uso y manejo del *maax ik* (*Capsicum annuum* var. *glabriusculum* (Dunal) Heiser & Pickersgill) en una comunidad rural Maya

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**Abstract**

**Background:** *Capsicum annuum* var. *glabriusculum* is the ancestor of most of the economically important chiles in the world. It is widely distributed throughout Mexico, and currently all indigenous groups interact with this plant species. On the Yucatan Peninsula wild chile is known as *maax ik* by the Maya. Although this area has been recognized as a domestication and diversification center of chile, ethnobotanical research on this species is still limited.

**Questions:** What ecological knowledge do local people have about *maax ik*? Where and how is *maax ik* gathered and managed? What uses does *maax ik* currently have?

**Studied species:** *Capsicum annuum* var. *glabriusculum*

**Study site and dates:** San Bernardo, Yucatan. Summer-Autumn 2021.

**Methods:** In-depth semi-structured interviews and participatory observation. The management practices were identified, and management intensity was estimated.

**Results:** Informants knew that *maax ik* reproduces sexually and recognized the role of birds in its seed dispersal. *Maax ik* was mainly gathered from homegardens where this species was tolerated and other non-selective incipient management practices such as protection and promotion were also carried out. Fruit was harvested without harming the plant and only a small portion of the available fruit was usually taken. The informants used *maax ik* essentially as food. The management intensity index was relatively high (5).

**Conclusions:** *Maax ik* is a sustenance food resource that is sustainably used and non-selectively managed in homegardens by our informants in San Bernardo, Yucatan.

**Keywords:** Crop wild relatives, homegardens, traditional agroecosystems, wild chile, Yucatan peninsula.

**Resumen**

**Antecedentes**: *Capsicum annuum* var. *glabriusculum* es el ancestro de los chiles cultivados económicamente más importantes del mundo. En México, esta planta tiene una amplia distribución y todos los pueblos originarios vivos del país interactúan con ella. En la península de Yucatán, los Mayas conocen al chile silvestre como *maax ik*. Aunque esta zona ha sido reconocida como un probable centro de domesticación y diversificación del chile, la investigación etnobotánica con el *maax ik*, es aún limitada.

**Preguntas:** ¿Qué conocimiento ecológico poseen las personas locales sobre el *maax ik*? ¿Dónde y cómo se recolecta y maneja el *maax ik*? ¿Qué usos actuales tiene el *maax ik*?

**Especie de estudio**: *Capsicum annuum* var. *glabriusculum.*

**Métodos:** Entrevistas semiestructuradas a profundidad y observación participante. Se identificaron las prácticas de manejo y se calculó un índice de intensidad de manejo.

**Resultados:** Los informantes saben cómo se reproduce el *maax ik* y sobre el papel que las aves juegan en la dispersión de sus semillas. *Maax ik* fue recolectado en huertos familiares, donde fue tolerada y sujeta a otras prácticas de manejo incipientes como la protección y promoción. La recolección fue no destructiva y usualmente solo se tomaba una pequeña porción de los frutos disponibles. El *maax ik* fue usado esencialmente como alimento. El índice de intensidad de manejo fue relativamente alto (5).

**Conclusiones:** *Maax ik* es un recurso alimenticio de subsistencia que nuestros informantes usan de forma sostenible y se manejan de forma no selectiva en los huertos familiares de San Bernardo, Yucatán.

**Palabras clave:** Agroecosistemas tradicionales, chile silvestre, huertos familiares, parientes silvestres de cultivos, Península de Yucatán.

Forest dwellers have a long history of interaction and dependence on a wide range of non-timber forest products (NTFPs) for sustenance (*e.g.,* Howell *et al*. 2010, Ghosal 2011). Generations of observations and experimentation while gathering NTFP have led to the development of a detailed body of ecological knowledge as well as sophisticated practices of sustainable management and use (Colding & Folke 2001, Toledo *et al*. 2008, Ticktin & Shackleton 2011). Among NTFPs, wild food plants gathered from forests and other habitats play an essential role in the food security of rural families, particularly for the most vulnerable (Chweya & Eyzaguirre 1999, Cruz-García & Struik 2015). Apart from subsistence consumption, the sale of products obtained from wild food plants offers a way to obtain cash income for gatherers (Shackleton *et al*. 2007a, b). Far from being only exclusively gathered from natural habitats, wild food plants can be harvested from lands across the full continuum of intensity of human use and disturbance *i.e.,* from extensive low-impact forests to cultivated fields (Ticktin & Shackleton 2011). In fact, pure extractivism and monoculture are just the extremes of the entire range of food plant management in forested landscapes that are cultural products or the result of millennia of large-scale management (Ford & Nigh 2009, Pretty *et al*. 2009).

Systematic gathering may act as an artificial selective pressure and may lead to the incipient domestication of wild food plants (Casas *et al*. 2007). This domestication process can be accelerated when wild food plants are naturally recruited or transplanted to human-created habitats because there, these plants are more accessible and more intensively managed, either consciously or unconsciously (García de Miguel 2000, Galluzzi *et al*. 2010, Thomas & Van Damme 2010). In domestication centers, cultivated plants often coexist with their wild relatives, but the latter are not necessarily replaced by improved varieties because wild plants continue to provide households with free-access food that complements their diet or income (Aguilar-Meléndez 2006, Miller & Nair 2006). Mesoamerica is one of the world's main centers of plant domestication (Vavilov 1951). In this region, ca. 200 native plant species have been domesticated, including crops of worldwide economic relevance, such as cultivated chiles: *Capsicum annuum* var. *annuum* L. (Casas *et al*. 2007, Pickersgill 2007). Although several domesticated varieties of this chile are cultivated in the region, the fruit of the wild ancestor of this crop (*C. annuum* var. *glabriusculum* (Dunal) Heiser & Pickersgill) is still extensively gathered and contributes not only as food, but also as medicine and materials for rituals, particularly for vulnerable groups (*e.g.,* Hernández-Verdugo *et al*. 1999, Perramond 2005, Aguilar-Meléndez 2006, Martínez-Torres 2007, Bañuelos *et al*. 2008, Aguilar-Meléndez *et al*. 2021).

The domestication of chile likely took place in central-east Mexico, 6,000 years BP; however, some evidence suggests that this may have occurred in more than one site within this broad region, including Yucatan Peninsula (Smith 1967, Pickersgill 1969, Aguilar-Meléndez *et al*. 2009, Kraft *et al*. 2014). In this country, ca. 90 landraces of this crop are associated with indigenous ethnic groups; thus, the territories of these groups are probably the most important *in situ* reservoir of germplasm of chile in the world (Aguilar-Meléndez *et al*. 2009, Güames-Jiménez & Aguilar-Meléndez 2018). *C. annuum* var. *glabriusculum* has a wide distribution, ranging from the southern United States of America to northern Bolivia and Brazil (Barboza *et al*. 2022). In Mexico, it occurs in the majority if not all of the country's states and across a wide array of habitats, both natural (*e.g.,* deserts, scrub lands, tropical and temperate forests) and anthropogenic (*e.g.,* milpa [a polyculture based on maize, beans and squash], homegardens, pastures and monocultures of perennial tropical crops) (Hernández-Verdugo *et al*. 1999, Kraft *et al*. 2013, Melchor-Contreras 2014, Hayano-Kanashiro *et al*. 2016, Aguilar-Meléndez & Lira-Noriega 2018, Gutiérrez-Burón *et al*. 2020). Across its distribution, all the living indigenous groups in Mexico still interact with this plant species (Long-Solís 1986, Aguilar-Meléndez 2006, Aguilar-Meléndez *et al*. 2021) and use a wide variety of management practices that range from no apparent management to small-scale cultivation, with non-selective gathering the most common practice (*e.g.,* Pennington 1982, Perramond 2005, Martínez-Torres *et al*. 2007, Bañuelos *et al*. 2008, Mares-Quiñones & Valiente-Banuet 2019). Given the long history of interaction between humans and wild chile (> 8,000 years) as well as their presence in human-created habitats, some authors have suggested that wild chile may no longer be a proper wild plant species and has become a semiwild, an arvence or even an incipiently domesticated crop (*e.g.,* Aguilar-Meléndez *et al*. 2009, Melchor-Contreras 2014, Hayano-Kanashiro *et al*. 2016, Mares-Quiñones & Valiente-Banuet 2019, Pérez-Martínez *et al*. 2022).

Studying current uses, preferences and management practices of plants (*i.e.,* ethnobotanical research) may shed some light that enables us to reconstruct the motives behind the domestication process (*e.g.,* Blancas *et al*. 2016). This is particularly true in domestication centers, where the descendants of former domesticators often continue interacting with crop wild relatives. Although some research has documented the uses and management of wild chile in some parts of Mexico (*e.g.,* Aguilar-Meléndez 2006, Martínez-Torres 2007, Bañuelos *et al*. 2008, Melchor-Contreras 2014), few studies have been done on the Yucatan Peninsula. Filling this gap in ethnobotanical knowledge of wild chile is highly relevant because Yucatan is considered one of the centers of domestication and diversification of this plant (Aguilar-Meléndez *et al*. 2009). Historically, the Yucatan Peninsula has been the territory of the Maya, one of the most important Mesoamerican cultures in terms of population size, area occupied, and diversification of their language (Gómez-Pompa & Kaus 1990). Wild chile is known as *maax ik* by the Maya (the proto-Maya word *iik* means chili pepper; Kaufman 1994, 2003) and despite not being planted, it is one of the most frequent plants found in traditional agroecosystems even today (*i.e.,* milpa and homegardens; Latournerie *et al*. 2001, 2002).

The goal of this paper was to assess the ecological knowledge, uses and management practices of *maax ik* in a small, rural village of central of Yucatan of Maya ethnicity known as San Bernardo. We selected this community because it is a typical Maya community of central Yucatan where the Maya is the first language and traditional agroecosystems as well as patches of surrounding secondary tropical dry forest are still actively being managed (Rejón-Marrufo 2020, Villicaña-Hernández *et al*. 2020). Previous research on the topic suggests that gathering is more intense and sometimes destructive (*i.e.,* branches and even the whole plant are harvested) in the north of Mexico where wild chile plants are mainly available in patchy natural vegetation, associated with fleshy-fruited perennials (*e.g.,* Tewksbury *et al*. 1999, Perramond 2005, Rivera-Lárraga 2022). Although management practices have not been documented in Yucatan, it is known that in the southern tropical regions of Mexico, wild chile plants can be found under broken canopies and naturally occurs in traditional agroecosystems near the settlements of their gatherers (*e.g.,* Aguilar-Meléndez 2006, Melchor-Contreras 2014, Gutiérrez-Burón *et al*. 2020, Pérez-Martínez *et al*. 2022). Therefore, uses and management practices of this species that differ from those previously described are expected in the study area. Our goal was to answer the following questions: What ecological knowledge do local people have about *maax ik*? What is *maax ik* currently used for? Where and how is *maax ik* being managed? We used an ethnographic approach to answer these questions, which is suitable for documenting in-depth knowledge (*i.e.,* corpus) and for understanding the motivation behind its uses and the management practices applied (*i.e.,* praxis) (Carvalho-Pires de Souza *et al*. 2019, Moreno-Brito-Moura *et al*. 2019). Management practices and intensity were also assessed.

## Materials and methods

*Study area.* The study was conducted in the locality of San Bernardo, in the municipality of Kopom**á**, in the Mexican state of Yucatan (20° 38' 09" N; 89° 57' 09" W, 10-16 m a.s.l., Figure 1). The climate is warm, subhumid with summer rains (June-September), mean annual temperature is 26-28 ºC and mean annual rain is 1,000-1,100 mm (INEGI 2009, 2017). San Bernardo is a small rural community surrounded mainly by a secondary tropical dry forest with *Lysiloma latisiliquum* (L.) Benth, *Piscidia piscipula* Sarg., *Bursera simaruba* Sarg, *Ehretia tinifolia* L. and wild *Cordia dodecandra* DC as the dominant tree species (Villicaña-Hernández *et al*. 2020, pers. obs.). In San Bernardo, 466 persons of Maya ethnicity live in 121 dwellings, all of them own relatively big homegardens (mean size 1,034 ± 20 $m^2$ [hereafter mean±1 SE]; Rejón-Marrufo 2020). The main economic activities in San Bernardo are small-scale agriculture as well as apiculture and low-scale production of charcoal (Rejón-Marrufo 2020, Villicaña-Hernández 2021). During early 1950s an important source of cash income was salaried work at a henequen (*Agave fourcroydes* Lem.) plantation managed by the Hacienda San Bernardo, an activity that severely declined 30-40 years ago (Gobierno del Estado de Yucatán 2022). The Hacienda San Bernardo completely stopped their activity in the study area 20 years ago (Gobierno del Estado de Yucatán 2022). San Bernardo is a community with a high degree of marginalization, with limited public facilities, accessibility to the village, and mobility of people (CONEVAL 2010). Local shops offer a limited inventory to local customers, particularly regarding vegetables; therefore, inhabitants rely on the food they themselves produce and hunt to complement their diet (SEDESOL 2018, pers. obs.).

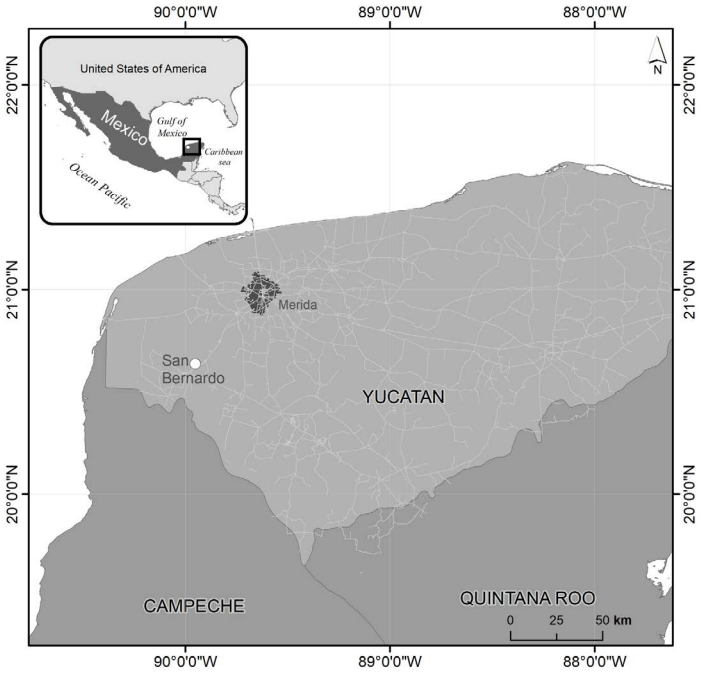


**Figure 1.** Location of San Bernardo, Yucatan (white circle). The location of Merida, the capital city of Yucatan (Merida), is also shown. The insert shows the location of San Bernardo and the Yucatan in the broader geographic context of Mesoamerica and the United States of America. Scale bar represents 50 km.

*Study species. Maax ik* (*Capsicum annuum* var. *glabriusculum* (Dunal) Heiser & Pickersgill) is a shrub that grows up to 2 m tall, flowers are perfect and actinomorphic (Barboza *et al*. 2022). This chile pepper plant exclusively reproduces sexually, fruits are small (4.8 ± 0.39 mm long, n = 127 fruits), green that turn red when ripe, the seeds are also small (diameter: 1-2 mm), whitish to yellowish (Tewksbury *et al*. 1999). Fruit production peaks between June and October in the study area and elsewhere (Hayano-Kanashiro *et al*. 2016, pers. obs.). Fruits are mainly bird dispersed (Carlo & Tewksbury 2014), the species that specifically feed on *maax ik* in the Yucatan are *Mimus gilvus* and *Pitangus sulphuratus* (Villicaña-Hernández 2021). In some sites, particularly in the north of Mexico and southern USA, there is a clear spatial association with nurse plants, and this association is well known to local harvesters; knowledge that is used to locate places to gather this species (Tewksbury *et al*. 1999, Bañuelos *et al*. 2008, Murillo-Amador *et al*. 2015). In contrast, the association with nurses is less clear in the south of Mexico, where wild chile plants are often seen in agroecosystems (Latournerie *et al*. 2001, Melchor-Contreras 2014, Gutiérrez-Burón *et al*. 2020, Pérez-Martínez *et al*. 2022). That seems to be the case for *maax ik* which, despite not being planted, is one of the three most common types of chile found in the traditional agroecosystems of the Yucatan (Latournerie *et al*. 2001). In addition to their importance as food, some ritual uses have been reported for this region, such as the *ch'a chaak*, an ancient ceremony to call the rains (Flores & Kantún 1997).

*Data collection.* Fieldwork was conducted during summer and autumn 2021. To achieve full immersion in the community, during fieldwork the first author was hosted by a key informant (a 56 years-old housewife), met during previous research in the study area. The host also facilitated initial rapport (*i.e.,* conveying empathy and understanding without judgment; Patton 2015) by introducing the interviewer to local people. A snowball sampling procedure was adopted, which consisted of identifying a network of key informants (Lohr 2019). These informants were defined as people with relevant knowledge about plants that also played an important role in bringing the ingredients and/or in preparing food as well as having *maax ik* on their land. Our host was also the initial informant and helped identify the

second informant who in turn, identified the third informant. This procedure was iterated until the saturation point of the information (*i.e.,* when the information provided by the informants became redundant) was achieved. Only one informant per domestic group (home) was interviewed to gain independence.

The main instrument we used was a semi-structured interview (Fylan 2005). The interview consisted of 46 items (mainly open questions) grouped into eight sections, originally written in Spanish (Supplementary material). Interviewing in Spanish was feasible because all the informants were bilingual (*i.e.,* speak Maya as their first and Spanish as their second language). We used plain appropriate language, intelligible to the local people. To achieve this goal, a pilot study with eight people from a community (Umán, Yucatan) that was similar in terms of cultural and sociodemographic variables was conducted and the instrument was modified accordingly. The first contact with all potential informants consisted of an informal introductory talk, during which a later date for the formal interview was agreed upon. All the interviews took place in the informants' homes at the scheduled time and lasted 1.5-2 hours. Fieldwork was conducted during the Covid-19 pandemic; therefore, the interviews were conducted in open spaces (mainly the garden), using face masks and with a distance of at least 1.5 m between the informant and the interviewer.

The eight sections of the interview were: i) Biographic information, where we asked the informants their name, age, sex, education, place of origin and occupation (six items). ii) General information about *maax ik* as well as the places and forms of acquisition (five items). iii) Ecological knowledge (three items), where their knowledge regarding habitat and reproduction of *maax ik* was documented. iv) Knowledge transmission (two items). Here we asked about the origin of their knowledge and whether this knowledge had been or was being transmitted to their relatives or community members and how. v) Management practices (11 items). Here we listed the managing practices of *maax ik*. vi) Uses of *maax ik* (11 items). vii) Perceived conservation *status* (four questions), where we asked about the availability of *maax ik*. viii) Commercialization and value chains (four items). Here we asked if *maax ik* was bought or sold, as well as how much it cost (Supplementary material).

Saturation point was reached after interviewing 42 people, most of whom (86 %) were women. All the informants gave verbal consent for us to record the interviews and to use the information for academic purposes (de Hek & Ladio 2019). All relevant context either observed or mentioned was recorded in a field journal (Almeida-Campos *et al*. 2019). Since management, uses and other relevant practices are sometimes performed unconsciously, both participatory and non-participatory observations were made during the daily activities of the members of the community (Almeida-Campos *et al*. 2019, Jiménez-Rojas *et al*. 2019). This included *in situ* demonstrations of plant management practices and walks around neighboring natural vegetation and agroecosystems from which *maax ik*, is or used to be gathered.

*Data analyses.* The interviews (55 recorded hours) were entirely transcribed. In the transcripts: pauses, emphasis and any relevant expressions were added as notes (de Hek & Ladio 2019). The transcripts were analyzed with a content analysis; that is, we identified the main topics (categories) and from each topic, the manifest content was taken and from this, the latent content was inferred (Almeida-Campos *et al*. 2019, Carvalho-Pires de Sousa *et al*. 2019, de Hek & Ladio 2019). Information from the field journal, along with that from the participatory and non-participatory observations, was used as a context for the narrative derived from content analysis (Almeida-Campos *et al*. 2019). This analysis was done with the help of RQDA package (Huang 2012) for R software (R Core Team 2022). Descriptive statistics of the information were also obtained.

Using the information provided by the informants and the information obtained during participatory and non-participatory observations, we identified the management practices that the informants performed on *maax ik* plants, and these practices were then classified as: gathering, tolerance, protection (against competitors, herbivores, etc.) or promotion (*i.e.,* practices that lead to a better performance of individual plants or an increase in population density such as watering, pruning, fertilization, *etc*.) (Bye 1993, Casas *et al*. 1997, Caballero & Cortés 2001, Casas *et al*. 2001). For each management practice, a complexity grade was assigned. That is, complexity = 1 for gathering and complexity = 2 if a given management practice was incipient and non-selective *e.g.,* non-selective tolerance, protection, or promotion. By non-selective management, we meant that a given management practice was performed

regardless of the phenotype of a plant or a plant organ (González-Insuasti & Caballero 2007). Although the management index outlined by González-Insausti & Caballero (2007) also considers selective management practices (complexity grade = 3), *ex situ* cultivation (complexity grade = 4) and agriculture (complexity grade = 5), these were not reported or observed during our study. The index of management intensity (IM) was then obtained by the following equation:

$$\text{IM} = \sum MCx\frac{n}{N}$$

Where MC was the grade of management complexity: one for gathering and two for incipient non-selective management. N was the total number of informants (N = 42 in this study) and n was the number of informants interviewed who used a given management practice (González-Insuasti & Caballero 2007). Thus, the IM has only positive values, it increases with the number of practices and the proportion of people that perform such practices (González-Insuasti & Caballero 2007). As a reference, plant species with 6-8 known management practices (including occasional ex-situ cultivation) and each practice was performed by less than 50 % of the informants had an IM value between 3 and 4 in a previous study (González-Insuasti & Caballero 2007).

## Results

*Informants.* Of the 42 informants involved in this study, 36 were women (86 %) and 6 were men (14 %). All of them were born in rural Yucatan, 83 % in San Bernardo. The mean age of informants was 49 ± 6.48 years old. The majority (93 %) of informants only attended elementary school. Regarding the main occupation, most of the women were housewives (92 %) and most of the men were retired (50 %) (Table 1).

*Ecological knowledge.* Most informants (64 %) thought that *maax ik* does not need a specific abiotic environment, because it may grow either in shade or in sunny places.

"*…le da lo mismo* [*refiriéndose al* maax ik]*, mientras que hay fresco allá sale; a veces en el sol, también allá sale…*"

…it does not care [referring to *maax ik*], as long as it is cool it grows; sometimes it also grows in the sun (Woman, 65 years old).

Most informants (69 %) identified the milpa as the main habitat for *maax ik*. The forest (the specific term used in Spanish was "*monte*") was also mentioned (41 %). However, as far as the informants are concerned, the milpa is within or belongs to the forest.

"*Cuando iba mi papá al monte a leñar o a su milpa, de allá lo traía* [*refiriéndose al* maax ik]".

My father used to bring it home [referring to *maax ik*] when he went to the forest for firewood or to his milpa (Woman, 55 years old).

"*Se traía del monte* [*refiriéndose al* maax ik]*…. de la milpa…cuando íbamos a tumbar* [*refiriéndose a los preparativos iniciales de la milpa*]".

It used to be brought from the forest…from the milpa… when we slashed the vegetation [referring initial step of slash and burn process of the traditional milpa] (Man, 68 years old).

The great majority (98 %) of informants affirmed that *maax ik* is reproduced by seeds and that these were dispersed by birds. The birds that eat the fruit of *maax ik* were identified and named in Maya. The bird species most frequently mentioned were: xchica (*Mimus gilvus*; 95 % of informants), xtacay (*Pitangus sulphuratus*; 45 % of informants) and xcoquita (*Turdus grayi*; 24 % of informants).

"*Sí, los pájaros lo vienen y lo cagan* [*las semillas del* maax ik]*, por eso sale. Dicen que… esten* (sic)*… esten* (sic)*… yuya, ese xcok que dicen…*"

Yes, the birds defecate them [the seeds of *maax ik*] and this why it grows. They say that. . . mmm. . . mmm. . . [it's] the yuya bird and that xcok bird they say. (Woman, 67 years old).

"…allá donde se pare xchica" …over there, where the xchica bird perches (Woman, 73 years old)

**Table 1.** Socio-demographic information for 42 informants from San Bernardo, Yucatan. Information for all the informants, only for men and only for women are given. The values are percentages, sample size is also given in parentheses.

| Variable | Category | % Informants (n = 42) | % Men (n = 6) | % Women (n = 36) |
|---|---|---|---|---|
| **Education** | Illiterate | 2.38 (1) | | 2.78 (1) |
| | Elementary | 92.86 (39) | 100 (6) | 91.66 (33) |
| | High school | 4.76 (2) | | 5.56 (2) |
| **Place of birth** | San Bernardo | 83.34 (35) | 100 (6) | 80.55 (29) |
| | Maxcanú, Yucatan | 9.52 (4) | | 11.11 (4) |
| | Kopomá, Yucatan | 2.38 (1) | | 2.78 (1) |
| | Kanachén, Yucatan | 2.38 (1) | | 2.78 (1) |
| | Halachó, Yucatan | 2.38 (1) | | 2.78 (1) |
| **Occupation** | Housework | 78.57 (33) | | 91.7 (33) |
| | Salaried work | 11.91 (5) | 33.34 (2) | 8.33 (3) |
| | Unemployed | 2.38 (1) | 16.66 (1) | |
| | Retired | 7.14 (3) | 50.00 (3) | |

The informants did not mention any other role of the birds that visited *maax ik* plants (*i.e.,* as pollinators or herbivores). Finally, the informants denied any spatial association between *maax ik* and any other plant.

The only means of transmission of ecological knowledge about *maax ik* reported by all the informants was direct observation, this means of transmission was also reported for knowledge regarding the care of *maax ik.* Some informants (20 %) did not consider the transmission of ecological knowledge regarding *maax ik* to be relevant because *maax ik* was a wild plant species ("*planta de monte*" in Spanish) and therefore, did not need any special care.

"*Nadie te enseña, porque no necesitan que los cuides* [*refiriéndose al* maax ik]..." Nobody teaches you, it [referring to *maax ik*] does not need any care… (Woman, 54 years old).

The majority of informants (85 %) perceived *maax ik* to be scarcer in the forest and milpa now than it used to be in the past. In contrast, *maax ik* was perceived as abundant in homegardens in recent years. Also, the informants did not consider this resource irreplaceable, because other types of domesticated chile (particularly habanero pepper) were available to them either from homegardens (theirs or a neighbor's) or from the markets in neighboring cities.

"*No me afectaría* [*haciendo referencia a la ausencia hipotética del* maax ik] *porque lo vamos a buscar con los vecinos, casi todos tienen, y si les pides, te lo regalan."*

It would not affect me [referring to the hypothetical absence of *maax ik*] because we would ask the neighbors for some, almost everyone here has it and, if you ask, they will give you some chile peppers for free… (Woman, 42 years old).

*"Todos tienen acá* [*refiriendose al* maax ik], *nomás para la sequía, se compra el 'jhabanero'* (sic) [*chile habanero*]*"*

Everybody here has it [referring to *maax ik*], only during the dry season, we buy some habanero pepper (Woman, 48 years old).

*Management.* Although the milpa used to be the main habitat of *maax ik*, there was general agreement among informants (100 %) that the cultivation of traditional milpa is being progressively lost. Nowadays, the young are more interested in going out to work in neighboring cities. Many of them have left San Bernardo and the older adults that stayed are unable to keep up with the physical demands of cultivating the milpa as they age. This trend was exacerbated by the abandonment of the henequen plantation that employed an important proportion of local workforce in the 1950s. People that worked there simultaneously worked on their own land, cultivating milpa.

*"Me acuerdo cuando tenía 10 años... como ahorita estamos perdiendo la milpa, mi esposo perdió la semilla de todo…"*

I remember when I was 10 years old… just as we are now losing the milpa, my husband lost the seeds of everything… (Woman, 52 years old).

*"Cuando yo nací, mi papá aún iba al plantel* [campo de cultivo de henequén] *a trabajar. Me quedaba en mi casita, mi papá se iba en la madrugada y después de estar en el plantel, iba a su milpa. Ya mucho después se dejó de trabajar el henequén, mi papá ya estaba grande así, ya no podía seguir la milpa… antes se juntaban todos y se ponían de acuerdo para hacer milpa, entre todos se ayudaban para quemar y hacer la siembra. Luego los hombres empezaron a trabajar de albañil y lo dejaron* [la milpa]. *Ahora los jóvenes no hacen milpa, ni saben cómo …. Por eso ahora creo que no hay* maaxito [en el monte]*, porque ya nadie va al monte a trabajar la milpa*"…

When I was born, my father used to work on the henequen plantation. I stayed at home, he used to leave very early and, once my father finished his work at the henequen plantation, he went to work in his milpa. Much later he stopped working on the henequen plantation, my father was already old, and so he could no longer continue with the milpa. In the past, all the men used to work together to slash, burn and sow the milpa. Then men started working as construction workers and left it [The milpa]. Nowadays the young do not do milpa anymore, they do not even know how to do it… I now believe that is why there is no longer little *maax ik* [in the forest], because nobody goes to the forest to work the milpa (Woman, 52 years old).

At present, *maax ik* is mainly gathered from the homegardens where it naturally recruits and has become a conspicuous element of this agroforestry system in San Bernardo.

"*Eso* [señalando una planta de *maax ik*]*, los pajaritos creo que lo comen, lo traen; porque ahorita tengo varias en mi solar"*

This [pointing out a *maax ik* plant], little birds feed on it and bring it; because right now I have several of them in my garden. (Women, 25 years old).

Gathering *maax ik* from homegardens is highly advantageous for the informants, mainly because it is freely available near the house. Also, during walks with the informants in the surrounding forest patches, we were unable to find any *maax ik* plants. According to our observations, the fruit of *maax ik* was gathered by hand, mainly green (71 % of informants) and only occasionally red (29 %). People often took only a small proportion of the available fruit and left the rest on the plant "for the birds". Gathering is not selective and there does not appear to be a specific time schedule for it. 76.4 % of informants emphasized the need to gather the fruit without damaging the plant; this way, according to the informants, they would have the possibility of harvesting from the same plant in the future.

In addition to fruit gathering (100 %) described above, the informants also reported other management practices that we also saw during our observations in the homegardens. i) All informants (100 %) tolerated *maax ik* in their gardens (Table 2). That is, naturally established *maax ik* plants in homegardens are not removed during daily cleaning or weeding. The reason behind tolerance was the production of edible fruits in all cases. ii) Protection of *maax ik* was reported/observed in 31 % of informants' homegardens (Table 2). Protection practices include weeding, and protection from domestic (goats and chicken) and wild (iguana, *Ctenosaura similis*) herbivores. iii) Promotion practices were reported and/or seen in 69 % of informants' homegardens (Table 2). This included activities such as unintentional watering *i.e.,* water used for watering other plants or the water from cleaning, dish and/or clothes washing that reached *maax ik*. We also observed that some plants were unconsciously fertilized when informants dropped food waste, the feces of domestic animals or the ashes of firewood used for cooking, near *maax ik* plants. When food waste was dropped, this sometimes led to unintentional seed dispersal because some of the waste included viable seeds. Far less frequent (2.6 %), was the transplant of some plants to a different place or pots, but always within the same garden.

At least two and up to four of these practices were performed in the same homegarden. None of these practices can be considered selective because the informants did not report a preferred trait or phenotype. This fact was confirmed during extensive participatory observation. No *ex situ* cultivation practices or agriculture were seen or reported. The management intensity index for *maax ik* in San Bernardo was 5.00 (Table 2).

**Table 2.** Management practices of *maax ik* plants performed in 42 homegardens in a small rural Mayan community of the Yucatan. When the management complexity degree (MC) was = 1, it means that the fruits were haphazardly gathered and when this value was = 2, it indicates that these practices were non-selective. The proportion of informants (proportion) that perform a given practice is also shown. Management intensity (MI index) is the sum of the product of MC x proportion for each management practice.

| | Management Practices | | | | |
|---|---|---|---|---|---|
| | **Gathering** | **Tolerance** | **Protection** | **Promotion** | **MI Index** |
| **Management complexity degree (MC)** | 1 | 2 | 2 | 2 | |
| **Informants performing the practice (proportion)** | 1 | 1 | 0.31 | 0.69 | |
| **MC x proportion** | 1 | 2 | 0.62 | 1.38 | 5.00 |

*Uses of* maax ik. During the study, *maax ik* was exclusively used as food in San Bernardo. According to most informants (90 %), the fruit of *maax ik* was available during most of the year, except during the harshest part of the dry season (March-May). Most informants (53 %) consumed *maax ik* every day of the week when it was available. This high frequency of use was due to its availability in the proximity of the house as well as its versatility as food in the kitchen. The majority of informants (71.41 %) mentioned that they consume *maax ik* green. The consumption of whole fresh fruit is now rare (13 %) (Table 3). However, the informants reported that it used to be more frequent in the past, especially for men who would eat it with "pozole" (a soup made of maize) during milpa cultivation. Another form of preparation was as a sauce (mashed alone or seasoned with garlic, onion and salt; Table 3). This sauce is used to garnish a large variety of dishes such as eggs, pumpkin flowers, beans, pork, chicken or even alone on a tortilla with some salt. This sauce can also be seasoned with lard together with salt, onion, and garlic as mentioned above (Table 3). Sometimes the fruit is cooked with bitter orange and lemon, and seasoned with onion, garlic and salt and served as a soup (Table 3). Aside from its use in sauces or soup, *maax ik* peppers were also cooked or fried (*i.e.,* "frito" in Spanish) on the "comal" (a smooth, flat griddle typically used to cook tortillas, toast spices or sear meat) together with onions, salt and lard. Also, *maax ik* was sometimes ground after being toasted ("tamulado" in Spanish) and sprinkled on cooked food, fresh fruit (*e.g.,* oranges, mango) and vegetables (*e.g.*, carrot, cucumber, yam, beans) (Table 3). An advantage of this technique is that toasted, dried *maax ik* can be consumed all year long. A type of conserve was made by pickling the chili in vinegar, onion and salt (*i.e.,* "curtido" in Spanish) (Table 3).

The main motivation (mentioned by 53 % of informants) behind the frequent consumption of *maax ik* was the flavor and the fragrance it adds to several dishes. The fact that *maax ik* was available in the gardens was also mentioned as an advantage by 41 % of the informants. *Maax ik* was essentially a substance food resource (as mentioned by 95 % of our informants). However, if it were unavailable, 57 % of informants mentioned that they would ask the neighbors, who typically gave it to them for free. The use of *maax ik* as merchandise and its contribution to the cash economy of San Bernardo was negligible. Only one informant mentioned that they once bought *maax ik* in the neighboring city of Maxcanú, and that it cost 10 MXN pesos per ca. 0.1 kg (ca. 0.5 USD per 100 grams).

## Discussion

Our results clearly show that, as their ancestors did, our informants of San Bernardo are still gathering *maax ik* and practicing other forms of non-selective incipient management. These informants also use *maax ik* essentially as food, particularly as a spice to flavor and improve the aroma of a wide variety of dishes. The informants were aware that *maax ik* is reproduced by seeds and recognized the relevance of birds to seed dispersal. The main source of *maax ik* for our informants was their own homegardens, with its presence in this agroecosystem highly advantageous because the energetic cost of gathering in these agroecosystems was low. Although the management of *maax ik* was not selec-

tive, all informants regularly carried out two to four management practices consciously and unconsciously which, together with the fact that homegardens are near human dwellings, have led to a relatively high management intensity index. These topics are discussed in detail below.

The informants know that *maax ik* reproduces by seed and that birds are the seed dispersers. The homegardens of San Bernardo are the habitat of a diverse assemblage of birds (Villicaña-Hernández 2021). Therefore, their daily visits to *maax ik* could hardly go unnoticed. Bird seed dispersal of this pepper across its distribution range has been also described in the scientific literature (*e.g.,* Tewksbury *et al*. 1999, Cázares-Sánchez *et al*. 2005, Carlo & Tewksbury 2014). Even though our informants knew that birds could consume some peppers, they did not perceive birds as noxious animals. Instead, they recognized that birds were necessary to have *maax ik* on their land. This is probably an example of ecological rationality in the use NTFPs previously described for indigenous peoples, including the Maya (*e.g.,* Colding & Folke 2001, Toledo *et al*. 2008). Previous research in northern Mexico identified a spatial association between wild chile plants and perennials (*e.g.,* Murillo-Amador *et al*. 2015). The local people there were aware of this and used this knowledge to identify harvesting places (Perramond 2005, Bañuelos *et al*. 2008). However, our informants in San Bernardo did not perceive a similar spatial association between *maax ik* and any perennial. This agrees with previous observations in other tropical areas of southern Mexico (Latournerie *et al*. 2001, Kraft *et al*. 2013, 2014) and our own field observations in San Bernardo which suggest that spatial association of *maax ik* to inanimate objects (*i.e.,* stone walls, the house, and other buildings) is stronger and more beneficial in terms of growth and fruit yield than the association to woody perennials (Solís-Montero *et al*. 2023).

Homegardens were not only the main site from which *maax ik* was gathered, but also currently represent an important habitat of this plant in San Bernardo. Despite exhaustively searching for *maax ik* in the surrounding secondary tropical dry forest in San Bernardo, we did not find any *maax ik* plants there. This high frequency of *maax ik* in homegardens and other human-created habitats (*e.g.,* monocultures, urban and botanical gardens) was also supported by the specimens deposited in the local herbarium (Herbario-Fibroteca "U Najil Tikin Xiw"); in which, from 57 specimens collected in the state of Yucatán, the majority (62 %) were found in human-created habitats. However, the specimens were collected several years ago (1976-1996) and it is unknown if the sampling effort was similar in agroecosystems and natural vegetation. Therefore, more research on the topic is needed. Also, in other tropical areas of southern Mexico, wild chile plants have been found in milpa, homegardens and other agroforestry systems such coffee, cocoa and banana plantations (Melchor-Contreras 2014, Gutiérrez-Burón *et al*. 2020, Martínez-Acosta 2020, Pérez-Martínez *et al*. 2022). *Maax ik* was associated with milpa and homegardens even in the most remote memories of the informants. It is known that the Maya have managed the forest of the Yucatan Peninsula for millennia (*i.e.,* Maya forest garden; Ford & Night 2009). For a very long time, when preparing the land for milpa and homegardens, the Maya have left useful wild species standing (García de Miguel 2000, Toledo *et al*. 2008, Ford & Night 2009). Some of these wild species encountered favorable environmental conditions and became locally adapted to these human-created environments, despite not being the direct object of selective management (de Wet & Harlan 1975, Manzanero-Medina *et al*. 2020). *Maax ik ex*hibits a particular ecological strategy that resembles that of weeds (de Wet & Harlan 1975). Not surprisingly, other authors have called wild chile plants growing spontaneously in the agricultural habitats of southern Mexico as arvense or semiwild, to emphasize its affinity to human-created habitats (*e.g.,* Aguilar-Meléndez *et al*. 2009, Pérez-Martínez *et al*. 2022).

Although *maax ik* was only non-selectively managed *in situ*, the index of management intensity (IM) was relatively high (5) when compared to that of other species incipiently managed *in situ* such as *Psidum guajava* L. (IM = 1.62), *Amaranthus hybridus* L. (IM = 2.13) and *Stenocereus stellatus* (Pfeiff.) Britton & Rose (IM = 3.25) (González-Insuasti & Caballero 2007). This is because, in contrast to plants cited above which are managed in their natural habitat, *maax ik* was managed in homegardens which are intensively managed systems and represent an arena of strong plant-human interactions given their proximity with human dwellings (García de Miguel 2000, Galluzzi *et al*. 2010, Martínez-Ballesté & Caballero 2016). While *maax ik* was not always the direct focus of management, it was indirectly favored by some management practices (*e.g.,* watering) on neighboring plants or during routine cleaning activities conducted in the garden (weeding, tossing water used to wash dishes and clothes). The informants did not

**Table 3.** Ways of cooking *maax ik* as reported by 42 informants from San Bernardo, Yucatan. Preparation, main complementary ingredients and the frequency of mentions (n = 42) are also shown.

| Cooking technique | Preparation and complementary ingredients | Frequency of mentions (%) |
|---|---|---|
| **Fresh** | Fruit taken directly from the plant and eaten. Sometimes eaten with pozole* or tortillas and salt. | 12.9 |
| **Sauce** | Fruit mashed alone or with garlic and onion, sometimes seasoned with lard. | 1.4 |
| **Soup** | Fruit cooked with bitter orange or lemon, onion, garlic, tomato and salt. | 15.7 |
| **Toasted** | Fruit cooked on the comal** alone or with garlic, onions and/or pork lard. | 30 |
| **Toasted and mashed** | Fruit cooked on the comal** and then mashed and seasoned with bitter orange or lemon, garlic, onion, and salt. | 37.1 |
| **Conserves** | Fruit boiled with some vinegar, onion, and salt. | 2.9 |

*Pozole: hot soup made of maize.

**Comal: smooth, flat griddle

feel that *maax ik* needed any care, but the reality is that the incipient management practices carried out in homegardens, such as leaving plants standing, are sometimes done unconsciously and are often only noticed on careful observation (Jiménez-Rojas *et al*. 2019). Another factor that contributed to the relatively high values of management intensity is that some management practices, although incipient, were conducted by all (gathering and tolerance) or by a large proportion of informants (protection and promotion). The presence of *maax ik* in homegardens not only increased management intensity but, for the household's members, also decreased the energetic cost of gathering it. NTFPs available in homegardens such as *maax ik* were even more accessible to vulnerable people such as the elderly. This is relevant in some marginalized rural communities such as San Bernardo, where the massive emigration of the young has led to disproportionate demographic changes with the elderly becoming an increasingly important age-group of residents in these villages (Echeverría & Lewin-Fisher 2016).

No other uses of *maax ik*, besides as a food, were reported or seen during this study. Some ritual uses of *maax ik* such as the Call of the Rains (*ch'a chaak*), may have disappeared locally due to the abandonment of rain fed agriculture, particularly the milpa (Flores & Kantún 1997). We are aware that in other Maya rural communities of central Yucatan, *maax ik* was used as food for domestic animals (Arriaga-López 2020). However, this practice does not seem to have geographically extended into our study region. Previous studies have reported the use of wild chile as medicine (Bañuelos *et al*. 2008, Aguilar-Meléndez *et al*. 2021); however, this practice was not observed in San Bernardo during the study. The relatively recent incursion of allopathic medicine even in the most remote rural areas of Yucatan has probably led to a reduction in the use of medicinal plants, among them, *maax ik*. The long-term use of *maax ik* as food is not surprising. The flavor and aroma of this spice are deeply rooted in Yucatec cuisine (Balam-Canché 2018). Wild chile may become the preferred pepper over cultivated chiles during its fruiting season in some regions of Mexico, given its peculiar but appealing flavor (Perramond 2005, Bañuelos *et al*. 2008).

*Maax ik* did not contribute directly to the cash economy of San Bernardo, however, it may make an indirect contribution to the household economy. That is, chile pepper is consumed daily and, domesticated chiles can be relatively expensive (*e.g.,* habanero pepper costs ca. 5 USD per kilogram). This money can be saved and used to meet other

needs when *maax ik* from the garden is consumed. The lack of value chains in the commercialization of *maax ik* may at least partially explain the observed sustainable use of this resource in San Bernardo. The coexistence of profitable commercialization (up to 20-52 USD per kilogram; Villalón-Mendoza *et al*. 2013, Ramírez-Meráz *et al*. 2018) and destructive harvesting (branch cut and whole plant removal) with population decline of wild chile plants in northern Mexico, reinforce the notion that economic profitability may increase the risk of overharvesting wild chiles (Perramond 2005, González-Jara *et al*. 2011, Rivera-Lárraga 2022).

*Maax ik* is not only a crop wild relative, but also an important food resource consumed almost daily in the study area and across the entire country (Long-Solís 1986, Aguilar-Meléndez *et al*. 2021). Therefore, its conservation must be given the highest priority. In areas of central-northern Mexico and the southern United States where wild chile plants grow in association with natural vegetation, overharvesting should be reduced and the populations effectively conserved *in situ* by establishing natural protected areas (Tewksbury *et al*. 1999, Martínez-Torres 2007, Riordan & Nabhan 2019). A noteworthy example of this is the Wild Chile Botanical Area, established in 1999 in the Rock Corral Canyon in southern Arizona. It was the first specialized botanical area in the United States designated for the protection of a crop wild relative (Khoury *et al*. 2020). However, some crop wild relatives, like *maax ik*, are probably adapted to managed anthropogenic habitats, and thus, an alternative conservation strategy is needed (Goettsch *et al*. 2021). The conservation of plants growing in homegardens is a particularly big challenge because the protection of their habitat would be insufficient for conservation purposes. These plants heavily rely on traditional management practices performed by indigenous peoples (Altieri & Merrick 1987, Altieri *et al*. 1987). In this sense, conservation models involving local people and traditional management practices such as biocultural reserves or centers of traditional agriculture could be a more effective way of conserving these plants (Nabhan 1985, Salazar-Dzul 2019).

To conclude, *maax ik* is a type of chile that is highly tolerated in the homegardens of our informants of San Bernardo, Yucatan, where its fruits are regularly gathered by household members. In this habitat, other non-selective, incipient management practices such as protection and promotion are performed, often unconsciously. Given that homegardens are a managed system, it is not surprising that the management intensity of *maax ik* in this agroecosystem was relatively high. Current use of *maax ik* is mainly as a sustenance food resource. Homegarden owners in San Bernardo are aware of the importance of seed dispersal and the relevance of a sustainable gathering practice to guarantee the long-term availability of *maax ik* in their gardens.

## Supplementary material

Supplemental data for this article can be accessed here: https://doi.org/10.17129/botsci.3290

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