frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 19 August 2025
DOI 10.3389/fsufs.2025.1630643

OPEN ACCESS

EDITED BY
Pradeep K. Dubey,
International Rice Research Institute South Asia Regional Centre, India

REVIEWED BY
Lucía Alcalá,
California State University, Fullerton, United States
Maricela Correa,
California State University, Long Beach, United States

*CORRESPONDENCE
Francisco J. Rosado-May
francisco.rosadomay@gmail.com

RECEIVED 18 May 2025
ACCEPTED 31 July 2025
PUBLISHED 19 August 2025

CITATION
Rosado-May FJ, Caamal Itzá B, Cuevas-Albarrán VB and Mukul LB (2025) Key role of learning by observing and pitching in (LOPI) in the resilience of Yucatec Maya food systems: foundations for culturally sensitive extension programs.
Front. Sustain. Food Syst. 9:1630643.
doi: 10.3389/fsufs.2025.1630643

Key role of learning by observing and pitching in (LOPI) in the resilience of Yucatec Maya food systems: foundations for culturally sensitive extension programs

Francisco J. Rosado-May[1]*, Bernardo Caamal Itzá[2], Valeria B. Cuevas-Albarrán[1] and Loida Briceño Mukul[3]

[1]Universidad Intercultural Maya de Quintana Roo, Quintana Roo, Mexico, [2]Instituto Nacional de los Pueblos Indígenas, Yucatan, Mexico, [3]Baktun Pueblo Maya, Quintana Roo, Mexico

The biodiversity in traditional Yucatec Maya food systems is well known and documented. However, over time, more and more Indigenous farmers are incorporating inputs related to the Green Revolution, harming biodiversity, beekeeping, and changing the design and management of the food systems. Thus, traditional resilience and biodiversity are threatened. To understand whether the resilience and biodiversity of Yucatec Maya food systems are related to their cultural ways of learning, information was gathered using the Yucatec Maya method called tsikbal in four Maya communities. In each community, two collaborating farmers were selected: one had been farming for at least 20 years using only traditional methods, and the other had been farming, incorporating elements of the Green Revolution, for at least 10 years. The information was organized based on the seven features of a paradigm called Learning by Observing and Pitching In, which emerged from several studies on how children in Indigenous communities, mostly Maya, learn. The results suggest that traditional farmers keep high biodiversity in their food system because their decisions and actions are based on the same features learned in their childhood. Based on these results, it is possible to suggest that the resilience and biodiversity of Yucatec Maya food systems are explained by their cultural ways of learning and creating knowledge developed over time. When Yucatec Maya farmers introduce practices from other ways of knowing and adapt their local learning methods, the resilience and biodiversity of their food systems are negatively affected. These findings can be applied to extension programs to help transform broken Indigenous food systems.

KEYWORDS

Yucatec Maya, LOPI, ALI, indigenous ways of learning, extension programs, food systems transformation

1 Introduction

Food systems, in general, are responsible for over 30% of global greenhouse gas emissions, 70% of freshwater use, and 80% of land conversion, which makes them the main driver of biodiversity loss (Foley et al., 2011; DeClerck et al., 2023). However, food systems known as local, traditional, or Indigenous are based on high biodiversity, providing adequate nutrition and aiding climate change mitigation (Dannenberg et al., 2023; Kanter et al., 2023). According

to Food and Agriculture Organization of the United Nations (2024), traditional food systems in Mexico are critical for conserving biodiversity and supporting nutrition.

Unlike conventional farming based on monocrops, the Maya food system is known for its high diversity of both crop species and varieties within the same species on the same plot (Fils Pierre et al., 2022). For instance, in a small town called Xoy, in the state of Yucatan, Mexico, Ku-Pech et al. (2020) registered that, only in the milpa subsystem, there were eight varieties of maize (*Zea mays*), 7 of a local bean called ib. (*Phaseolus lunatus*), four varieties of squash (*Cucurbita pepo*), and three varieties of common beans (*Phaseolus vulgaris*). Multicropping provides a higher potential for nutrient adequacy than conventional monocropping (López-Ridaura et al., 2021).

According to the literature reviewed by Toledo et al. (2007), there are between 2,500 and 3,000 plant species in the Maya forest of the Yucatán Peninsula. Approximately 900 of them are known to be used for different purposes. Home gardens may occupy from 500 to 5,000 m^2 and contain between 50 and 387 species, including plants and animals. The milpa system may have up to 50 plant species for human use. In addition, the Maya people produce honey and other products through beekeeping practices that include European and stingless bees, as well as hunting and fishing. Approximately 24 animal species have been documented in their hunting practices. In communities with water bodies, 14 fish species have been recorded, mostly for food, and a few species of small turtles and crocodiles.

However, not all Indigenous or local food systems retain their traditional design and management. A recent study showed that the percentage of Maya farmers in the Yucatán Peninsula who still maintain their food systems using their traditional techniques (TR) has been slowly declining (Rosado-May et al., 2025a). In 2020, this group represented 26% of farmers, decreasing slightly to 25% in 2023. In contrast, the proportion of Maya farmers using components of the Green Revolution (GR) has been increasing from 50% in 2020 to 51% in 2023. The remaining percentage, accounting for 24% of farmers in both years, represents those exclusively using GR technologies.

The change in the way of production using GR components has a negative impact on the biodiversity of food systems, as well as on soil and water, including social inequalities (John and Babu, 2021; Pingali, 2012). According to DeClerck et al. (2023), agriculture is the largest single source of environmental degradation and the single largest driver of biodiversity loss. The majority of food production systems in the world are widely considered unsustainable, demanding the transformation of how food is produced (Dubey et al., 2020; Meadu et al., 2023). This trend needs to be reversed.

2 Transforming food systems via extension programs

Interventions on training and extension, seeking to transform food systems, have followed different methodologies and approaches. On the one hand, extension programs have been used to transform traditional systems by incorporating components of GR; on the other hand, they have been used to transform conventional GR systems by incorporating elements of sustainable systems such as agroecology (Landini and Beramendi, 2020). In Mexico, the classic concept of extension, described by Landín-Alcántar et al. (2019), is considered a system of assistance and education to improve yields. Gallardo-López et al. (2022) studied the role of rural extension workers in Mexico in the process of agroecological transition of food systems located in rural areas. Their results indicate that extension programs that promote the use of GR techniques persist.

Extension programs, as instruments for transforming food production systems, are practices that have been implemented for many years. De Janvry et al. (2016) describe the ways in which the practice is carried out: from training and visits, farmer field schools, extension and advisory service systems, and extension as part of the value chain, to the need to consider the way in which farmers learn. On the other hand, Swanson and Rajalahti (2010) identified the following extension models: the technology transfer model; participatory approaches; market-oriented approaches; and non-formal education/extension approaches.

Even though de Janvry et al. (2016) agree with Swanson and Rajalahti (2010) that farmers' learning methods are crucial for successful extension processes, they fail to specify how to implement this approach or identify the specific methods that must be considered.

According to Holt-Giménez (2006), in Latin America, farmers developed a movement of exchanging experiences to produce food away from Green Revolution components. Their methodology was later known as the campesino-to-campesino (farmer-to-farmer) exchange of knowledge. The farmer-to-farmer method has also been used to introduce non-local technologies; Nakano et al. (2018), for instance, documented this process in Tanzania.

Studying the introduction and expansion of sustainable agricultural practices in southern Africa and using the theoretical and methodological tools of cultural historical activity theory and critical realism, Mukute and Lotz-Sisitka (2012) examine three case studies. Their article argues that top-down knowledge transfer and bottom-up participation in extension programs lack a theoretical "bridge" and concludes that plural ways of knowing have become imperative in a society where "normal science" is not adequate to deal with the complexity of present and future development. Although the authors do not describe in detail the ways of learning in any of the three cases studied, they identify five factors that shape how farmers learn: time and place, sociocultural background and work opportunities, economic and social capital, policies and budgets, and diseases such as human immunodeficiency virus (HIV) and acquired immunodeficiency syndrome (AIDS).

The above literature indicates (1) There is a need to transform food systems, indigenous or not, into more sustainable methods; (2) Extension programs are an important mechanism for promoting the transformation of food systems; and (3) It is critical to learn as much as possible about the ways of learning that farmers have, especially Indigenous farmers, to design innovations adapted to local conditions and contexts.

It is in this context that several authors (Antonelli, 2023; Kennedy et al., 2022; Martínez-Cruz and Rosado-May, 2022) point out the critical importance of incorporating Indigenous knowledge and ways of learning in discussions on how to transform unsustainable food systems, both at the local and global levels.

3 Indigenous ways of learning and LOPI

Indigenous ways of learning (IWL) is an area of research that has been growing in recent years. In the Americas, the majority of studies

on IWL focus on children (e.g., the special issue of the Journal for the Study of Education and Development, 2022, vol. 45), few on higher education (Jones Brayboy et al., 2015; López, 2013; Rosado-May et al., 2022), and even fewer on adult education (Schmelkes, 2011). Research on how to apply IWL in extension work in Indigenous communities is also very limited. Through a transformative convergent mixed methods design, Hartmann and Martin (2021) propose the following characteristics of a successful extension program in Indigenous communities in the US: the community goals should be at the center of the program, have an insider collaborator, and create culturally relevant programming and pedagogy.

One of the major motivations for research on IWL is the acknowledgment of different ways of learning and creating knowledge and that the world can benefit from opening spaces for different knowledges to coexist and participate in understanding and contributing to solutions to complex global and local issues (Bang et al., 2018), such as the transformation of broken food systems.

A growing body of scientific literature demonstrates that IWL rests on deep epistemological understandings that contrast with the assumptions and ways of learning that are often the bases of Western schooling (Bang et al., 2015; Rogoff, 2016; Rosado-May, 2016a; Rosado-May et al., 2020).

Although IWL has important commonalities across a wide variety of Indigenous communities in the Americas, the use of IWL, in the plural, does not assume that these complex processes are general to all Indigenous communities. Ways of learning in Indigenous communities may change over time and circumstances (Madjidi and Restoule, 2008; Rogoff et al., 2014) but participating in family endeavors seems to be constant and is critical in the learning process of Indigenous communities (Chavajay and Rogoff, 2002; Gaskins, 2003).

It is not unusual in Indigenous communities of the Americas to see children and youth engaging in household activities in ways that they are integrated into family and community social, cultural, political, and economic realities (Ames, 2013). Usually, children are not excluded from participation in collective events, even when that participation is intense, such as dealing with death and loss during moments of crisis or festivities (Gutiérrez et al., 2015). Thus, Indigenous children not only learn skills but also broader concepts about life itself and worldviews that are important in their community and in the broader contexts of Indigenous life (Chilisa, 2012). To Indigenous peoples, mistakes are part of a process that helps children become competent and respectful members of the family and community (Bolin, 2006). IWL articulates everyday life rather than dividing activities into isolated, sequential steps as in school-style teaching (Rogoff, 2014). Learning is generally productive for real purposes (Brayboy and Maughan, 2009; Paradise and Rogoff, 2009).

In 2014, Rogoff described the scientific evidence of the process of learning in family and community endeavors in Indigenous communities and identified two key elements: observation and participation. He proposed a model called Learning by Observing and Pitching In (LOPI). LOPI not only explains the learning process for Yucatec Maya children; according to Rosado-May (2016a) and Rosado-May et al. (2022), it also partially explains the learning process for Yucatec Maya university students.

LOPI identifies seven facets in the process of learning (Rogoff, 2014): (1) Community organization of learning; (2) Motivation; (3) Social organization of endeavors; (4) Goals of learning; (5) Learning occurs through wide, keen attention and sometimes with guidance; (6) Communication is based on coordination through shared reference in collective endeavors using verbal and nonverbal means; and (7) Assessment.

4 Research questions

The literature reviewed highlights at least two important, but not very conspicuous, elements that are critical in the process of transforming broken food systems.

The first element is that, although traditional Yucatec Maya food systems have been under strong pressure since the 1950s (Rendón Medel et al., 2015), there are still examples of resilience in adopting GR components via extension programs (Rosado-May et al., 2025a). What are the driving forces that explain this resilience?

The second element is related to the fact that the socio-economic, environmental, technological, and political contexts that shaped the Yucatec Maya food systems have originally changed drastically since the introduction of GR in the 1950s; these changes are still influencing the design and management of food systems and have led to an increasing percentage of systems abandoning the traditional ways of food production (Rosado-May et al., 2025a). This situation creates a need to develop innovative programs for the exchange of knowledge, either via farmer-to-farmer or via extension programs, with the objective of transforming broken food systems. Understanding the importance of culture, settings, context, proper communication, and differences in ways of learning, what are the specific and critical elements in the ways of learning among adult Yucatec Maya farmers? How can those critical elements be used in culturally sensitive extension programs for the transformation of Indigenous food systems in the Yucatán?

This research was conducted under the premise that the Yucatec Maya ways of learning, which are related to LOPI (Cervera-Montejano, 2022), are a critical factor that explains the resilience of Yucatec Maya food systems. The loss of local ways of learning is reflected in the loss of elements of sustainability, such as biodiversity, and affects the capacity for innovation (Rosado-May et al., 2020). Understanding the ways of learning by Yucatec Maya farmers will contribute significantly to designing effective, culturally sensitive extension programs aimed at transforming broken food systems.

5 Materials and methods

Three of the authors of this paper are Yucatec Maya by origin, and the fourth has lived with Maya people since childhood. Our ways of learning in childhood were closely tied to LOPI and food systems; through our formal government education, we frequently explored facets of LOPI. The researchers have a minimum of 15 years of experience working in Maya communities.

The methodology of this research was designed based on the arguments presented by Crouch et al. (2023) in relation to working with Indigenous elders. To avoid a colonial and de-indigenizing method when conducting research involving Indigenous Peoples, Crouch et al. (2023) advocate for the use of the two-eyes-seeing framework, culturally responsive participant observation, a

person-centered approach, and a community-based and tribal-participatory approach.

Regarding the application of culturally responsive participant observation, as described by Campbell and Lassiter (2015), the results reported in this research are based on a Yucatec Maya word called *tsikbal*. Tsikbal is often translated as conversation, dialogue, conference, or chatting; however, according to Rosado-May (2016b), the word tsikbal is a sophisticated concept that goes beyond the simple exchange of words. Tsikbal combines words with body language, manual action, constant practice, verification of results, and continuous feedback, all of which are critical aspects of a process that involves the development of a sophisticated skill of observation, transmission, and creation of knowledge in a community. Tsikbal is the operational and intangible part of a community process that, through the effective generation of knowledge, insights, and actions, guides its development. It is a keystone for innovations (Rosado-May et al., 2020).

From a non-Indigenous perspective, the word "research" refers to searching for knowledge. Tsikbal is a Yucatec Maya way of researching. The concept of tsikbal has been used successfully by Rosado-May and Poot Cahun (2020) as a research method to confirm the presence of sophisticated ecological concepts in Yucatec Maya thinking.

Based on the above interpretation, tsikbal, as a concept and methodology, includes the other two elements described by Crouch et al. (2023): a person-centered approach and a community-based, tribal-participatory approach.

5.1 Selection of participants

The following criteria were established to select Yucatec Maya farmers collaborating on the project. The idea was to ensure the highest quality of information gathered during interactions with the collaborators.

a) All collaborators must be of Indigenous Yucatec Maya origin.
b) At least 5 years of continuous interaction with any of the researchers. This ensures that a long-term trust has been established and there is mutual respect.
c) At least 20 years of experience in farming. Farmers using GR inputs should have been doing so for at least 10 years. Determining the number of years needed for an agricultural practice to be adopted is not easy; there are too many variables. Nevertheless, the number of years established in this study is based on the findings by Kuehne et al. (2017), who developed a model called ADOPT and determined that the peak time for adoption is 13.5 years, but the results of adoption can be seen much earlier.
d) From the same community, two participants were selected. One of them must not have used any input from GR technology, and the other must have been using GR inputs (e.g., fertilizers, pesticides) continuously for at least 10 years.
e) Based on the classification of the Yucatec Maya food system by Rosado-May et al. (2025a), participants not using GR inputs must have at least the following rainfed subsystems: a milpa (see Figure 1 for an idea of a traditional milpa), a home garden—including animals—and the use of the forest for collecting food, lumber, or medicine. It would be best if, in addition, the farmer engaged in beekeeping, either with local stingless species (e.g., *Melipona* spp.) and/or *Apis mellifera*. Participants using GR inputs could have at least one of the subsystems listed and may or may not use irrigation on their farms. The size of the land under food production is not considered critical.
f) All farmers should have land tenure security.
g) Willingness to adapt to the presence of the researcher while working in the field and to allow his/her active help in different activities, both in the field and in the community.
h) Farmers not using GR inputs must be recognized by the community as knowledge holders (in Yucatec Maya, the word is *nool iknal*).
i) Must be farming during the research period.
j) All collaborators must have Yucatec Maya as their maternal language. Although they could also communicate in Spanish, the language used in this research was Yucatec Maya.

Based on the above criteria, the farmers collaborating in this project were selected from the following Yucatec Maya communities (the geographic coordinates are in parentheses): Xpichil (latitude 19.695833, longitude −88.378056) and Xyatil (latitude 19.66233, longitude −88.44337) from the municipality of Felipe Carrillo Puerto (FCP); Tabasco (lat. 19.9771, long. -88.6850) from the municipality of Jose Maria Morelos (JMM); and Chacsinkin (lat. 20.93333, long. -89.66667) from the municipality holding the same name. The municipalities of FCP and JMM are located in the state of Quintana Roo, while the municipality of Chacsinkin is situated in the state of Yucatán (Figure 2). Notably, within each community, one farmer does not use GR inputs, whereas the other does. Thus, the total sample size was four farmers not using GR inputs and four using GR inputs.

The sample size used in this research was determined by the following considerations. Investigating the traditional food of Indigenous Peoples in Canada, Kuhnlein (2000) reflects on the difficulties of getting the right precision in the field, meaning the correct sample size. However, in the field, working with Indigenous communities, many unknowns prevent the estimation of a "statistically correct" sample size. One of these factors is selecting special collaborators who are recognized by their communities as knowledge holders due to their wisdom, experience, and successful transmission of knowledge. The number of farmers meeting these conditions is very low; there is a rapid loss of traditional knowledge by Indigenous Peoples (Crouch et al., 2023; Gómez-Baggethum, 2022; Reyes-García et al., 2013b), which is the case in Yucatec Maya communities. Selecting a sample size under the conditions described in this research is known as purposive sampling (Harris et al., 2009, based on Barbour, 2001, and Hoepfl, 1997), where there is a methodical way to find specific participants.

5.2 *Tsikbal* in action

The word tsikbal in Yucatec Maya is composed of two parts: *tsik*, which means to carefully break down what is being discussed—the details of the topic—and *bal*, which means the subject discussed in the interactions. Thus, the Yucatec Maya people are used to in-depth, detailed conversations to thoroughly understand a situation or a subject. During the tsikbal, the researchers were always aware that the

10.3389/fsufs.2025.1630643

FIGURE 1
Details of a Yucatec Maya milpa. Clockwise, **(a)** a collaborator from XYatil, JBWC, mentor of the lead author; **(b)** a collaborator from XPichil explaining his slash-and-burn technique before planting; **(c)** the lead author in his milpa; **(d)** an interior view of a milpa with the three sisters: maize, beans, and squash. Pictures by FJRM.

farmer collaborator might have other activities to take care of and that there could be pauses between conversations; if there was a need to clarify or to understand a subject much better, then the tsikbal continued at another time. It is a dynamic process; information flows in a continuum. Up to two researchers had a tsikbal with the same collaborator, especially when field activities demanded attention and help.

The results presented in this paper reflect more than 3 years of tsikbal between the researchers and the collaborators. This means that for food systems under annual cycles, e.g., milpa, there were three occasions to understand and confirm processes. For perennial crops, e.g., beekeeping, home garden fruits, or forest collection, there were three annual cycles for collecting and processing food. The following stages in each annual cycle of the food system, regularly followed by the farmers, were selected for visiting the field to collect information: planning, preparing the field, planting, managing the crops for weed and pest control when needed, harvesting, and post-harvest activities such as storing the harvest, exchanging with family or community, or selling. In each of these six stages, the researchers visited each community up to three times and had a tsikbal with each collaborator. In each visit, the researchers tried to fully understand the process and identify elements for each of the seven facets of LOPI.

There was no previous structure for the tsikbal; the conversations flowed freely; it was up to the researchers to organize the information gathered during the tsikbal based on each of the seven related facets of LOPI (Rogoff, 2014). The facets of LOPI are based on a community structure in which children—and/or adults—are included as contributors, like anyone else, in family and community endeavors (Facet 1). They are interested in doing their part (Facet 2). The organization of groups is also collaborative, with fluid coordination and initiative and leadership from children as well as adults (Facet 3). In LOPI, the goal of learning is for people to develop their skills, knowledge, and attitudes as contributors to family and community activities, with consideration and responsibility (Facet 4). Wide, keen attention and pitching in to ongoing events are key means of learning, along with guidance provided by other people and by community

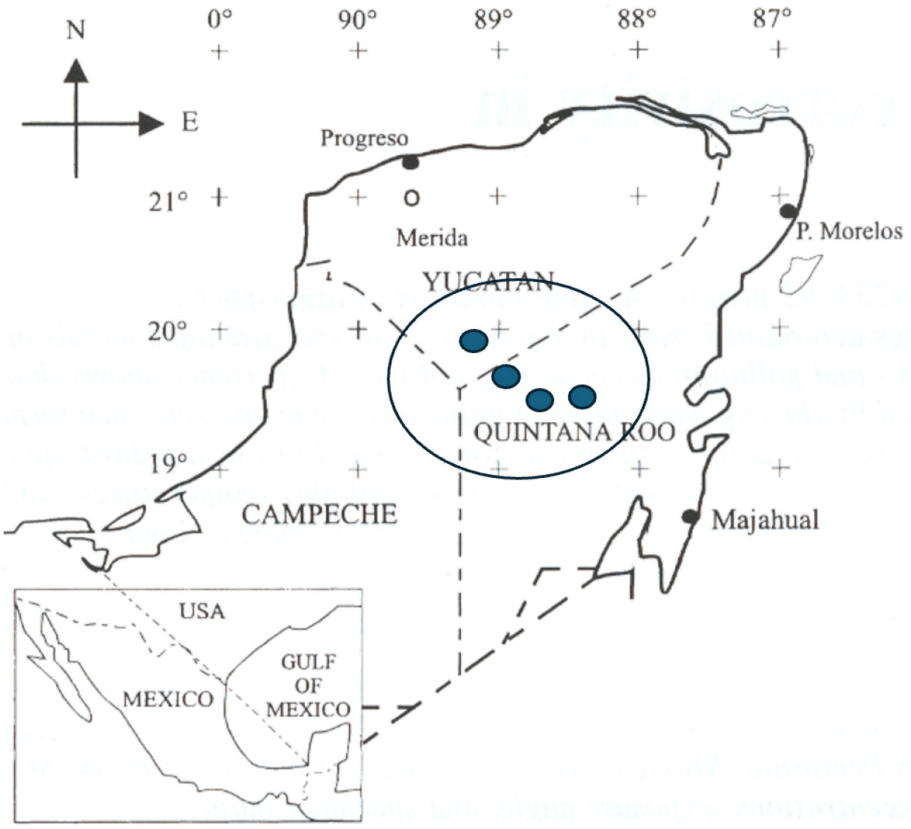

FIGURE 2
Study area, from left to right: Chacsinkin, Tabasco, Xyatil, and Xpichil Map based on: https://cuentame.inegi.org.mx/mapas/pdf/entidades/div_municipal/qroompioscolor.pdf.

expectations (Facet 5), and communication is based on the shared context of the ongoing activity (Facet 6). Evaluation of learning aims to improve learners' contributions within the activity's ongoing context, focusing not only on learners' contributions but also on how guidance and support can enhance learning and the success of the endeavor (Facet 7).

The information collected in the Tsikbal was processed as follows: During the first year, the objective was to gather and organize information based on the seven facets of LOPI; in the second year, the objective was to confirm, update, correct, and reorganize the information; and in the third year, the aim was to validate the information at the individual, community, and regional levels. The idea was to determine similarities or differences, if any, and to reach a consensus for each of the seven facets of LOPI and for each of the two types, TR and GR, of farmers.

After a tsikbal session, the researchers articulated the information in a paragraph that reflected an expression from a collaborator and organized it based on the facets of LOPI. The expression was confirmed through field observations, including hands-on experience by the researchers, and clarification with the farmers; the idea was to eliminate contradictions or misinterpretations in the conversations. Discussions among the researchers were based on successive approximations, which helped reach a consensus in paragraphs before presenting them to the farmers for validation. For each of the seven facets of LOPI, three paragraphs were constructed: one from conversations with the TR farmer, another from the GR farmer, and the third from observations *in situ*, on the farm and in the community. When two or more researchers participated in the tsikbal, the paragraphs from conversations and observations were co-constructed among them, reaching a consensus before being presented to the farmers for validation.

During the second year, the list of expressions and observations for each of the features of LOPI, created by the researchers, was confirmed or updated, again through tsikbal, in conversations and field activities.

In the third year, a process of validating each of the expressions and observations with each of the collaborators was implemented. In this stage of the research, the tsikbal was focused on each of the LOPI facets. This process took two steps.

The first step involved validating the expressions and observations obtained from each of the four TR and four GR farmers. To do so, the researchers created written expressions and observations that clearly expressed the thinking and actions of each of the farmers in each of the communities. The expressions and observations were then validated through tsikbal with each collaborator. This was an individual validation of the expressions constructed by the researchers. The structure of each expression was designed under the principle of culturally pertinent communication.

The researchers studied each of the validated expressions for each facet of LOPI and from each of the two groups of farmers. They created a culturally relevant single expression that reflected all four TR and GR farmers. This single expression, from each facet of LOPI and

each of the two groups of farmers, was then taken back to the farmers for validation. The idea was to determine whether there was a consensus for each expression in each facet of LOPI across communities for each group of farmers. This was the second step in the validation process.

6 Results

Two Yucatec Maya farmers were selected in each of the four communities chosen, and all met the criteria established in the methodology. One of the farmers in each community has maintained traditional farming practices (TR) for at least 20 years, while the other has utilized Green Revolution (GR) inputs for at least 10 years. Table 1 shows the typology of the food system from each of the farmers selected; the following is a description.

6.1 Typology of the food systems

Indigenous TR farmers have between 3 and 4 systems (milpa, home garden, forest, and/or beekeeping), whereas the GR farmers have between 1 and 2 systems. The average number of species planted is 191 for TR farmers and 9 for GR farmers. The number of varieties cultivated for each staple food was 5, 3, and 2 for maize, beans, and squash in the TR food systems. In contrast, for the GR systems, the number of varieties cultivated was 1, 1, and 0 for maize, beans, and squash, respectively. The average number of species tolerated, not planted, including animals, was 130 for TR food systems and 3 for GR systems. High biodiversity is an intrinsic feature of TR farming, whereas, for GR farming, it is the opposite. The data support the idea that the ways of learning and creating knowledge explain the decisions and actions behind the design of the structure and function of the food system.

The following describes the expressions and observations validated at the individual and regional levels for each of the two types of farmers, categorized by seven facets of LOPI. The paragraphs presented in many of the seven facets are written in first person but reflect the collective perception. In other facets, the paragraph is written in the third person. This approach enabled effective and culturally pertinent communication, as evidenced by Manzini's (2003) findings, when presenting the findings to the farmers and ensuring the right perception in the validation of the paragraphs. The decision of using first or third person in the texts depended on the facet. There are two explanations for this decision. First, in Yucatec Maya, the word I (*teen*) and the word us (*to'on*) are closely related, which could explain the effectiveness of using paragraphs in the first person; the context is important. Second, depending on the subject, a Yucatec Maya farmer is more comfortable with an expression in the first person because the subject might seem more personal and does not affect other people's opinions; the use of a third-person expression is used when there is

TABLE 1 Typology of the food systems from each collaborator.

Indicators	Communities							
	Chacsinkin		Tabasco		Xyatil		Xpichil	
	TR	GR	TR	GR	TR	GR	TR	GR
Food systems	Milpa HG Forest Bee keeping	Milpa HG	Milpa HG Forest Bee keeping	Milpa HG	Milpa HG Forest	Milpa HG	Milpa HG Forest Bee Keeping	Milpa
No. Spp. planted, not considering animals or insects.	Mi-9 HG-47 Fo-0 Be-3	Mi-2 HG- 12	Mi-10 HG-39 Fo-0 Be-3	Mi-1 HG-10	Mi-9 HG-53 Fo-0	Mi-2 HG-8	Mi-11 HG-58 Fo-0 Be-3	Mi- 2
No. of varieties of staple food planted	Maize-6 Beans-3 Squash-2	Maize-1 Beans-1 Squash-0	Maize-4 Beans-3 Squash-2	Maize-1 Beans-1 Squash-0	Maize-5 Beans-2 Squash-2	Maize-1 Beans-1 Squash-0	Maize-4 Beans-3 Squash-2	Maize-1 Beans-1 Squash-0
No of Spp. used, tolerated, not planted, plus animals and insects	Mi-14 HG-7 Fo-82 Be-6	Mi-3 HG-0	Mi-17 HG-9 Fo-94 Be-9	Mi-0 HG-0	Mi-17 HG-7 Fo-97 Be-13	Mi-0 HG-0	Mi-19 HG-11 Fo-104 Be-13	Mi-0
Area under management	Mi-1.0 ha HG-0.25 ha Fo-4.0 ha Be- 0.25 ha	Mi-2.0 ha HG-0.08 ha	Mi-0.5 ha HG-0.3 ha Fo-5.0 ha Be-0.25 ha	Mi-3.0 ha HG-0.08 ha	Mi-1.0 ha HG-0.75 ha Fo-5.0 ha Be-0.25	Mi-2.0 ha HG-0.08 ha	Mi- 1.0 ha HG-0.25 Fo-5.0 Be-0.25	Mi-2.0 ha
Age group	50–60	40–50	40–50	40–50	50–60	50–60	50–60	40–50
Years of formal schooling	5	12	7	9	0	9	0	6
Years of farming	> 20	≥ 10	> 20	≥ 10	> 20	≥ 10	> 20	≥ 10

more certainty of coincidence with other people. When a paragraph is taken from a direct expression by one specific collaborator, an acknowledgment is given by using the initials of the source at the end of the paragraph.

6.2 Facet 1: community organization and learning

6.2.1 Expression TR

The hardest work in the milpa, such as felling, burning, and sometimes harvesting, is done with the help of friends and family. We are in constant communication. Until a few years ago, all the farmers in the community helped each other; nowadays, only a few of us do. In those times, young people joined the work motivated by the opportunity to learn because they were in the process of having their own milpa; nowadays, very few want to farm. I have a support network; I know when I need help and who can help me, and I know when to support my friends or relatives with the fieldwork. To date, this way of working has been good for me.

I started learning the way we work during childhood. That is how our parents and grandparents did it as well. From the age of 6, I would wake up at approximately 4:00 am, drink *atole* (a thick maize-based beverage), walk to the milpa, and work hard until the sun was too strong. Through this routine, I learned how to work with others to produce food. My father allowed me to accompany him when he worked alone or with other men; no one objected, they accepted me, and some even gave me advice. When relatives or friends are unable to help, the family takes on the activities without complaint and with enthusiasm; everyone participates because we all share in the meal. So far, we have been able to produce enough food for the family, our animals, and a little to sell.

6.2.2 Expression GR

Working in the milpa is very demanding. In my case, I have to pay wages, and I cannot do it alone; it is too much. Unfortunately, not only are there few people willing to work in agriculture, but they also often do not perform their tasks effectively. There is a lot of irresponsibility. That is why I have to use agrochemicals to reduce labor, make enough to pay the workers, and still have a profit. When I was a kid, I accompanied my father in the milpa, but because I also went to school, I was not forced to work in the field with him. I learned to farm the land anyway. Currently, I have another job; I do not depend solely on the milpa.

6.2.3 Observation

According to Rosado-May et al. (2020), the Yucatec Maya developed a concept called *iknal*, which refers to the space that community relationships create to be able to exchange goods and knowledge; thus, a community creates conditions to ensure that new generations have good knowledge of what needs to be done. Unfortunately, iknal has been changing; it used to work for the entire community, but nowadays it seems to work only for part of it. An increasing number of cases suggest that iknal does not exist, even within some families. The social fabric in the community and the connection with nature, both glued by iknal, as in the case of food systems, are disappearing.

6.3 Facet 2: motive

6.3.1 Expression TR

Why do my friends, family, and I work together in the field? We have an obligation to feed our families and animals and to share food and seeds with other people in the community. Through mutual aid, we not only produce food but also strengthen our support network and our community. When working together, we learn from each other; young people learn values and respect that relate to each other and with nature, both tangible and non-tangible components. That is why we also involve the youth in spiritual offering activities. Work and collaboration bring peace to the community, so our children can grow up well and with respect. We know that by working together, we demonstrate our knowledge in practice, thus earning the respect not only from our family but from everyone in the community, whether in the milpa, hunting, or at home.

6.3.2 Expression GR

Farming is a way of life that provides us with food and other essentials, such as sending our children to school. There is not much else to do in our community—no industry, no tourism—so I attempt to do well in farming. I would like my children to have a better life, one that does not depend only on traditional farming, because sometimes there is good harvesting, and other times, we barely make it.

6.3.3 Observation

There is a clear difference between the TR and the GR farmers in understanding the role of food production in the community; both have different motives and visions on how best to achieve good farming. This difference in vision reflects the values that guide the activities of each farmer in the community. An intangible situation is developing with these differences in values; on the one hand, with TR farming, there is a greater likelihood of identifying great knowledge to transform the food system; on the other, with GR farming, the communities are facing high economic costs and increasing possibilities of negative impacts on the environment as well as creating conditions for substituting their traditional knowledge. There are already conflicts, small ones so far, in which the use of agrochemicals is harming beekeeping. It appears that TR farmers, with their diverse range of practices that underpin the community's social fabric, have a long-term vision, whereas GR farmers focus on immediate results and outcomes, often overlooking community processes.

6.4 Facet 3: social organization and endeavors

6.4.1 Expression TR

When we work with several people, whether related or not, we do not feel like a boss is telling us what to do. We do know that one of us knows more than the others about something specific, such as how to corner a deer when hunting, how to cut down a hardwood tree, or how to manage the fire well when burning the field before planting. A knowledgeable person shares knowledge by doing, not by ordering or supervising. The rest of us know that we must be attentive, observing details carefully, and practice what we learn until we master the task and perhaps develop a way to do it better. This is how we adapt to new

conditions, in nature or in the community, and pass on new ways of doing things. The work comes out naturally and flows well without a boss, supervision, or payment; everyone knows what to do, and there is confidence that everyone will do his/her part well. We like this way of working.

6.4.2 Expression GR

I organize the work myself and decide when and how each task needs to be done, such as planting, applying fertilizer, and using herbicides. If I let the workers take the initiative, it might not go the way I want, so I have to give them instructions as detailed as possible. I do this because they lack the knowledge to handle hybrid seeds or agrochemicals. Sometimes I make sure they listen to an extension agent's presentation so they understand what to do with the crop; my goal is to use inputs more efficiently.

6.4.3 Observation

Field observations indicate that the social organization of work in the traditional system is more cordial and flows more smoothly. Despite the hard work, participants appear relaxed. In the system that uses agrochemicals, workers do not seem to feel committed; they do it for the wage. There are cases of tension over late payments or complaints from the boss because of poor work.

6.5 Facet 4: goal of learning

6.5.1 Expression TR

I like working with my support network, friends, or family for several reasons. Besides easing the workload and allowing us to produce enough food for our needs, it is also the best way to learn things and to maintain unity within the family and with the community we are part of. We talk in the park and at home, but there is nothing better than doing things to test whether what we talked about is the best way to do a particular thing in the field. Because I am continuously learning, I can teach my children new things. I have heard that many people who come from outside, from universities, from the city, students, and sometimes foreigners, are surprised by how I can keep everything running smoothly: the milpa, the home garden, my bees, going to the forest, hunting, my animals, and so on. Yes, it is a lot of work, but one thing I have learned from my elders and try to teach my children is the importance of thinking hard, observing, and finding ways to accomplish a lot and a little at the same time. Having a diversity of plants and animals is beneficial; growing only one type of plant or animal requires more time and work. You also need to consider not harming nature or disturbing the true owners (spiritual beings) of the forest; instead, you should acknowledge them and make offerings.

6.5.2 Expression GR

I like working in the fields, where I amm learning to improve my skills and earn a bit more money. I take courses and workshops, talk to agronomists, attend demonstrations, read, and try to practice what I learn with my workers. I like to see healthy, strong plants and animals, and I think about what buyers are looking for. I have also read and heard about the negative effects of agrochemicals; I know that some people in other communities have been poisoned by their excessive use. I am careful; I have no choice. I hope that someday we'll have alternatives to agrochemicals while maintaining or improving production, since fewer and fewer people are producing food.

6.5.3 Observation

The goals of each group of farmers, TR and GR, are very different. The first group's thinking is dominated by the search for and harmonious coexistence with their network, their family, and nature; the second group's thinking is dominated by commercial purposes. When farmers in the first group think about the next cycle, they do so by thinking about what they must do to ensure they produce enough food to satisfy the needs of their family and animals and to share or sell some with the community, but without affecting nature or having to depend on the government, as Rosado-May et al. (2025a) have reported. Another expression that represents the way of thinking that guides decisions and actions by the Maya of Yucatan is "we nurture nature because nature nurtures us" (Rosado-May et al., 2023).

In a secluded conversation about learning, one farmer said, roughly, "When I was young, it caught my attention that my father and grandfather handled many forms of food production: milpa, beekeeping, hunting in the forest, and the home garden, and they had time to help friends. How did they manage to do it all so well, allowing us to have a good life? Over time, I realized that my elders had a gift; what they did was not magic; it was part of their identity, their way of being. It is the gift of ubiquity. This gift is developed through practice, observation, and the continuous search for how to do things simply but better and efficiently. It is the gift of knowing how to organize time and space; everything should be in its place and at its proper time. My grandfather and my father worked the milpa well into old age; they continued to farm the land. Their wisdom consisted of how to do things that did not require so much labor; that is, time and space management applied to life and food production (JBWC). This is probably the essence and objective of learning among the Maya of Yucatán, but it is not visible.

There is another important but hidden issue embedded in the findings related to facet 4. The goal of implicit learning is to learn how to learn. In sharing her initial years of research in Guatemala, Rogoff (2012) cites an expression she heard from mothers when asked how they teach their children to weave; their reply was "I do not teach them to weave; they learn" (p. 234). In adulthood, amongst TR farmers, learning is an ongoing process; the expression found in this research that reflects the process is "I do not teach, I share my knowledge." In both expressions, knowing how to learn is the key to successful knowledge transmission, and it is a cultural community process, which is rarely acknowledged and encouraged, unfortunately.

6.6 Facet 5: means of learning

6.6.1 Expression TR

How did I learn what I know about the milpa and other food systems? Well, it is still ongoing; learning never ends. My father took me to the milpa for the first time when I was 6 years old. I wanted to go because I heard stories from my father and other people about the milpa, the animals, and the forest, and because it is delicious to eat the produce of your hard work. My father was not a person who talked much. Over time, I realized that the most important thing to learn was observing and practicing, which I complemented by listening to comments from adults and the games we played in childhood. My

father, my mother, or some other adult advised us, guided us, and sometimes scolded us.

As adults, we continue to learn, keep using observation, practice, and tsikbal. We learn from each other; learning is a collective, communal process. This is how we have managed not to survive, as some people say, but to successfully adapt to changes in climate, politics, and governments, and keep moving forward. We do not believe that learning involves errors but rather accumulating experience. In Yucatec Maya, we use the word *kaxan* to mean both "seeking" and "finding." This means that we have a continuous search for answers that allow us to adapt to different conditions. For us, finding something is only part of a continuous "seeking" process, which is why we use the same word.

6.6.2 Expression GR

In my case, I attended school from kindergarten to high school, but I also took various courses to learn a professional activity, in case I needed it in life. That did not allow me to spend much time with my father or grandfather in the milpa. At school, I learned to read and write, and after many years, I realize that memorization and individual work dominated my learning style; my teachers were my learning models. At school, we rarely discussed farm work, community, or family life, as these topics were unrelated to our community context. We did not have a library, and in those years, we could not even imagine the internet. I know many things that farmers who did not go to school do not know, but I recognize that they know things about farming that I do not.

6.6.3 Observation

In Yucatec Maya, the word "search" (*kaxan*) is the same as the one used to say "find." This has been interpreted as a reflection of a long-standing cultural process of continuous searching for answers (Rosado-May et al., 2020) that has allowed traditional farmers to adapt to changes in environmental, social, and political contexts, as well as in government program conditions. The word "kaxan" loses its logic and epistemological support when non-local education processes are forced to distinguish between "seeking" and "finding." The way of thinking behind the word "kaxan" is absent in formal education, which could explain why many farmers stop innovating by themselves and rely more on external help, such as extension programs. The more years a farmer has been exposed to formal education, the more effect it appears to have on the traditional ways of learning.

6.7 Facet 6: communication

6.7.1 Expression TR

Our basic, yet effective, form of communication is through what we call tsikbal. We engage in conversation, listen attentively, test their statements, and observe their behavior to ensure that the actions of the person providing information align with their words. We also examine their eye contact and body language to verify their honesty and consistency in their actions. Sometimes we have to discuss the same topic repeatedly until all participants understand it correctly and no one gets upset. When I reflect on how my father manages our family's food system and compare it to my approach today, I notice changes, such as the use of different crop varieties obtained through seed exchanges with other farmers. I have tried planting sweet potatoes to control weeds, following the success of another farmer. All of this is not only about adapting to changing conditions but also about sharing knowledge. For efficient exchange of seeds and knowledge, we need to get along with each other in the community and continuously use the tsikbal, especially with our children and young people. Many of us are not big talkers; we speak through actions when we are doing things, whether at home or in the field. Our children watch and learn by doing. We do not need to talk much; on the one hand, a certain look or a body movement reinforces what one says in words, even if they do not talk much. On the other hand, the people listening, whether children or adults, know how to interpret actions, words, or movements of the person talking.

6.7.2 Expression GR

How I learn and how I share my knowledge efficiently with my children or adults have one element in common: the ability to read and understand texts. Sometimes we listen to extension agents when they explain the use of an input, or sometimes we seek advice from government people; all is mostly oral, with very little information to read. With my workers, I verbally explain what they should do; sometimes I teach them in practice, and when I do, I do not consider it necessary to repeat the same activity twice. We are adults; we should be able to understand, pay attention, and do things well in the field.

6.7.3 Observation

The farmers' responses are almost diametrically different. TR farmers share cultural elements that make communication efficient, flexible, multidirectional, and fluid. On the other hand, farmers who use RG inputs do not have fluid or effective communication with their workers; it is more unidirectional from the owner to the workers. There are clearly different cultural elements in learning. Reading and receiving training from one person offering information who, it is assumed, knows more than those listening, clearly contradicts the local form of tsikbal.

6.8 Facet 7: assessment

6.8.1 Expression TR

We believe that the best way to assess our work in our farming is knowing that we are bringing home enough food, that we have what we need, that we are living peacefully within our families and with neighbors in our support network, and that our children who want to study can do so. It is not easy; we have to face challenging moments in farming, such as the felling and burning of the milpa, as well as climate change and pressures on land distribution and government programs. Since last year, the government has been giving free fertilizer and hybrid seeds, but I do not like using them. I prefer what I know and understand well; my traditional way makes me feel that my chances of failing are reduced. When I say being at peace, I am referring not only to the absence of conflict between people but also between people and nature. That is why, before farming and after the first harvest, we do offerings to the spirits.

6.8.2 Expression GR

The way I know whether or not I am doing a good job farming is the income after covering production costs. With that income, I can meet my family's needs, buy things, and ensure my children can attend

college. To date, I have achieved all of that, so I am sure I have done my job well.

6.8.3 Observation

The above expressions are two almost opposite descriptions of how to measure success. Behind each of them, although different, are values driving decisions and actions. Understanding these ways of thinking allows us not only to understand the processes behind food systems among the Yucatec Maya but also how to design interventions to support necessary changes. TR farmers recognize that their yields have been declining and could be improved, but they are unable to do so without using agrochemicals; they need assistance.

On the other hand, GR farmers are aware of rising costs and potential environmental problems caused by using agrochemicals. They would like to stop using them without sacrificing yield, but they need help to do so. In both cases, there is open space for the incorporation of scientific knowledge in co-creating solutions with local knowledge. Thus, a new way to measure the performance of food systems would be through advances in transforming food systems into more sustainable ones, meeting the needed yields.

7 Discussion and concluding remarks

Table 1 shows that the biodiversity in food systems under TR farming by Yucatec Maya peoples is considerably higher than food systems under GR influence; the data support reports from several authors (Dannenberg et al., 2023; Food and Agriculture Organization of the United Nations, 2024; Toledo et al., 2007).

The biodiversity in TR Maya food systems is the result of centuries, as suggested by Fedick et al. (2024), of a practice incorporated in the design and management of their food systems. This practice can be explained not only by the experiences and innovations accumulated over the years but also by an efficient system of learning, creating, innovating, and transmitting knowledge from one generation to the next (Rosado-May and Poot Cahun, 2020; Rosado-May et al., 2020).

The process of creation, innovation, and transmission of knowledge starts with learning, which begins in childhood and continues in adulthood. Decisions and actions by adults on their food systems could be explained by the effect of childhood education, by the influence of adult education programs, or by a combination of both. In this context, it has been well established that the type and quality of childhood education affect well-being and development in adulthood (Edosomwan, 2016; Reynolds and Ou, 2011).

On the other hand, there are studies on the integration of Indigenous knowledge into adult education practices, considering learners' learning needs and their experiences (Assefa, 2021), or the role of culture in adult Indigenous language learning (Troughton, 2023), or the importance of incorporating the gender perspective in adult education for Indigenous people (Rao and Robinson-Pant, 2006). In reviewing the educational situation for Indigenous peoples in Latin America and identifying the historical, structural and institutional barriers to greater involvement in adult education, Schmelkes (2011) proposes to look at Indigenous demands on education as a potential way out of the educational stagnation of Indigenous adults and emphasizes that there must be an active participation of Indigenous peoples 'themselves in the process of designing and implementing innovative ways in education for young and adult populations.

Some of those adult education processes could substitute elements of the Indigenous culture, leading to traditional knowledge loss among contemporary Indigenous societies (Reyes-García et al., 2013a), including biodiversity (Wilder et al., 2016). For the Maya, the loss of biodiversity may affect the traditional processes of ecosystem appropriation (García-Frapolli et al., 2008), loss of nutrition (Becerril, 2013), loss of food security (Gutiérrez-Carbajal et al., 2019), or even losing opportunities for community-based conservation of biodiversity (Reyes-García et al., 2013b).

According to Rosado-May et al. (2020, 2025b), the resilience of Yucatec Maya food systems rests on processes of innovation carried out by the farmers. The constant creation of varieties adapted to environmental or social changes is evidence of innovation; it involves ways of learning, creating, and transmitting knowledge based on the cultural identity of the farmer. An in-depth study demonstrated that Yucatec Maya TR farmers create knowledge through learning new things using the seven features of LOPI used during their childhood (Rosado-May et al., 2025b). These local methods served as a foundation for learning new techniques to accelerate the development of a new local maize variety (*Nal Balam*), distinct from hybrids, in collaboration with a CIMMYT scientist. The study demonstrated that the Nal Balam variety is the result of a process called "intercultural co-creation of knowledge," because two different cultural ways of creating knowledge (science and local) worked together successfully; the study also showed that a successful intercultural co-creation process requires a previous step called intra-co-creation of knowledge (Rosado-May et al., 2025b). Intracultural co-creation of knowledge refers to the process in which two or more people from the same cultural background collaborate to create new knowledge.

When compared to the description of each of the seven facets of LOPI, it is possible to note strong similarities with key features of the TR expressions (Table 2). Although both the facets and their description are the results of several studies on Indigenous children's ways of learning, the description provided by the TR farmers coincides with the LOPI paradigm. The interpretation is that Yucatec Maya ways of learning in childhood are kept and used during adulthood by those practicing TR farming.

Organized by each facet of LOPI, Table 2 compares the description by Rogoff (2014) and Rogoff and Mejía-Arauz (2022) with key features found from expressions of adult TR Maya farmers. The following exercise involves articulating childhood learnings with adult practices in the context of LOPI. Facet 1, community organization of learning: In both cases, the participants are incorporated in the endeavors and contribute. Facet 2, motive: In both cases, the participants contribute willingly, with no expectation of payment; there is a sense of accomplishing tasks and reinforcing community values. Facet 3, social organization of endeavors: the participation is flexible and flows naturally; there is leadership by elders, but not a leader directing actions. Facet 4, goal of learning: learning to learn values and skills, and increasing the possibilities of passing on solid knowledge to future generations. Facet 5, means of learning: developing skills of sharp and holistic observations, practicing new learnings, and sometimes getting guidance from the community, especially in observing traditional family values. Facet 6, communication: there is a shared reference in collective

TABLE 2 Description of each facet of Learning by Observing and Pitching In (LOPI) in relation to findings from TR Yucatec Maya adult farmers.

Facet	Description from Rogoff (2014) and Rogoff and Mejía-Arauz (2022)	Description from this study
1	Community organization of learning: Learner is incorporated and contributing to family/community endeavors	Farmers are organized in groups that help each other. Young people are welcome to join and learn how to farm and work in groups.
2	Motive: learner is eager to contribute and belong, to accomplish an endeavor (and maybe to guide).	Everyone in the group contributes to producing food for their families and animals and for keeping traditions and values.
3	Social organization of endeavors: collaborative, flexible ensemble, fluidly coordinating and blending ideas, agendas, and pace; all engage, and anyone may take the initiative.	There is no formal boss or supervision when working as a group; everyone knows what to do and how to do it. Young people learn by observing and practicing how more experienced people work.
4	Goal of learning: to transform participation, learn considerations and responsibility along with information and skills, and to contribute and belong in the community.	To ensure good production of food, foster strong social relationships, and care for nature. Good learning increases the possibilities of passing on solid knowledge to new generations.
5	Learning by means of: wide, keen attention and contribution (current or anticipated) to events, with guidance from community-wide expectations and sometimes people.	How to produce food in adulthood is closely related to the learning in childhood. It is with sharp and holistic observations, close attention to how experienced people do things, practicing, and always observing the traditional family values.
6	Communication is based on: coordination through shared reference in collective endeavors, using nonverbal (and verbal) conversation; narratives and dramatizations.	In adulthood, the best communication tool is called tsikbal in Yucatec Maya. Tsikbal, as a concept, articulates verbal and non-verbal conversations and uses examples, visits, observations, and trials to confirm information. Tsikbal is fluid and multidirectional.
7	Assessment: appraises both the learner's mastery and the supports that are provided to aid the learner's contributions during the endeavor; feedback on the adequacy of contribution (and its acceptance or correction).	The food production in itself, along with the conservation of the environment and keeping traditional values, are the indicators used in the assessment of farming. In between planting seasons, there are periods of exchange of experiences that could lead to innovations for the next season.

LOPI is the result of studying how Maya children learn.

endeavors through the use of tsikbal, a Yucatec Maya concept that articulates verbal and non-verbal conversations and uses examples, visits, observations, and trials to confirm information. Tsikbal is multidirectional. Adults use tsikbal in more advanced ways than children. Facet 7, assessment: Achieving the goals of endeavors, as well as the support and feedback provided in the process, is critical in the assessment. In adulthood, this means producing enough food to meet the family's needs, including those of animals, and sharing some with the community without affecting the environment.

The expressions from GR farmers are almost not related to LOPI. Rogoff (2014) and Rogoff and Mejía-Arauz (2022) studied the ways of learning by non-Indigenous children, using the same seven facets in LOPI, and proposed a paradigm called ALI (Assembly-Line Instruction); the description for each facet is different. ALI is associated with instructions provided in the public education system to children (Rogoff et al., 2007, p. 499).

Organized by each facet of ALI, Table 3 compares the description by Rogoff (2014) and Rogoff and Mejía-Arauz (2022) with key features found from expressions of adult GR Maya farmers. The following exercise involves articulating childhood learnings with adult practices in the context of ALI. Facet 1, community organization of learning: even though the participants may be from the same community, they are only part of a community of practice. The instructions are provided vertically by someone accredited by an organization, usually government-related, or by the owner of a farm in the case of adults. Facet 2, motive: the participants seek monetary rewards, either by using the learnings or by harvesting agricultural products. The instructors are paid. Facet 3, social organization of endeavors: the expert or the owner has control over the knowledge shared, decisions, and practices, without getting involved. Facet 4, goal of learning: to get a job or to increase profits. The farmers seek cost reduction and efficient use of agrochemicals. Facet 5 means of learning: receiving information, lessons, training, and the like, in person or online, mostly theoretical. Facet 6, communication: unidirectional, from the knowledge holder to the learners, could be oral, in print, or recorded, in person or online. Facet 7, assessment: learners are evaluated based on the objective of the endeavor. In schools or academic training, theoretical tests are typically used. In contrast, farmers evaluate their work based on profits.

The description of each facet of ALI is the result of several studies on children (Rogoff, 2014; Rogoff and Mejía-Arauz, 2022). When compared with the descriptions provided by the GR farmers, similarities become evident. Although the number of years of formal schooling for the GR Yucatec Maya farmers is not high (6–12 years; Table 1), the interpretation is that their ways of learning in adulthood have moved away from their childhood's ways of learning at home. The interactions with extension workers, the advertisement of GR benefits, and the frequency and length of conversations with other farmers fond of GR methods and working on GR-based agriculture are factors that may explain the changes in the ways of learning, from LOPI to ALI.

The Yucatec Maya GR farmers retain features from LOPI, such as listening and observing, but the practice and community values do not seem to be as strong as those of the TR farmers. Assuming that this is the case, as the findings suggest, moving away from LOPI most likely prevents self-processes of innovation in adult Maya farmers.

TABLE 3 Description of each facet of Assembly Line Instruction, ALI, in relation to findings from GR Yucatec Maya adult farmers.

Facet	Description from Rogoff (2014) and Rogoff and Mejia-Arauz (2022).	Description from this study
1	Community organization of learning: learners are segregated from the community; the instruction is provided by bureaucratic institutions.	Workers are temporarily hired and given instructions by the owner or by an extension worker.
2	Motive: learners participate because it is required and seek monetary rewards. The instructor is paid to deliver knowledge and determine success or failure	To profit from farming, meet the needs of the family, and provide some food.
3	Social organization of endeavors: the expert unilaterally controls the pace and the learner's motivation, attention, and actions. The expert does not join in the endeavor but divides and directs labor. The learner does as told.	The person who hires the workers is responsible for decisions in the field, controls the activities, and sets the pace.
4	Goal of learning: isolated information and skills transmitted could be a prerequisite to obtaining a job.	To increase profits, reduce costs, and minimize negative impacts from using agrichemicals.
5	Learning is by means of: receiving lessons, exercises, or tests out of context, such as this study, which focuses on the cultural context.	Conventional workshops, in person or online, readings, school training for academic degrees, and the like. Almost no or very little practice when learning.
6	Communication is based on: a limited range of formats; explanations are often long and out of cultural context.	Communication is unidirectional, from the knowledge holder (owner or extension worker) to the receiver (hired farmer); it could be oral, in print, or recorded, in person or online.
7	Assessment: learners are evaluated narrowly, focusing on the objective of the explanation given, usually without a practical context.	The assessment is based on profits. Sometimes it could be based on innovations, but within the context of GR farming.

ALI is the result of studying how children learn at school.

Based on the above analysis, it is possible to say that the critical elements in the ways of learning among adult Yucatec Maya TR farmers are closely related to LOPI. In contrast, Yucatec Maya GR farmers are closely associated with ALI. The findings in this research clearly show that, in an indigenous community, there could be different ways of learning.

The use of GR is an important but not the only factor negatively affecting the Yucatec Maya food systems; other factors such as public policies, social organization, environmental conditions, and poverty are related to food production (Martín-Castillo, 2016), and they affect the resilience of the culture because they change the social fabric and the traditional structure and function of the agroecosystems toward intensive monocropping.

The findings of this research introduce an element that has long been overlooked in processes related to the transformation of food systems: the ways of knowing play an important role in the efficiency of the design of programs related to the transformation of broken food systems and to encouraging biodiversity. Some authors have argued the importance of restoring the food systems' resilience through the dialogue of knowledges, meaning science and local knowledge (Lugo-Morin, 2023); other authors have identified critical factors that prevent successful biodiversity conservation in Yucatán, where Maya peoples are present (García-Frapolli et al., 2008); however, none of the papers incorporate the role of the ways of learning or knowing by the stakeholders.

Different authors have called for incorporating Indigenous knowledge in processes designed to transform broken food systems into more sustainable ones (Antonelli, 2023; Kennedy et al., 2022; Martínez-Cruz and Rosado-May, 2022), but none of them address in detail the ways of learning or knowing by Indigenous peoples. Thus, the sole identification of the gaps in public policies (Gallardo-López et al., 2022; Lugo-Morin, 2023) or the implementation of extension programs with an agroecological approach (Landini and Beramendi, 2020) may need the incorporation of the features from either LOPI or ALI to design effective interventions to transform food systems in Indigenous settings.

The success of the farmer-to-farmer exchange of knowledge may be explained by the alignment of ways of knowing and learning among the participants. Holt-Giménez (2006) does not describe the process of learning by the participants in a farmer-to-farmer exchange, but in chapter three of the book (pp. 77–110), it is possible to identify the seven facets of LOPI and ALI.

It is important to note that the results of this research do not aim to demonstrate which type of knowledge or learning methods are superior, but rather to identify processes that facilitate understanding the transition from learning to applying knowledge in farming. It aims to investigate whether there is a relationship between ways of knowing and actions related to farming systems. The results suggest that the design of extension programs and the training of the extensionists should incorporate elements related to the ways of learning that the farmers have in processes of the efficient transformation of broken food systems.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

FR-M: Supervision, Conceptualization, Writing – review & editing, Methodology, Data curation, Formal analysis, Writing – original draft, Investigation. BC: Writing – review & editing, Methodology, Investigation, Data curation. VC-A: Investigation, Formal analysis, Project administration, Conceptualization, Writing – review & editing. LM: Investigation, Writing – review & editing, Formal analysis, Data curation.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Acknowledgments

The authors are very grateful to the eight collaborators, especially to those still keeping and innovating their Indigenous traditional practices, and are very concerned for the rapid loss of their knowledge because the process of transmission of knowledge has been disrupted: IYA, from Chacsinkin; to MKB, from Tabasquito; to JBWC, from Xyatil, and SPM from Xpichil, who patiently shared their priceless knowledge. An important set of information was obtained while working on another project related to the agroecological performance evaluation (TAPE) of food systems in the central part of the state of Quintana Roo and the southern area of the state of Yucatan, Mexico.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

References

Ames, P. (2013). Niños y niñas Andinas en el Perú: Crecer en un mundo de relaciones y responsabilidades. *Bull. Inst. Fr. Études Andin.* 42, 389–409. doi: 10.4000/bifea.4166

Antonelli, A. (2023). Indigenous knowledge is key to sustainable food systems. *Nature* 613, 239–242. doi: 10.1038/d41586-023-00021-4

Assefa, Y. (2021). Integration of indigenous knowledge into adult learning material development and the facilitation methodology. *Educ. Res. Int.* 2021, 1–10. doi: 10.1155/2021/2231759

Bang, M., Marin, A., and Medin, D. (2018). If indigenous peoples stand with the sciences, will scientists stand with us? *Dædalus J. Am. Acad. Arts Sci.* 147, 148–159. doi: 10.1162/DAED_a_00498

Bang, M., Marin, A., Medin, D., and Washinawatok, K. (2015). Learning by observing, pitching in, and being in relations in the natural world. *Adv. Child Dev. Behav.* 49, 303–313. doi: 10.1016/bs.acdb.2015.10.004

Barbour, R. (2001). Checklist for improving the rigour in qualitative research: a case of the tail wagging the dog? *Br. Med. J.* 322, 1115–1117. doi: 10.1136/bmj.322.7294.1115

Becerril, J. (2013). Agrodiversidad y nutrición en Yucatán: una mirada al mundo Maya rural. *Reg. Soc.* 25, 123–163. doi: 10.22198/rys.2013.58.a126

Bolin, I. (2006). Growing up in a culture of respect: child rearing in highland Peru. Austin: U of Texas Press.

Brayboy, B. M. J., and Maughan, E. (2009). Indigenous knowledges and the story of the bean. *Harv. Educ. Rev.* 79, 1–21. doi: 10.17763/haer.79.1.l0u6435086352229

Campbell, E., and Lassiter, L. E. (2015). Doing ethnography today: theories, methods, exercises. Chichester, West Sussex, UK: Wiley-Blackwell.

Cervera-Montejano, M. D. (2022). Children's learning to be vernacular architects: Yucatec Maya theory behind LOPI (Cómo aprenden los niños mayas a ser arquitectos vernáculos: la teoría maya yucateca detrás de LOPI). *J. Study Educ. Dev.* 45, 549–566. doi: 10.1080/02103702.2022.2059948

Chavajay, P., and Rogoff, B. (2002). Schooling and traditional collaborative social organization of problem solving by Mayan mothers and children. *Dev. Psychol.* 38, 55–66. doi: 10.1037//0012-1649.38.1.55

Chilisa, B. (2012). Indigenous research methodologies. Thousand Oaks, CA: Sage Publications.

Crouch, M. C., Kim, S. M., Asquith-Heinz, Z., Decker, E., Andrew, N. T., Lewis, J. P., et al. (2023). Indigenous elder-centered methodology: research that decolonizes and indigenizes. *AlterNative* 19, 447–456. doi: 10.1177/11771801231155437

Dannenberg, P., Braun, B., Greiner, C., Follmann, A., Haug, M., Hargo Yuwono, P. S., et al. (2023). Eight arguments why biodiversity is important to safeguard food security. *Plants People Planet* 6, 604–610. doi: 10.1002/ppp3.10492

de Janvry, A., Sadoulet, E., and Rao, M. (2016). Adjusting extension models to the way farmers learn. *Policy brief no. 159.* Prepared for the Ferdi and SPIA workshop learning for adopting: technology adoption in developing country agriculture, held in Clermont-Ferrand (France), June 1 and 2. Available online at: https://ferdi.fr/dl/df-nxCnD1XEYKfpXcM9HeV3A4dB/ferdi-b159-adjusting-extension-models-to-the-way-farmers-learn.pdf (Accessed March 10, 2025).

DeClerck, F. A. J., Koziell, I., Benton, T., Garibaldi, L. A., Kremen, C., Maron, M., et al. (2023). "A whole earth approach to nature-positive food: biodiversity and agriculture" in Science and innovations for food systems transformation. eds. BraunJ. Von, K. Afsana, L. O. Fresco and M. H. A. Hassan (Cham, Switzerland: Springer), 469–496.

Dubey, P. K., Singh, G. S., and Abhilash, P. C. (2020). Adaptive agricultural practices: building resilience under changing climate. Cham, Switzerland: Springer Nature Switzerland.

Edosomwan, S. O. (2016). Childhood learning vs. adulthood learning: the theory of pedagogy and andragogy. *US-China Educ. Rev. A* 6, 115–123. doi: 10.17265/2161-623X/2016.02.004

Fedick, S. L., Morell-Hart, S., and Dussol, L. (2024). Agriculture in the ancient Maya lowlands (part 2): Landesque capital and long-term resource management strategies. *J. Archaeol. Res.* 32, 103–154. doi: 10.1007/s10814-023-09185-z

Fils Pierre, J., Latournerie-Moreno, L., Garuña-Hernández, R., Jacobsen, K., Guevara-Hernández, F., Labosky, C. A. M., et al. (2022). Maize legume intercropping Systems in Southern Mexico: a review of benefits and challenges. *Cienc. Rural* 52:e20210409. doi: 10.1590/0103-8478cr20210409

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., et al. (2011). Solutions for a cultivated planet. *Nature* 478, 337–342. doi: 10.1038/nature10452

Food and Agriculture Organization of the United Nations. (2024). Traditional agrifood systems conserve biodiversity and support nutrition in Mexico. FAO featured story, 22/05/2024. Available online at https://www.fao.org/newsroom/story/traditional-agrifood-systems-conserve-biodiversity-and-support-nutrition-in-mexico/en (Accessed March 15, 2025)

Gallardo-López, F., Landini, F., and Hernández-Chontal, M. A. (2022). The productive orientation of rural extensionists in the regions of Mexico: a key element for agroecological transition. *Sustainability* 14:4062. doi: 10.3390/su14074062

García-Frapolli, E., Toledo, V. M., and Martínez-Alier, J. (2008). Apropiación de la naturaleza por una comunidad Maya yucateca: un análisis económico-ecológico. *Rev. Iberoam. Econ. Ecol.* 7, 27–42.

Gaskins, S. (2003). From corn to cash: change and continuity within Mayan families. *Ethos* 31, 248–273. doi: 10.1525/eth.2003.31.2.248

Gómez-Baggethum, E. (2022). Is there a future for indigenous and local knowledge? *J. Peasant Stud.* 49, 1139–1157. doi: 10.1080/03066150.2021.1926994

Gutiérrez, I. T., Rosengren, K. S., and Miller, P. J. (2015). "Día de los muertos: learning about death through observing and pitching in" in Children learn by observing and contributing to family and community endeavors: a cultural paradigm. eds. M. Correa-Chavez, R. Mejía-Arauz and B. Rogoff (Waltham, MA, USA: Academic Press), 229–252.

Gutiérrez-Carbajal, M. G., Magaña Magaña, M. A., Zizumbo Villarreal, D., and Ballina Gómez, H. (2019). Diversidad agrícola y seguridad alimentaria nutricional en dos localidades Mayas de Yucatán. *Acta Univ.* 29:e1996. doi: 10.15174.au.2019.1996

Harris, J. E., Gleason, P. M., Sheean, P. M., Boushey, C., Beto, J. A., and Bruemmer, B. (2009). An introduction to qualitative research for food and nutrition professionals. *J. Am. Diet. Assoc.* 109, 80–90. doi: 10.1016/j.jada.2008.10.018

Hartmann, K., and Martin, M. J. (2021). Cooperative extension in indigenous communities: characteristics of successful programs. *J. Agric. Educ.* 62, 9–19. doi: 10.5032/jae.2021.03009

Hoepfl, M. (1997). Choosing qualitative research: a primer for technology education researchers. *J. Technol. Educ.* 9, 47–63. doi: 10.21061/jte.v9i1.a.4

Holt-Giménez, E. (2006). Campesino a campesino: Voices from Latin America's farmer to farmer movement for sustainable agriculture. Oakland: Food First Books.

John, D. A., and Babu, G. R. (2021). Lessons from the aftermaths of the green revolution of food systems and health. *Front. Sustain. Food Syst.* 5:644559. doi: 10.3389/fsufs.2021.644559

Jones Brayboy, B. M., Solyom, J. A., and Castagno, A. E. (2015). Indigenous peoples in higher education. *J. Am. Indian Educ.* 54, 154–186. doi: 10.5749/jamerindieduc.54.1.0154

Kanter, R., Kennedy, G., and Boza, S. (2023). Local traditional and indigenous food systems in the 21st century to combat obesity, undernutrition and climate change. *Front. Sustain. Food Syst.* 7:1195741. doi: 10.3389/fsufs.2023.1195741

Kennedy, G., Wang, Z., Maundu, P., and Hunter, D. (2022). The role of traditional knowledge and food biodiversity to transform modern food systems. *Trends Food Sci. Technol.* 130, 32–41. doi: 10.1016/j.tifs.2022.09.011

Kuehne, G., Llewellyn, R., Pannel, D. J., Wilkinson, R., Dolling, P., Ouzman, J., et al. (2017). Predicting farmer uptake of new agricultural practices: a tool for research extension and policy. *Agric. Syst.* 156, 115–125. doi: 10.1016/j.agsy.2017.06.007

Kuhnlein, H. V. (2000). The joys and pains of sampling and analysis of traditional food of indigenous peoples. *J. Food Compos. Anal.* 13, 649–658. doi: 10.006/jfca.1999.0857

Ku-Pech, E. M., Mijangos-Cortés, J. O., Andueza Noh, R. H., Chávez-Pesqueira, M., Simá-Polanco, P., Simá-Gómez, J. L., et al. (2020). Estrategias de Manejo de la Milpa Maya en Xoy, Peto, Yucatán. *Ecosis. Recur. Agropec.* 7:e2244. doi: 10.19136/era.a7n1.2244

Landín-Alcántar, H., Vázquez-Miramontes, N., Palomino-Núñez, S. J., and Mena-Castañeda, J. P. (2019). Extensionism in Mexico and its impact on changes in agricultural production yields. *J. Res. Dev.* 5, 1–11. doi: 10.35429/JRD/.2019.15.5.1.11

Landini, F., and Beramendi, M. A. (2020). Agroecology or modern conventional agriculture? Positions of argentine rural extensionists. *Adv. Mod. Agric.* 1, 1–12. doi: 10.5451/7ama.v1i1.1985

López, L. E. (2013). Keys to indigenous youth and adult education in Latin America. Lessons learned in the pursuit of social literacy. *Tertium Comparationis* 19, 109–146. doi: 10.25656/01:24507

López-Ridaura, S., Barba-Escoto, L., Reyna-Ramírez, C. A., Sum, C., Palacios-Rojas, N., and Gerard, B. (2021). Maize intercropping in the Milpa system. Diversity, extent and importance for nutritional security in the Western highlands of Guatemala. *Sci. Rep.* 11:3696. doi: 10.1038/s41598-021-82784-2

Lugo-Morin, D. R. (2023). Restoring the food systems resilience through the dialogue of knowledge: a case study from Mexico. *Forum Dev. Stud.* 50, 183–206. doi: 10.1080/08039410.2022.2097124

Madjidi, K., and Restoule, J. (2008). "Comparative indigenous ways of knowing and learning" in Comparative and international education. eds. K. Mundy, K. Bickmore, R. Hayhoe, M. Madden and K. Madjidi (New York: Teachers College Press), 77–106.

Manzini, S. (2003). Effective communication of science in a culturally diverse society. *Sci. Commun.* 25, 191–197. doi: 10.1177/1075547003259432

Martín-Castillo, M. (2016). Milpa y capitalism: opciones para los campesinos Mayas contemporáneos. *LiminaR* 14, 101–114. doi: 10.29043/liminar.v14i2.463

Martínez-Cruz, T. E., and Rosado-May, F. J. (2022). "Indigenous peoples food systems: using traditional knowledge to transform unsustainable practices" in Indigenous peoples' knowledge, ed. religions for peace and the UN environment Programme. Available online at: https://www.rfp.org/wp-content/uploads/2023/04/Indigenous-Peoples-Food-Systems-Using-Traditoinal-Knowledge-to-Transform-Unsustainable-Practices.pdf (Accessed March 15, 2025)

Meadu, V., Spillane, C., Challinor, A. J., and McKeown, P. C. (2023). "Fixing our broken food system: the why and how" in Transforming food systems under climate change through innovation. eds. B. Campbell, P. Thornton, A. M. Loboguerrero, D. Dinesh and A. Nowak (Cambridge, UK: Cambridge University Press), 1–10.

Mukute, M., and Lotz-Sisitka, H. (2012). Working with cultural-historical activity theory and critical realism to investigate and expand farmer learning in southern Africa. *Mind Cult. Act.* 19, 342–367. doi: 10.1080/10749039.2012.656173

Nakano, Y., Tsusaka, T. W., Aida, T., and Pede, V. O. (2018). Is farmer-to-farmer extension effective? The impact of training on technology adoption and rice farming productivity in Tanzania. *World Dev.* 105, 336–351. doi: 10.1016/j.worlddev.2017.12.013

Paradise, R., and Rogoff, B. (2009). Side by side: learning through observing and pitching in. *Ethos* 37, 102–138. doi: 10.1111/j.1548-1352.2009.01033.x

Pingali, P. L. (2012). Green revolution: impacts, limits, and the path ahead. *Proc. Natl. Acad. Sci. U S A* 109, 12302–12308. doi: 10.1073/pnas.0912953109

Rao, N., and Robinson-Pant, A. (2006). Adult education and indigenous people: addressing gender in policy and practice. *Int. J. Educ. Dev.* 26, 209–223. doi: 10.1016/j.ijedudev.2005.07.026

Rendón Medel, R., Roldán Suárez, E., Hernández Hernández, B., and Cadena Íñiguez, P. (2015). Los procesos de extensión rural en México. *Rev. Mexicana Cienc. Agríc.* 6, 151–161. doi: 10.29312/remexca.v6i1.746

Reyes-García, V., Guezen, M., Luz, A. C., Paneque-Gálvez, J., Macía, J., Orta-Martínez, M., et al. (2013a). Evidence of traditional knowledge among a contemporary indigenous society. *Evol. Hum. Behav.* 34, 249–257. doi: 10.1016/j.evolhumbehav.2013.03.002

Reyes-García, V., Ruiz-Mallen, I., Porter-Bolland, L., García-Frapolli, E., Ellis, E. A., Méndez, M.-E., et al. (2013b). Local understanding of conservation in southeastern Mexico and their implications for community-based conservation as an alternative paradigm. *Conserv. Biol.* 27, 856–865. doi: 10.1111/cobi.12056

Reynolds, A. J., and Ou, S-R. (2011). Paths of effects from preschool to adult well-being: a confirmatory analysis of the child-parent center program. Child Dev., 82, 555–582. doi: 10. 1111/j.1467–8624.2010.01562.x, doi: 10.1111/j.1467-8624.2010.01562.x

Rogoff, B. (2012). Learning without lessons: opportunities to expand knowledge. *J. Study Educ. Dev.* 35, 233–252. doi: 10.1174/021037012800217970

Rogoff, B. (2014). Learning by observing and pitching in to family and community endeavors: an orientation. *Hum. Dev.* 57, 69–81. doi: 10.1159/000356757

Rogoff, B. (2016). Culture and participation: a paradigm shift. *Curr. Opin. Psychol.* 8, 182–189. doi: 10.1016/j.copsyc.2015.12.002

Rogoff, B., and Mejía-Arauz, R. (2022). The key role of community in learning by observing and pitching in to family and community endeavors. *J. Study Educ. Dev.* 45, 494–548. doi: 10.1080/02103702.2022.2086770

Rogoff, B., Moore, L., Najafi, B., Dexter, A., Correa-Chávez, M., and Solís, J. (2007). "Children's development of cultural repertoires through participation in everyday routines and practices" in Handbook of socialization: Theory and research. eds. J. E. Grusec and P. D. Hastings (New York: The Guilford Press).

Rogoff, B., Najafi, B., and Mejía-Arauz, R. (2014). Constellations of cultural practices across generations: indigenous American heritage and learning by observing and pitching in. *Hum. Dev.* 57, 82–95. doi: 10.1159/000356761

Rosado-May, F. J. (2016a). Role of intercultural education in the conservation and sustainable management of natural resources with emphasis on food systems. *Nuevo Humanismo* 4, 75–91. doi: 10.15359/rnh.4-2.4

Rosado-May, F.J. (2016b). Gestión académica con la milpa y los milperos. ¿Estamos haciendo un buen trabajo en las universidades? X Congreso Mexicano de Etnobiología, Mérida, Yucatán, México, September 23rd. Available online at: https://www.researchgate.net/publication/310643966_GESTION_ACADEMICA_CON_LA_MILPA_Y_LOS_MILPEROS_Estamos_haciendo_un_buen_trabajo_en_las_Universidades (Accessed March 16, 2025).

Rosado-May, F.J., Cuevas-Albarrán, V.B., and Jiménez-Pat, N.F. (2023). The role of shared vision and values in effective governance for natural resource conservation in a Yucatec Maya community. Policy Matters, 23, 104–120. Available online at: https://portals.iucn.org/library/sites/library/files/documents/Policy-Matters-Issue-23_0.pdf (Accessed March 20, 2025).

Rosado-May, F. J., Ku Balam, M., Cuevas-Albarrán, V. B., and Huchin Chan, J. (2025b). "From learning to innovation in Yucatec Maya food systems: a co-creation process" in The Bloomsbury handbook of indigenous education and research. eds. S. Styres and R. Neepin (London: Bloomsbury Publishing). [In press]

Rosado-May, F. J., and Poot Cahun, H. (2020). Cosmovisión Maya reflejada en palabras y conceptos relacionados con desarrollo sostenible, ecología y agroecología. *Das Questões* 10, 33–48. doi: 10.26512/dasquestoes.v10i1.32342

Rosado-May, F. J., Poot Moo, C. B., Kú Martínez, M. V., and Cuevas-Albarrán, V. B. (2022). "Yucatec Maya students' learning in times of the Covid-19 pandemic: from elementary to higher education" in Handbook of research on family literacy practices and home-school connections. eds. K. R. Fox and L. E. Szech (Hershey, PA: IGI Global), 227–251.

Rosado-May, F. J., Tec Tun, J. M., Cuevas-Albarrán, V. B., and Ramírez-Silva, J. H. (2025a). Constructing an indigenous knowledge approach to agroecology and regenerative agriculture: the case of the Yucatec Maya. *Elem. Sci. Anthrop.* 13:1. doi: 10.1525/elementa.2023.00121

Rosado-May, F. J., Urrieta, L.Jr., Dayton, A., and Rogoff, B. (2020). "Innovation as key feature of indigenous ways of learning: individuals and communities generating knowledge" in Handbook of the cultural foundations of learning. eds. N. S. Nasir, C. D. Lee, R. Pea and M. McKinney de Royston (New York: Routledge), 79–96.

Schmelkes, S. (2011). Adult education and indigenous peoples in Latin America. *Int. Rev. Educ.* 57, 89–105. doi: 10.1007/s11159-011-9191-2

Swanson, B. E., and Rajalahti, R. (2010). Strengthening agricultural extension and advisory systems: procedures for assessing, transforming, and evaluating extension systems. Agriculture and rural development discussion paper 44. The International Bank for Reconstruction and Development/The World Bank. Available online at: https://documents1.worldbank.org/curated/en/873411468159312382/pdf/565870NWP0ARD0110Stren1combined1web.pdf (Accessed March 15, 2025).

Toledo, V. M., Bassols, N. B., Frapolli, E. G., and Chaires, P. A. (2007). Manejo y uso de la biodiversidad entre los Mayas yucatecos. *Biodiversitas* 70, 10–15.

Troughton, T. (2023). The role of cultural instruction in adult indigenous language learning. *Can. J. New Sch. Educ.* 14, 38–45.

Wilder, B. T., O'Meara, C., Monti, L., and Nabhan, G. P. (2016). The importance of indigenous knowledge in curbing the loss of language and biodiversity. *Bioscience* 66, 499–509. doi: 10.1093/biosci/biw026