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RESEARCH ARTICLE

Constructing an Indigenous knowledge approach to agroecology and regenerative agriculture: The case of Yucatec Maya

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Yucatec Maya farmers are abandoning traditional sustainable practices. At least 75% are already using conventional practices related to unprecedented challenges from climate change, loss of biodiversity, natural resources degradation, and the like. Thus, the call for transforming broken food systems also includes Indigenous systems. Two major approaches are being implemented in the region to transform broken Yucatec Maya food systems: one is based on agroecology and the other one on regenerative agriculture. However, there is basically no research that shows how to articulate these approaches with Indigenous knowledge. Under the premise that the more Indigenous thinking regarding their food systems is understood, the stronger the co-creation process of knowledge is with nonlocal ways of knowing (e.g., science), thus increasing the probability of long-term success in transforming Yucatec Maya broken food systems through agroecology or regenerative agriculture. Our article uncovers key Yucatec Maya thinking about the design and management of their traditional food system. Concepts such as food system, diversity, certainty of uncertainty, food security, sufficiency, and sovereignty are present in the planning of the Yucatec Maya food system, which in turn explains their high level of resilience and sustainability. This type of knowledge should be appreciated, recognized, and incorporated into the processes of food systems transformation.

Keywords: Yucatec Maya food system, Indigenous knowledge, Agroecology, Regenerative agriculture, Intercultural co-creation of knowledge

Introduction

Food systems worldwide are facing unprecedented challenges. According to De Clerk et al. (2023), agriculture is the largest single source of environmental degradation, responsible for over 30% of global greenhouse gas emissions, 70% of freshwater use, and 80% of land conversion. It is also the single largest driver of biodiversity loss. The food production system is widely considered unsustainable, demanding the transformation of how food is produced (Meadu et al., 2023). The need for a change is so great that in July 2023 the UN Secretary-General António Guterres acknowledged that food systems are broken and billions of people are paying the price (Cooper, 2024).

Food systems, however, are not homogenous; they are diverse. Gaitán-Cremaschi et al. (2019) characterize the diversity of food systems based on a set of structural characteristics at a certain geographical scale and in terms of their support by mainstream practices. Marshall et al. (2021), on the other hand, identify five food system types: rural and traditional, informal and expanding, emerging and diversifying, modernizing and formalizing, and industrial and consolidated. These authors recognize the existence of hybrid systems, basically meaning conventional mixed with traditional practices, as part of the diversity of food systems. This characterization opens the possibility of considering some food systems managed by local and/or Indigenous farmers to be unsustainable and broken. For example, Indigenous communities in Canada are facing a food and health crisis (Rudolph and McLachlan, 2013; Malli et al., 2023) due to the substitution of traditional practices with conventional ones.

This literature is only a small sample of the many calls for the transformation of food systems. Although there is a diversity of definitions of this concept, there seems to be agreement on some aspects, which led Juri et al. (2024) to propose that "food systems transformations refer to significant re-configurations of the assemblage of food system activities, actors, outcomes, and relationships

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(dynamics) to move away from the current globalized industrial model and ensure sustainable, resilient and just models of production and consumption." The idea of food systems transformation is widely accepted and embraced by organizations and researchers around the world.

In Mexico and the Yucatan Peninsula, two main approaches have been more recently implemented by governments, scientists, and nonprofit organizations to transform food systems toward sustainability. One is agroecology (Pérez and Hernández García, 2022; Toledo and Argueta, 2024), and the other is regenerative agriculture (Breña Naranjo, 2021; McLaughlin, 2022; Selibas, 2022).

Transforming food systems is a very complex process and several factors have to be considered (Meadu et al., 2023; Gupta, 2024; O'Malley and Friling, 2024). One factor identified as critical is the effective participation of stakeholders, especially farmers, in decision-making and creating the knowledge needed (European Commission, 2021). Effective participation has been proven to be a critical component for the sustainability of food systems in Europe (de Vries et al., 2024). In a different context, and using an agroecological approach, Utter et al. (2021) discuss the importance of achieving food systems transformation through *co-creation* of knowledge, thereby opening the participation of different ways of knowing, including what is often known as traditional, Indigenous, or local knowledge, alongside scientific, Western, or generalized knowledge. Regenerative agriculture, on the other hand, is trying to position itself as an approach that also incorporates Indigenous knowledge into its practices. According to Wilson et al. (2024), regenerative agriculture is trying to overcome farmers' perceptions of it as coopting the work they do and even diluting the meaning of their practices. However, Sands et al. (2023) demonstrate that the farming techniques associated with regenerative agriculture have been practiced for centuries by Indigenous and local communities around the world.

Both approaches are connected to local/Indigenous knowledge; therefore, knowing the present conditions of Yucatec Maya food systems and the thinking that drives the decisions and actions by Yucatec Maya farmers, reflected in their design and management of those systems, could contribute greatly to the success of transforming broken Yucatec Maya food systems, encourage the use of systems and practices that can be considered sustainable, and at the same time develop appropriate ways to increase their food production. This knowledge-making system has not been addressed enough in the Mexican food systems literature. Existing government, nonprofit organizations, and foundation efforts to foster agroecology or regenerative agriculture are having difficulties, at a time when conventional farming methods are increasingly encroaching on the traditional Yucatec Maya farming system.

Based on findings that describe the actual situation of Yucatec Maya food systems and under the assumption that the present goal of Maya farmers is to increase yields while at the same time developing means for the conservation of soil and biodiversity, the transformation process must consider that the success of food systems also rests on the culture of the farmers, not only on the technological package offered by agroecology, regenerative agriculture, or any other approach. Our article therefore presents critical elements of the Yucatec Maya thinking that explain decisions and actions around their food systems. The premise is that the more Indigenous thinking is understood, regarding their food systems, the stronger the co-creation process of knowledge is with nonlocal ways of knowing (e.g., science). This would increase the probability of the long-term success of agroecology or regenerative agriculture in transforming broken Yucatec Maya food systems.

Methodological approach

To address the premise presented in the previous paragraph, this article describes (1) A typology of Yucatec Maya farming practices; (2) Knowing that yield is an issue, the average production of maize, beans, and squash was determined in the Maya communities studied; (3) The next step was to examine the Yucatec Maya peoples' understanding of the concept of food systems as an entry point to (4) Uncover the critical thinking that drives the design and management of the Yucatec Maya food system. The results are then discussed in the context of the critical importance of Indigenous knowledge in the process of intercultural co-creation of knowledge to design strategies for long-term projects aiming at the transformation of broken food systems, Indigenous or not.

The 13 communities selected for steps (1) and (2) are located in the municipalities of Felipe Carrillo Puerto and Jose Maria Morelos in the state of Quintana Roo, Mexico (**Figure 1**). This selection was based on two criteria: the community should have students enrolled at the Universidad Intercultural Maya de Quintana Roo (UIMQRoo), and the communities should be located in the central part of the state of Quintana Roo. The academic model of UIMQRoo demands students to carry out projects in their own communities and faculty working with them on their projects (Rosado-May, 2017), thus there were good conditions to connect and build trust with farmers for interviews and data collection. On the other hand, the Yucatec Maya communities located in the central part of the state of Quintana Roo, Mexico, are considered the most traditional in the Yucatan because that area was where the settlement of the Mayas occurred during and after the Casta War in Yucatan[1] between 1847 and 1901 (Reed, 2001). **Table 1** shows the list of communities and basic demographic features.

1. The rebellion of the Maya people in the Yucatan, known as the Casta War, was an expression of years of accumulated discontent against the bad conditions of working in sugarcane and hemp (henequen). It was a bloody war, the Maya took over most of the Peninsula but did not dare to enter Merida o Campeche, the two largest cities. This decision gave time to the local and federal government to reorganize and later take over the Maya settlements, especially the capital of the Maya set in what is today known as Felipe Carrillo Puerto, in the state of Quintana Roo. Some authors say that the Maya did not take the two large cities because they had to go back to plant their milpas, and other authors say that the Maya considered that their message was already heard and did not want more bloodshed. Most people living in the central region of Quintana Roo are descendants of the Maya who fought in the Casta war.

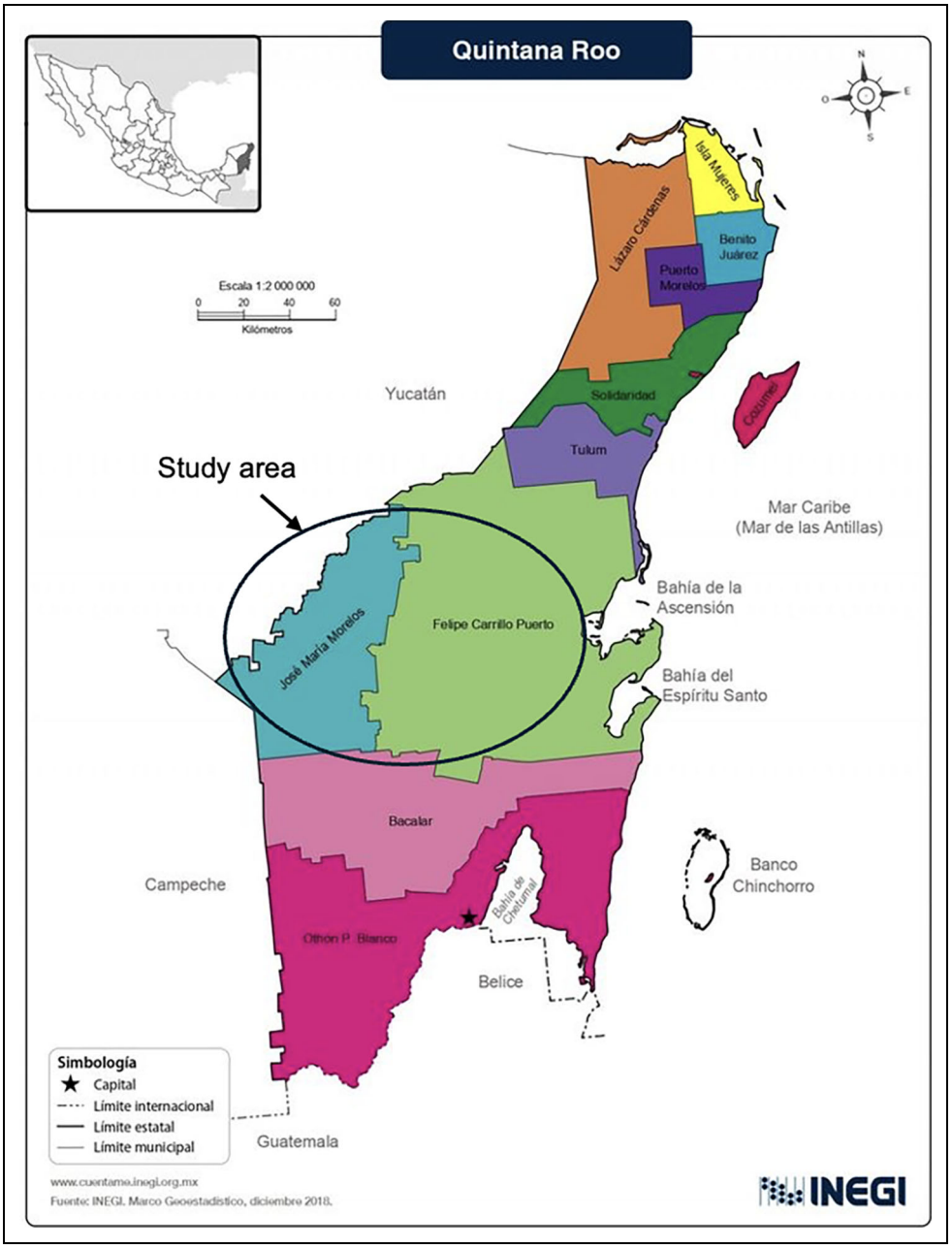

Figure 1. Study area, the central region of Quintana Roo, Mexico. Source: https://cuentame.inegi.org.mx/mapas/pdf/entidades/div_municipal/qroompioscolor.pdf.

To describe the typology of the food systems, 10 of the 13 communities were selected, based on the availability of informants and the conditions of the crops in the summer of 2020, during the COVID-19 pandemic. In each community, one or two informants were asked to grant permission to observe their farming practices, to visit their fields, and to talk about other farmers' practices in their communities. The selection of the farmers interviewed was based on their accessibility and reputation in their communities as knowledgeable farmers. Based on the opinion of the first one or two farmers, eight or nine more farmers were included in the process. The objective of the interview was to determine whether each of the 10 farmers per community had practices that incorporated agrichemicals or not, to what extent the agrichemicals were used, what were their observations regarding yields, and, if agrichemicals were used, what effects they were observing both in their crops/bees/animals and on their personal health. The 10 farmers per community shared their observations on what were the practices that at least one other farmer in the community, avoiding repetitions, carried out in their farming. The idea was to have at least 20 sources of information in each community. Students from UIMQ-Roo helped greatly in the process of gathering information in their own communities.

In March 2023, more than a year after the COVID-19 restrictions were lifted, the study carried out in 2020 was replicated, following the same methodology. The idea was to determine whether or not the farmers had changed their practices after going through a tough situation of

Table 1. Population data in each of the Yucatec Maya communities (INEGI, 2020)

Community	Municipality	Population				% of EAP Dedicated to Farming
		Total	Men	Women	EAP	
Cafetal Grande	JMM	291	144	146	82	97
Dzulá	FCP	1,172	588	584	343	94
Jose Maria Morelos	JMM	9,446	4,757	4,689	2,934	43
Kankabchen	JMM	951	476	475	287	98
La Presumida	JMM	1,313	649	664	696	77
Puerto Arturo	JMM	561	314	247	228	95
Saczuquil	JMM	399	202	197	84	87
San Diego	JMM	517	283	234	149	98
San Felipe I	JMM	665	352	313	165	95
Señor	FCP	2,362	1,202	1,202	1,160	91
Tepich	FCP	2,145	1,109	1,036	554	96
Xyatil	FCP	926	459	467	463	93
Yaxley	FCP	565	300	265	152	94

EAP = economically active population; JMM = municipality of Jose Maria Morelos; FCP = municipality of Felipe Carrillo Puerto.

not having access to agrichemicals. The expectation was to find an increase in the percentage of farmers not using agrichemicals in their farming.

To determine the yield of maize, beans, and squash, 10 Maya communities were selected for this study; in each community, six randomly selected farmers representing all typologies were interviewed to determine the yield of the three crops in 2020 and 2022. The farmers remember very well the number of sacks that they harvested for each "mecate" (a local measuring system for an area, equivalent to 20 × 20 m); based on the number of sacks and the kilos in each sack in relation to a mecate, the figure of k/ha was obtained. The selected communities for this part of the research included three that were different from the ones selected for developing the typology of farming practices; the reason for this change was the availability and the confidentiality of the data collected.

The nature of the information required for steps (3) and (4) of this research means we needed to connect with Yucatec Maya knowledge holders. Our research identifies knowledge holders as "members of Indigenous and local communities who are knowledgeable in various aspects and forms of Indigenous knowledge. Such members are recognized in their communities for their expertise and depth of knowledge" (Mosimege, 2017). The authors of this article consider Yucatec Maya knowledge holders to have the capacity of explaining, in their own words and language, the epistemological bases of their thinking and concepts. In Yucatec Maya, the local knowledge holders are known as *nool iknal* (Rosado-May et al., 2016; Rosado-May et al., 2020, p. 86). Working with these special people requires the researchers to speak the local language and to devote hours of conversations, field visits and work, until there is a clear understanding of the meanings, ideas, and concepts that emerged in the conversations.

The methodology to understand Yucatec Maya thinking in relation to the concept of food system required the following steps.

The first step was to consider a community as a territory in which the main parts of the processes in a food system take place. All communities consider their "ejido" as a synonym of territory (see Rosado-May et al., 2023, for the concept of ejido). Next was to identify the different sources of food, either from human-driven work (e.g., agriculture) or natural (e.g., forest). Assuming that an idea of food system exists in a community, close to the definition from von Braun et al. (2021), the third step was to find a word or words in the local language, Yucatec Maya, that express the concept. This last part required hours of interactions through what is known as *tsikbal* in the Yucatan with people considered as knowledge holders in their communities. Although there has been some research on *tsikbal*, its interpretation has strong limitations. Berkley (2001) considers *tsikbal* as respectful conversation, whereas Rivera Vázquez and Mijangos Noh (2024) consider *tsikbal* as collaborative communication. In this article, *tsikbal* is defined as a system developed by the Yucatec Maya for effective communication in exchanging knowledge which includes verbal and non-verbal conversations as well as field checking and continuous feedback between the farmers. The *tsikbal* reached a point in which both parts, the researchers and the local knowledge holders (either a man or a woman), had to have a clear understanding of the concept of food system. Once the concept was well understood, the next step was to identify actions that can have a Maya name, or expressions, in which the concept was applied; the reason was that even if the local word was lost or not familiar, the thinking could be identified through practices in their food system.

The following step, to make sure that the word or words identified do reflect the concept discussed, was to understand them linguistically. Once the words were identified, the spelling was checked in the Maya-Spanish Dictionary prepared by Bastarrachea et al. (1992). This step, together with the previous ones, is important because the Yucatec Maya language is being eroded rapidly (Sima Lozano and Perales Escudero, 2015; Guerrettaz et al., 2020), and so is valuable knowledge (Wilder et al., 2016).

The methodology to determine the thinking that drives the design and management of the food systems among the Yucatec Maya had two components. The first one was to identify words in Yucatec Maya related to key concepts such as food system, farming or its synonym, agriculture, milpa, and diversity. These words were identified using the communication/learning system developed by the Maya, called *tsikbal*, described in the previous paragraph. Exploring the thinking that drives decisions and actions on their food system requires more than identifying words in the local Indigenous language; this is addressed by the second component of the methodology.

The second component had the objective of identifying key words/expressions in critical moments. Based on the experience of the authors, the two critical moments selected were: (a) after finishing planting in any of the components of their food system; and (b) at the end or beginning of the regular year, which is usually the time when the Yucatec Maya farmers envision and plan the activities for the next year or season.

Both components, the identified words and expressions, were presented to Don JWC from Xyatil, Q. Roo (see Buenrostro-Alba, 2015), JMTT (a coauthor of this article), and MKB (who received the recognition of the Milpa Maya as a Globally Important Agricultural Heritage Systems). They all have the status of *nool iknal*, as described above. The *nool iknal* revised and approved both the words and the expressions. Then, both were taken back to at least five farmers in each of the following communities: Jose Maria Morelos, San Felipe I, Señor, and Dzulá. The idea was to explore if they understood the words and expressions and notice their reactions. After this process, the most important thinking that drives decisions and actions in the design and management of the Yucatec Maya food system was identified.

A typology of Yucatec Maya farming practices and present yields

Typology. The study was conducted in 2020, during the COVID-19 pandemic, in 10 Yucatec Maya communities in the state of Quintana Roo (Q. Roo), Mexico. The average figure of the three groups identified as a result (**Table 2**) was: 26% of the farmers kept their traditional ways of farming (as defined by IPBES, 2019); 24% used only conventional ways (systems that meet at least three of the criteria established by Sumberg and Giller, 2022); and 50% mixed traditional with conventional means (e.g., use of traditional seeds and synthetic fertilizers). The research identified the main concerns expressed by all communities. The group farming with traditional means had two main concerns: How to improve yields without using external inputs such as fertilizers? How to strengthen traditional knowledge to improve yield? The main concerns of the group farming with a mixture of traditional and conventional ways of farming were: How to improve yield without using agrochemicals? How to sell the surplus produced? The main concern in the group farming with only conventional ways was: How to transition to a system that uses less, or substitutes, external inputs without losing yield?

In March 2023, more than a year after the COVID restrictions were lifted, the composition of the groups in Q. Roo identified in 2020 was basically within the same percentage (**Table 2**), and their concerns were still the same. This is a nonsustainable situation; their concerns are a call for changing their present ways of farming, for transforming the food system.

Table 2. Percentage of Yucatec Maya farmers by farming typology per community

	Typology					
	100% Traditional		100% Conventional		Mixture	
Community	2020	2023	2020	2023	2020	2023
Jose Maria Morelos	20	25	30	30	50	45
San Felipe I	25	25	15	15	60	60
San Diego	30	25	10	10	60	65
Cafetal Grande	30	30	35	35	35	35
Kankabchen	25	25	35	35	40	40
Puerto Arturo	10	10	40	40	50	50
Yaxley	35	35	15	15	50	50
Señor	30	25	20	20	50	55
Dzulá	25	20	15	15	60	65
Tepich	30	30	25	25	45	45
Average	26	25	24	24	50	51

Yields. The crops selected to measure the yields—maize, beans, and squash—are considered the backbone of the milpa. The milpa has been described by many authors as the most important component of the Maya food system, the main source of staple food (Nigh and Diemont, 2013; Mijangos-Cortés et al., 2019; Rodríguez-Robayo et al., 2020; Terán Contreras, 2023).

The figures registered are as follows: between 300 and 1,000 k/ha of maize, between 200 and 700 k/ha of beans, and between 200 and 400 k/ha of squash (**Table 3**). These figures are not too different from the ones reported previously (Graefe, 2003, p. 61). When using only conventional means, Yucatec Maya farmers harvest between 3,000 and 6,000 k/ha of maize, in monocropping, according to Ramírez-Silva et al. (2022).

Table 3 clearly supports the concern expressed by farmers; the production of staple foods is very low at present days, in many cases not enough to meet the demand of a family, much less of a community. A common answer when the farmers were asked to compare these yields to what they had 15–20 years ago was that in the past, yields were 3–4 times higher, similar to the findings by Schwartz and Corzo (2015).

The context in which Indigenous farmers are nowadays facing challenges is without precedent and coming from different directions, not just environmental. Some of the most conspicuous factors that Yucatec Maya farmers in Mexico have identified are: the predictability of the timing of rain is much more uncertain, the soils do not get enough moisture for the whole season of the crops; the soils seem to lose strength faster than before. Bees are under threat because of the expansion of agricultural fields for conventional farming and the use of pesticides; the biodiversity is not as usual, birds and animals eating the crops do not seem to have the same population as before, they have grown in numbers. Government programs provide hybrid seeds and agrochemicals, not only in low quantity or quality but without proper training. More and more of the new generations are not willing to continue farming under any approach, traditional or conventional; as a result, the transmission of knowledge is interrupted, and valuable traditional knowledge is being lost at a rapid rate. Finally, government policies regulate the use of fire for farming, but without solid grounds, thus effective shifting cultivation is at risk. Ebel et al. (2018) have reported similar findings for a community close to those in this study.

The factors identified by Indigenous farmers are closely related to well-identified worldwide risk factors in food systems today (Fan et al., 2021), for example, climate change, loss of biodiversity, bad policies, poor yields and nutrition, loss of soil fertility, rural migration, and the like. Indigenous farmers, including conventional ones, are facing the same challenges as non-Indigenous farmers.

The concern regarding yields expressed by the farmers is not recent. Empirical evidence demonstrates that for at least a decade Yucatec Maya farmers have had difficulties meeting their food needs, especially maize, the most important staple food, from their own systems (Salazar Barrientos and Magaña Magaña, 2016; Gutiérrez Carbajal et al., 2019). It is in this context that the Mexican government implemented in 2018 a program in the Southern states and the Yucatan Peninsula called "Sembrando Vida" (sowing life), which has been considered an example of applied agroecology (Pérez and Hernández García, 2022; Toledo and Argueta, 2024), to mitigate rural poverty and environmental degradation (Gouttefanjat, 2023). In the Yucatan Peninsula, most of the beneficiaries of Sembrando Vida are Indigenous farmers. According to official information (Secretaría del Bienestar, 2020), the objective of Sembrando Vida was to contribute to the social well-being of farmers by encouraging food self-sufficiency. The

Table 3. Yield harvested in k/ha for each of the main crops in a milpa in 2020 and 2022[a]

	Maize		Beans		Squash	
Community	**2020**	**2022**	**2020**	**2022**	**2020**	**2022**
Cafetal Grande	1,000	950	700	450	350	350
Jose Maria Morelos	950	900	650	400	350	350
Kancabchen	950	950	700	400	350	350
La Presumida	700	800	600	300	300	250
Saczuquil	900	850	700	350	300	400
San Diego	750	950	650	300	300	250
San Felipe I	1,000	900	600	350	250	300
Señor	700	550	600	200	200	200
Tepich	700	300	650	200	200	200
Xyatil	750	400	500	250	200	200
Average	840	755	635	320	280	285

[a]Each figure is the average of six interviews per Maya community, in central Quintana Roo, Mexico. The figures represent an average of all farming typologies in each community.

strategy of Sembrando Vida rests on two concepts: Agroforestry (including lumber and fruit trees) and Milpa, basically meaning maize intercalated with fruit trees. However, the effectiveness of Sembrando Vida has been questioned (Baca del Moral et al., 2021; Pedraza López, 2021; Cortez Egremy et al., 2022), basically because there is no evidence that the program has improved food production or reduced poverty significantly.

The increasing unsustainability of small, local/Indigenous food systems in the Yucatan Peninsula could explain the announcement in 2021 of the launch of the Agroecology Fund of the Peninsula de Yucatan (FAPY in Spanish), with funding from the W.K. Kellogg Foundation. "FAPY's mission is to support innovative projects that focus on strengthening agroecological production, deepening agroecology research and knowledge, improving access to markets, and building a just and more climate-resilient food system in the states of Yucatan, Campeche and Quintana Roo" (FAO, 2024).

Agroecology is not the only approach implemented in Mexico with the objective of improving conditions in food production. For a number of years, the regenerative agriculture approach, as defined by the World Economic Forum, via Masterson (2022), has been used in small, Indigenous, farms (Selibas, 2022), as well as in large industrially driven farms such as Grupo Bimbo, in partnership with CIMMYT (McLaughlin, 2022), aiming at cultivating 200,000 ha with regenerative practices by 2030. International organizations such as WWF and AXA Foundation (WWF, 2021) are promoting the implementation of regenerative agriculture in the Indigenous territories of Oaxaca. The Mexican government and IKI Alliance have been actively promoting regenerative agriculture in the country (IKI, 2021), especially focusing on soil conservation and restoration of aquifers (Breña Naranjo, 2021). In 2019, The Nature Conservancy reported that in the Yucatan, there are almost 1,000 farmers in 42 communities already using the regenerative agriculture approach in their farming (TNC, 2020).

In sum, agroecology and regenerative agriculture are present in the Yucatan Peninsula, practiced by Maya farmers through different programs, and encouraged by both governmental and nongovernmental organizations. However, the review of the information available shows very few scientific research on either agroecology or regenerative agriculture that can be considered strong enough to meet the expectations of the farmers regarding the increasing of yields and almost none regarding processes for transformation of the Maya food system, based on cultural grounds, to ensure the use of either approach in the long term. In other words, the interface between science/knowledge and policy is weak; there is strong application of public policies regarding agroecology and regenerative agriculture, among the Yucatec Maya farmers, but almost no scientific support to accompany the process of transforming the food systems. Fonteyne et al. (2023) reviewed several databases to learn the directions and outcomes of research on milpa in general, not only the Maya; their findings seem to support the idea of a weak interface between science/knowledge and policies in the implementation of Sembrando Vida (agroecology) and regenerative agriculture.

The introduction of agroecology or regenerative agriculture to Indigenous Maya farmers demands a strong understanding of a process in which different cultures, each with different ways of creating knowledge, interact. The way both approaches, agroecology and regenerative agriculture, are implemented in the Yucatan is missing strong cultural bases in their participatory processes. It might not be enough to know that agroecology has strong bases on traditional/Indigenous agriculture (Rosado-May, 2016) and that regenerative agriculture practices are very similar to the ones practiced for centuries by Indigenous and local communities around the world (Sands et al., 2023). It cannot be assumed that the desired transformation of food systems will take place simply because the two approaches have Indigenous components.

The weak interface between science/knowledge and policy can be explained by the lack of studies on how to successfully transform unsustainable food systems in Indigenous settings. The main promoters of agroecology and regenerative agriculture programs in the Yucatan Peninsula are not Indigenous. On the other hand, the farmers implementing either of the two are Maya. Thus, like Turnhout et al. (2021) point out, credibility, legitimacy, and diversity of knowledge are critical for an efficient science/knowledge–policy interface for food system. It is extremely important to understand the best ways on how to have an efficient intercultural knowledge interaction to achieve the desired transformation of the food systems. Some of the critical elements missing in the process are the understanding of the thinking behind decisions and actions by Yucatec Maya farmers, how to identify components of their food system that can benefit from agroecology, regenerative agriculture, or both, and how to build bridges between cultures so that the transformation of the food systems can be sustainable.

Based on the results of the survey in Q. Roo, presented earlier, neither traditional knowledge nor the conventional way of farming, as the farmers know them now, seem to have the conditions to provide strong and reliable answers to the concerns expressed by the farmers. It is in this context in which the two approaches, agroecology and regenerative agriculture, already at work in Yucatec Maya communities, must build a stronger science/knowledge–policy interface, incorporating in their transformation processes Indigenous knowledge as Turnhout et al. (2021) point out.

Understanding the Yucatec Maya food system

The literature shows two different trends regarding the interpretation of the term "food system" when referring to the Maya. One of them focuses only on the well-known milpa as a system (Nigh and Diemont, 2013; D'Alessandro and González, 2017; Rodríguez-Robayo et al., 2020). The other trend considers the milpa as a part of a greater system (Wilken, 1971; Barrera-Bassols and Toledo, 2005; Toledo et al., 2008; Salazar et al., 2016). Based on the definition of a system provided by Backlund (2000), both interpretations are correct. However, for this research, to

Table 4. Components, subsystems, and stages of today's Yucatec Maya food system[a]

	Yucatec Maya Food System						
Stages	**Milpa, *Ich Kool***	**Home Garden, *Pach Pakal***	**Bee Keeping, *Kanáanil Kaab***	**Animals**	***Ka'anche'*[b]**	**Forest**	**Sembrando Vida**
Planning and preparing the ground Planting and management Harvesting, use, sell, share Postharvest management	The design and management of each subsystem requires[c]: – Species adapted to soil variability and climate conditions. This requires continuous creation and testing of varieties. – Intra- and inter-specific diversity in each subsystem, meaning that there is diversity not only in species but also in varieties per species as much as possible. – Given the unpredictability of climate conditions and the number of subsystems to attend, each of them is designed with elements thinking of as much self-maintenance as possible. This is how resilience is achieved. – Values guiding the destiny of the harvest, beyond meeting the needs of the family. This includes selling, exchanging, bartering, or simply sharing.						

[a]Only Sembrando Vida is very recent, since 2019; the other six have been in use since pre-Hispanic times.

[b]*Ka'anche'* is an elevated bed made with thick wooden sticks (see López Barreto et al., 2016, for a description).

[c]From hours of conversations, mainly from Don JHC, a well-known *nool iknal* in Xyatil, Q. Roo, to understand the bases of the Maya food system.

identify and understand how the food system works in Maya communities in Q. Roo, the point of reference was the definition of food systems provided by von Braun et al. (2021) for the UN Food Systems Summit in November 2021.[2]

Table 4 shows the components for the design and management of the food systems found in each of the 10 Maya communities listed in **Table 1**. None of them has access to aquatic sources such as lakes and rivers or carries out fish farming and the like. Four stages were identified for each subsystem: planning, planting and caring, harvesting and use, and postharvest management for soil/vegetation recovery.

The implementation of each of the four stages for each of the subsystems requires that their cycle, from planning to harvesting, has to be articulated with each other. The *ich kool*, milpa, is a combination of two cycles: one is annual to ensure harvesting of staple foods like maize, beans, and squash and starts after the slash and burn process; the other one is the use of the area for 3–4 years until the fallow period starts, which should last between 15 and 30 years. The number of species recorded from the *ich kool*, used for food, can reach a figure of 50; additionally several of these species have many varieties, especially of maize, beans, and squash, planted in the same field (Terán and Rasmussen, 2009). The *ich kool*, milpa, is located outside the settlement of the community and could be in the range of 1–7 km from the town.

The *pach pakal* (home garden) is designed to include an area for medicinal plants, another for ornamental plants, one more area for farmers to test some varieties and observe their adaptation before deciding to plant them in their *ich kool* or in their *pach pakal*, and another area where most of the plants are fruit and trees used to build houses. Many of the plants are also melliferous for the stingless bees, *Melipona*, (located within the *pach pakal*) or European bees (located near the *ich kool*, milpa). The first three areas have annual cycles, but the renewal of the species is constant; thus, completing the four stages mentioned in **Table 2** can be considered multiannual. The area dedicated to trees has a multiyear cycle. The home garden remains as a subsystem of the food system for many years; when a fruit tree needs replacement, the farmers do so, and the cycle continues. The typical size of a home garden nowadays is around 2,000 m^2. According to Toledo et al. (2007), the number of species recorded in Yucatec *pach pakal* fluctuates between 50 and 387, depending on the environmental conditions. For more details on Maya home gardens see Mariaca Méndez (2012) and Rosado-May (2012) for the meaning of *pach pakal*. The cycle of this subsystem lasts several years.

The *kanáanil kaab* (bee keeping), also known in Yucatec Maya as *meyabil kaab* and *kaláanil kaab*, is based on the pre-Hispanic domestication of stingless bees. According to Ayala (1999), 17 species of stingless bees are present in the Yucatan Peninsula, in addition to *Apis melifera*. However, the most important one, *Melipona beecheii*, is undergoing a rapid process of extinction (Villanueva-G et al., 2005). The cycle of this subsystem lasts several years.

Edible animals are part of a subsystem that has three expressions. One is animals as part of the *pach pakal*, including turkeys, chickens, ducks, pigs, or sheep; in this case, the number of animals is low, between 3 and 30.

2. Von Braun et al. (2021) say: "Food systems encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, and food industries, and the broader economic, societal and natural environments in which they are embedded."

Another one is for those farmers who like to profit from selling animals, then they have from a few dozen to hundreds of any of the abovementioned species; in this case, the animals are raised in special areas, not in the home garden. The third source of animals are the wild ones, hunted in the *ich kool* or the forest (e.g., *Crax rubra, Meleagris ocellata, Tayassu tajacu, Odocoileus virginianus, Dasyprocta punctata, Meles meles, Cuniculus paca*); the farmers create conditions for those animals to find food and then trap or hunt them (Santos-Fita et al., 2013). For all three options, the cycle lasts several years until the habitats are no longer suitable for those animals.

When animals are around, the best way to grow species like *Coriandrum sativum, Allium schoenoprasum, Dysphania ambrosioides, Mentha spicata,* and *Ocinum basilicum* is in a *Ka'anche'*, which is an elevated bed, constructed with thick wooden sticks, of around 1.30 m above the ground level, 0.90 m wide, and 1.5 m in length. The bed thickness is about 20 cm, filled with black soil. The location of the *Ka'anche'* is close to the house; the idea is to facilitate the planting, weeding, watering, and other management needs. Some houses have more than one. Usually, the production is high and sold in the neighborhood; part of it is exchanged for other food products. This subsystem has an annual cycle and is used intensively year after year, until the wooden sticks no longer can hold the soil; this takes from 3 to 5 years.

Forest, *ka'aax*, is a source of many resources to the Maya people. A proper management of the forest ensures the success of the *ich kool* food subsystem. According to Toledo et al. (2008), a range of 100–250 species are extracted from the forest to use in different activities by the Maya, including food, medicine, firewood, and construction material for houses; they estimate a consumption of around 4 metric tons of firewood per family. Maya people depend so much on their forest that they must have developed a sophisticated management. Gómez-Pompa et al. (1987) suggest that the high conservation in low deciduous forest in Yucatan is due to human, Maya, intervention. On the other hand, Rico-Gray and García-Franco (1991) present evidence that not all forest conservation in Yucatan is due to human intervention but to environmental conditions. Using paleoenvironmental, ethnobiological, and archaeological data, Ford and Nigh (2009) propose that the ancestral Maya established an intimate relationship with an expanding tropical forest, modifying the landscape to meet their subsistence needs. Following the assumption that a well-conserved forest is critical to the Maya, Toledo et al. (2008) report Maya names for different stages of the forest succession for a medium sub evergreen forest after three cycles of *ich kool*: *pokché ka'aax*, 2–3 years of recovery; *kabal hub-ché*, 5–10 years; *x'mehen ka'aax*, 10–20 years; *tankelem ka'aax*, 20–40 años; *nakuch ka'aax*, 40–100 years; *hobon ka'aax*, mature forest. The names are important because they represent concepts that indicate a very good knowledge of their system.

The newest food subsystem in Yucatec Maya communities is called Sembrando Vida (sowing life, SV). It is a federal government program implemented since 2019. SV was designed as an agroecological approach for small producers in Southern states and the Yucatan Peninsula of Mexico. SV claims to value local knowledge and to achieve food sovereignty while reducing environmental degradation (Pérez and Hernández García, 2022). SV is offered to farmers who can work on 2.5 ha, authorized by the ejido (see Perramond, 2008, for a description of a Mexican ejido land tenure system). In each community, SV is organized in groups of 25 farmers and 2 technicians who assist them and provide technical support; they are known as a Learning Community (Comunidad de Aprendizaje Comunitario, CAC, in Spanish). Each farmer receives monthly around $350.00 USD given by the government as an incentive to work and to appropriate the technics and agroecological concepts behind SV. In their 2.5 ha, each farmer develops two subsystems: one is called Agroforestry System, with forest species (Sistema Agro Forestal, SAF, in Spanish), and the other is called Integrated Milpa in Agroforestry but with fruit trees (Milpa Integrada a Árboles Frutales, MIAF, in Spanish). Each CAC has a nursery and facilities to produce its own fertilizers, liquid and solid, called biol fertilizer (see Rojas-Espinoza et al., 2023, for technical description). Two main concerns were detected in the interviews for this work. One is the uncertainty of the continuation of SV in the years to come, and the other is about creating conditions for selling the fruit products beyond their own communities. The objective of SV in achieving food sovereignty is still not clear (Pedraza López, 2021; Hernández Chontal et al., 2024).

Each farmer in each community has at least two food subsystems. The most common ones are the *ich kool* (milpa) and the *pach pakal* (home garden). Farmers managing three or more subsystems most likely do not have time to join SV. At a family and community level, there is a clear understanding that their access to food within the community depends on a system that they have developed to supply their needs; each subsystem plays an important role and is articulated with the rest in the community. The social fabric is also designed under this thinking and explains why the process of exchange of seeds, labor, goods, or food works well. The different sources of food from a specific farmer and the connection with other sources of food from other farmers within the community invite us to think that the Yucatec Maya farmers do have a good and solid understanding of "food system." Thus, the next step was to look for a word or words that reflect the concept of food system and the thinking that drives the hard work behind the production, consumption, and distribution of food, as well as caring for the environment.

Identifying the thinking that drives the design and management of the Yucatec Maya food system

The description of each subsystem of the Yucatec Maya food system, in the previous section, leads us to think that the concept of food system is present in Maya thinking. A combination of Maya words that reflect the idea of food system was identified: *u pak'alil tséentajil*. This colloquial expression assumes that food comes from nature. In all communities studied, nature means a combination of soil,

forest, including the species living there, people, and non-living beings. The words *u pak'alil tséentajil* derive from the following: *u* is the possessive pronoun for a third party; *pak'alil* comes from the word *pak'al* which is used to refer to a plantation or to farm; *tséentajil* is the combination of two words, *tséen* means to sustain, to care, and *tajil,* a modification of *tajal*, which means to cook, to season, to ripe. Altogether, this means that "*food is the result of a process that requires time, farming and caring for nature, to ripe well.*"

So far, the meaning of *u pak'alil tséentajil* gives the impression of system thinking but does not seem to reflect yet the same meaning of food system provided by von Braun et al. (2021). Two other words, associated with *u pak'alil tséentajil*, are important to incorporate in the analysis. One is farming, and the other one is milpa. Farming can be considered a synonym of agriculture. The Yucatec Maya word for agriculture is *meyajbil k'áax*, meaning working with nature or working with the forest (Rosado-May, 2016, p. 132); farming, or *pak'alil*, means a human way to work with nature.

The word milpa, probably the most well-known farming system in Mesoamerica (Barrera-Bassols and Toledo, 2005), associated with slash and burning in the Yucatan, does not have a Maya origin. It comes from the Nahuatl *milpan*, which is a combination of *milli*, meaning planted plot, and *pan*, which means upon (CONABIO, 2023). The word in Yucatec Maya for milpa is *ich kool*, which means the fruit (*ich*) that results from the work carried out on a land that has been cleared (*kool*), implying slash and burning practices. Not all milpas in Mesoamerica are farmed under shifting cultivation and slash and burning, but the *ich kool* is. When FAO announced on April 11, 2022, the inclusion of the milpa Maya as a Globally Important Agricultural Heritage System, they used the word *ich kool* first, respecting the local name and meaning of a food subsystem (FAO, 2022b).

By articulating the description of the subsystems of the Yucatec Maya food system, with the words *u pak'alil tséentajil*, *meyajbil k'áax*, *and ich kool*, the concept of food system emerges more clearly. This is a guide to understand the thinking of the Yucatec Maya on how to design and manage their food production.

To complete the analysis, two other elements were identified. One is based on a common feature that emerges from the description of the subsystems: diversity. The Yucatec Maya word *jeel* is used to mean different, varied, change, or supplement. The word changes a bit when the meaning refers to something diverse; the word for "diverse" changes from *jeel* to *jejeláas* or *jela'an*. In a conversation around the diversity of crops or varieties in the food system, the word that emerges more frequently is *jejeláasil*. A phrase used by the farmer, which led to finding the word for diversity, was "*in my ich kool or pach pakal, I always try to have several species and different varieties of the same species in the same area, so I will be prepared for any changes in the weather*" (in Yucatec Maya: *Ichil in paak'alo'ob ichkoole', kin kaxtik u yantal jejeláas paak'alo'ob yéetel u jejeláasil utia'al in máansik bix u k'éexpajal u yooxol k'iin*).

The other element was determined through recurrent colloquial phrases that Maya farmers use, which reflect the thinking that guides their decisions and actions around the design and management of their food system. The phrases were collected in two periods of time: after the planting in any of the subsystems and at the end of the year or a harvesting season. The phrases are not from a specific farmer; they were created as a result of several conversations directed at trying to identify a guiding idea. Once a phrase was created, it was discussed with a *nool iknal* to make sense out of it. The opinion of the *nool iknal* guided the final structure of each phrase, then it was tested, with farmers to determine if they relate to the idea expressed in the phrase.

For the moment related to finishing planting, a critical phrase that reflects the thinking of the farmers in that part of the production process was determined. The first idea that emerged was about certainty and uncertainty. The idea is expressed in ways that usually do not allow an easy detection. They are so common and usually not related to the concept of certainty and uncertainty because they are perceived in a religious/spiritual context. For example, after finishing planting, many farmers would say: "*I have done my part, now it is in the hands of God,*" or "*I did my best, but I am not sure how much I will harvest,*" two very common expressions. Basically, the interpretation is that the result of their actions, before and after planting, is now entering the realm of uncertainty.

The constructed paragraph, related to the moment after the planting, was: "*the only certainty I have in relation to farming, is that many things can go wrong. Many uncertain things, such as rain, pests, birds, rodents, etc., can happen. That is why I have to think hard on what and how to plant and not to rely on only one variety*" (in Yucatec Maya: *Ba'ax jach in woojel ti' in paak'alo'obe'; ichkool, paak'al ich kaaj, wa ti' jun xóot' lu'ume', yaan ba'al ma' in woojel bix kun yúuchul ti' ya'ab ba'alo'ob, nojla'ayile' yoolal cháak, iik'elo'ob, ch'íich'o'ob, bajo'ob, yéetel uláak' ba'alo'ob. Le beetike', yaan in tuklik ma'alob ba'ax ken in pak'ej yéetel bix ken in pak'ej, le beetik kin pak'ik u jejeláasil, yaan u jóok'ol jump'éel ma'alobi' utia'al uts'áaik u yich*). The idea behind the phrase is that the only certainty the farmers have is that there is uncertainty in their farming; many factors are not under their control, such as rain. All farmers exposed to this phrase showed their agreement.

The concept of certainty and uncertainty is present in many cultures, and it has been studied from different angles, especially for understanding climate adaptation processes (Horwitz, 2003; Wakeman, 2015; Mehta et al., 2019). According to Lewandosky et al. (2015), uncertainty creates conditions for innovation of knowledge, especially in dealing with climate. By having thousands of years of experience in farming, dealing with uncertainty, the Yucatec Maya farmers have a tremendous amount of knowledge that is waiting to be discovered by scientists. If given the proper conditions, through public policies with a strong interface with science and knowledge, those farmers could transform their food system to meet the expectations expressed at the beginning of this article.

Nevertheless, now we know that certainty of uncertainty, a concept that science has studied, is also present in the Maya thinking and it drives decisions and actions.

The second phrase found that helps to identify the thinking that guides the design and management of their food system was determined in a period of time when the farmers dedicate time to think and to plan their next season. Like in other cultures, the guiding questions for the planning of next season, by Yucatec Maya farmers, were how much to produce for different species, and how to do it. The response to these guiding questions depends on the resources available to the farmer, including land, time, conditions of the land, seeds, and the like. The word in Maya for "how much" is *buka'aj*, and to "produce," meaning agricultural production, is translated as *pak'ej*; the expression "how much" to produce is *buka'aj ken a pak'ej*. The word in Maya for "how to" is *bix*, and the expression "how to produce" is *bix ken a pak'ej*.

Based on the above and on ideas expressed in conversations, the following paragraph was created, discussed with the *nool iknal*, JWC, and then tested with farmers to get their reaction and comments: "*when I think about my farming for next season, I would like to make sure that I can produce enough food for my family, animals, and to sell or share a bit, without having to depend on others or the government and without harming the forest*" (in Yucatec Maya: *Le kéen in tukult in paak'al ti' jump'éel ja'abile', kin tuklik unaj in kaxtik bix ken in beet ya'ab jaanal utia'al in láaktsilo'ob,in waalak'o'ob, yéetel utia'al in konej wa utia'al in síiej beeyxan in k'exik yéetel uláak' ba'alo'ob wa janalo'ob ku beetik u jeel máak, mix k'a'abéet in ch'uytal ti' u jeel máako'obi' mix ti' yum ja'alach, yéetel kin kaláantik le yóok'olkaba'*). The agreement was unanimous, and the expression is aligned with all previous linguistic analyses of words and expressions related to the Yucatec Maya food system.

It is important to highlight three components of the above expression. One is about "making sure," the other one is about "enough food," and the third one is "without having to depend." Knowing that the Yucatec Maya food system has several subsystems and that diversity is an important feature in all of them, the first component, "making sure," sounds related to the definition of food security from FAO (2001): food security is the product of food availability, food access, stability of supplies, and biological utilization. The second component, "enough food," obviously produced locally, sounds related to the concept of food self-sufficiency expressed by FAO (1999) as the extent to which a country can satisfy its food needs from its own domestic production. The third component, "without having to depend," sounds related to the concept of food sovereignty established by La Vía Campesina (2009) and defined as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems."

In other words, to the Yucatec Maya, a food system has to meet all three: food security, food sufficiency, and food sovereignty. Usually, in non-Indigenous settings, those three concepts are used separately. Indigenous farmers do not fully understand programs that rest on only one of those three concepts. The thinking behind the need to combine all three together is that when each decision and action taken in a program is based on only one of those three components, there will most likely be difficulties. For instance, food security does not say where, when, whom, and how the food was produced; food sufficiency might have issues when a climate factor prevents to harvest as much as expected in a community; and food sovereignty might prevent the efficiency of social networks built between communities around food issues, especially between farmers and communities who choose different ways of producing their food (e.g., conventional, organic, or traditional).

Discussion

Yucatec Maya farmers are not alone in their concerns detected in 2020 and 2023, regarding their food system: yields not enough to meet their needs, loss of traditional knowledge, and openness to try new ways of farming that would not harm the environment. The need for transforming food systems has been in discussions for a number of years, especially for small farms (McCullough et al., 2008). In a recent publication, FAO (2022a) recognized that meeting the demand for food in the world's growing population is under threat without broader socioeconomic and environmental change. FAO notes there is a need to think beyond short-term needs and warns that a lack of vision and quick fixes will come at a high cost for everyone. The report does not mention directly, only implies it, the great potential there is for creating conditions so that different ways of creating knowledge can work together to understand and design comprehensive long-term public policies and actions to curb the threat of not producing enough food without harm to the environment and to the social fabrics in communities.

Indigenous Peoples have the longest experience in food systems (FAO, 2021) and have tried very hard to have their voices heard in different ways. They are usually among the most food insecure groups in many countries, yet their knowledge and understanding of food system processes are often sidelined or fully discarded (Elliott et al., 2012; Flanagan et al., 2021; Swiderska et al., 2022; UNEP, et al., 2023).

According to Garnett (2013), achieving a food system sustainability must be a global priority, but there are different views on how to do it. There is a need to understand the values underlying different approaches, and building common ground on understanding each other is critical, especially in multicultural societies and in working with Indigenous Peoples.

Research on Indigenous knowledge as potential contributions to food systems transformation is growing (Lemke and Delormier, 2018; Kennedy et al., 2022; Kuhnlein and Chotiboriboon, 2022; Vijayan et al., 2022); on the other hand, the thinking on the type of knowledge needed for food systems transformation is no longer biased toward only scientifically obtained knowledge. More and more organizations are broadening their understanding of knowledge, including local and Indigenous knowledge,

as a condition to search for innovative strategies to induce changes, transformation, of food systems, especially for small-scale farmers (Global Alliance for the Future of Food, 2021; OECD, 2022; von Braun et al., 2023; Brock et al., 2024).

The transformation of food systems is a complex process; the economy, environmental, social, and cultural components are different from one territory to the next. Thus, general principles are needed to guide the transformation. Assuming that agroecology was the best approach, in 2018 FAO presented 10 elements to guide the transition to sustainable food and agricultural systems. One of the 10 elements is called "co-creation and sharing of knowledge," which acknowledges that the path to transformation demands agricultural innovation and that the best way to have significant responses to local challenges is when they are co-created through a participatory process. This means that the local knowledge is appreciated and welcome to be a significant part of the process to design innovations in the food system. A few years later, in 2021, the International Panel of Experts on Sustainable Food Systems (IPES FOOD) with IFOAM Organics International, Agroecology Europe, FiBL, and Regeneration International published 13 key principles as a unifying framework for food systems transformation. Principle 8 is co-creation of knowledge, "aiming at enhancing co-creation and horizontal sharing of knowledge including local and scientific innovation, especially through farmer-to-farmer exchange."

Co-creation of knowledge has been increasingly recognized as an important component in scientific research. In fact, when a scientific article has two or more authors, it is the result of co-creation between individuals, in that these authors discussed ideas and data in the process of building the article. However, co-creation (sometimes called "co-production") can happen between scientists and technical researchers, and other people like government officials or community members. For example, Pearce et al. (2020) define co-creation as:

> *The generation of new knowledge that is derived from the application of rigorous research methods that are embedded into the delivery of a program or policy (by researchers and a range of actors including service providers, service users, community organisations and policymakers) through four collaborative processes: (1) generating an idea (co-ideation); (2) designing the program or policy and the research methods (co-design); (3) implementing the program or policy according to the agreed research methods (co-implementation), and (4) the collection, analysis and interpretation of data (co-evaluation).*

The concept of co-creation of knowledge has attracted the attention of organizations related to economic development. For example, OECD (2021) also has a definition focused on innovation:

> *[Co-creation] is the process of joint production of innovation between industry, research and possibly other stakeholders, notably civil society. These co-creation initiatives can take different forms such as projects, mechanisms or diverse institutional arrangements ranging from joint laboratories to industry-led innovation ecosystems.*

Agroecologists have embraced the concept of co-creation of knowledge, emphasizing ways in which different knowledge systems can be bridged. This has been described as a "diálogo de saberes," a dialogue between knowledges. The term emerged in the 1960s in the context of political resistance by people's movements in Latin America (Argueta Villamar, 2012). According to Leff (2006) and Val et al. (2024), dialogue of knowledges is a concept that implies processes of interactions between different ways of knowing and thus knowledges, including scientific, traditional, and popular or peoples' knowledge, as a way to enrich each other (see Vandermeer and Perfecto, 2013). It seeks to promote mutual comprehension and horizontal collaboration between these different kinds and ways of knowledge, with the goal of addressing social and environmental challenges in a more effective and sustainable way. The concept recognizes that knowledge is not neutral, it is a construction within a social, economic, and culturally specific context. Utter et al. (2021) address co-creation in agroecology without providing any specific definition, nor do they cite FAO (2018) or IPES FOOD (IPES FOOD et al., 2021). However, they provide some elements that give an idea on what they mean by co-creation:

> *Knowledge co-creation fosters participatory learning and development, which differs from passive knowledge sharing. This approach can bridge the real and perceived gaps across diverse forms of knowledge, including what is often distinguished as farmers' traditional, Indigenous, tacit, or local knowledge and experts' scientific, western, or generalizable knowledge.*

Our article does not intend to present an exhaustive review on the differences in the understanding of co-creation of knowledge. However, it is possible to say that the use of the term co-creation, without an adjective like intercultural, does not clearly imply the participation of different cultures and their respective ways of learning, creating, innovating, and transmitting knowledge. The idea of co-creation of knowledge has been around in Indigenous thinking for a number of years. Many Indigenous participants during the UN Food System Summit in 2021, and during the preparations, were talking about the importance of co-creation but not just any type of co-creation—they referred to intercultural co-creation of knowledge.

Building on previous definitions from Rosado-May (2015; 2016; Rosado-May et al., 2020), we propose to use the words "intercultural co-creation of knowledge" when

it comes to the participation of representatives of different cultures coming together to create new knowledge. This leads to the following definition: "Intercultural co-creation of knowledge is the result of a process that takes place in a safe space, in which different ways of learning, creating, innovating, and transmitting knowledge, coexist with mutual respect, allowing condition for new knowledge, intercultural knowledge, to emerge." When participating in a process of intercultural co-creation of knowledge, whether for conceptual or practical purposes, it is critical to follow high-standard principles to avoid misinterpretations, misconducts, or even difficult legal or economic situations. For instance, Kloppenburg et al. (2024) have documented the importance of equity even when applying a procedure for free, prior and informed consent, or the Nagoya Protocol when working on a project. Respecting the opinion and decisions of the knowledge holders, including a denial of open access to data, while researching or using data obtained from Indigenous Peoples, is a principle that should be observed by the researchers (Ravidran, 2024). Identifying principles and values to guide effective intercultural co-creation of knowledge is an area that needs further development.

Our article presents evidence that the Yucatec Maya farmers do have sophisticated knowledge in relation to their food system, demonstrated not only because of their resilience but also conceptually through sophisticated words and thoughts. Not only all the selected Western concepts, such as food systems, diversity, milpa (a Spanish adaptation of the original Nahuatl word), and home garden, were present in the Yucatec Maya vocabulary, but the two sophisticated phrases constructed (certainty in uncertainty, and the articulation of food security, sufficiency, and sovereignty) may be considered proof of the Yucatec Maya's strong and millennial resilience (Ford and Nigh, 2009) in their food system, as part of what is called in the Western thinking as "Cosmogony."

By providing this evidence of thinking and key words, it is now possible to consider how a solid process of co-creation of knowledge and innovation can happen between the Yucatec Maya and scientists or government programs to adapt agroecology and regenerative agriculture to local needs and ecological conditions. This is a missing component in the Sembrado Vida program, in Fundación Agroecología en la Peninsula de Yucatán (FAPY), as well as in the Regenerative Agriculture projects which focus only on soil recovery. None of them is actually focusing fully on the Maya food system, only on a small part of it. Having now words and concepts from both the Western scientific world and the Yucatec Maya world, the process of co-creation can happen under better conditions. New bridges can be built to allow the horizontal exchange of knowledge.

Data accessibility statement

The data presented in this article can be available by contacting the corresponding author. For the data collected from the *nool iknal*, a special permission from him is needed; the corresponding author can request it.

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Competing interests

The authors declare no conflicts of interests.

Author contributions

Conception and design: FJRM, VBCA.
Data collection and analysis: FJRM, JMTT, VBCA, JHRS.
Linguistic analysis: JMTT.
Crop yield data: JHRS, FJRM.

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