Colegio de Postgraduados

The traditional coffee agroecosystem in Chiapas: a systemic analysis of its ecological, productive, and sociocultural relevance

Guevara-Hernández, Francisco[1]; **Somá-Alvarez Luis Alberto**[1]; **La O-Arias, Manuel Alejandro**[1*]; **Cadena-Iñiguez, Pedro**[2]; **Aryal, Deb Raj**[3]; **Bonazzi-Piasentin Flora**[4]

[1] Universidad Autónoma de Chiapas. Facultad de Ciencias Agronómicas, Campus V. Cuerpo Académico Consolidado de Agroforestería Pecuaria. Carretera Ocozocoautla–Villaflores, Villaflores, Chiapas km. 84.5. C. P. 30470. Chiapas, México.

[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Centro de Chiapas del INIFAP/Km. 3.0, Carretera Ocozocoautla-Cintalapa, Ocozocoautla de Espinosa, Chiapas, México.

[3] Secretaria de Ciencia Humanidades Tecnología e Innovación (SECIHTI), Ciudad de México, México.

[4] Universidade Federal do Recôncavo da Bahia. Mestro Irineu Sacramento, S/N - Centro Cachoeira - BA, 44300-000, Brasil.

* Correspondence: manuel.arias@unach.mx

ABSTRACT

Objective: To analyze the traditional coffee agroecosystem in Chiapas from a systemic perspective to understand its ecological, productive, and sociocultural dimensions and to identify the relationships that explain its functioning and resilience.

Design/methodology/approach: A structured documentary review with a systemic and rational-deductive orientation was conducted using 42 scientific sources. The analysis was organized around ecological, productive, and sociocultural criteria and incorporated a SWOT matrix to synthesize the strengths, weaknesses, opportunities, and threats of shade-grown coffee systems in Chiapas and the Frailesca region.

Results: Three core attributes of the agroecosystem were identified: structural diversity, ecological and productive multifunctionality, and smallholder management supported by local knowledge. These characteristics contribute to productive stability and socioecological resilience. The review also revealed tensions associated with socio-environmental disturbances, phytosanitary vulnerability, and outmigration of young people. The SWOT matrix highlighted opportunities linked to differentiated coffees, the cultural value of the crop, and the role of shade in biodiversity conservation.

Research limitations/implications: The study relies on secondary sources and exposes gaps in systemic analyses of coffee production in the Frailesca region. Nevertheless, the review enabled the development of an integrative conceptualization of the agroecosystem and underscores the relevance of holistic approaches that articulate ecological, productive, social, and economic dimensions to guide future research and public policy.

Findings/conclusions: The traditional coffee agroecosystem is a complex system whose resilience depends on the interaction among diversity, multifunctionality, and smallholder management. Its long-term sustainability will require stronger ecological management, protection of local knowledge, and fairer market conditions for producers.

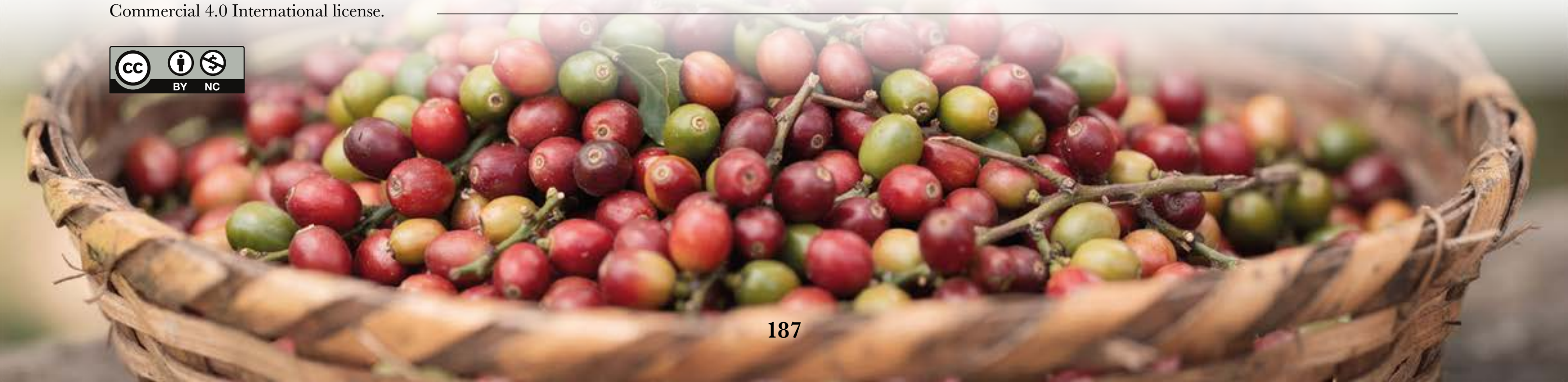
Keywords: Shade-grown coffee, agroforestry systems, biodiversity, climate resilience, family farming.

Citation: Guevara-Hernández, F., Somá-Alvarez, L. A., La O-Arias, M.A., Cadena-Iñiguez, P., Aryal, D. R., & Bonazzi-Piasentin F. (2026). The traditional coffee agroecosystem in Chiapas: a systemic analysis of its ecological, productive, and sociocultural relevance *Agro Productividad*. https://doi.org/10.32854/eth0bz65

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Juan Francisco Aguirre Medina

Received: January 5, 2026.
Accepted: March 27, 2026.
Published on-line: May 15, 2026.

Agro Productividad, 19(4). April. 2026. pp: 187-200.



INTRODUCTION

Coffee remains a significant commodity in international agricultural trade, with yearly production exceeding 10 million tons (FAO, 2020) and a consistent rise in global consumption (Delgado *et al.*, 2018). Cultivated primarily in tropical areas, coffee farming supports local economies and the livelihoods of countless smallholder producers.

Brazil, Vietnam, Indonesia, Colombia, and Ethiopia are the main producers, dominating the global supply chain (United States Department of Agriculture [USDA], 2023). Conversely, Mexico and Central America experienced a 7.7% decline in exports, attributable to adverse climatic conditions and escalating production expenses (International Coffee Organization [ICO], 2023).

Agroforestry systems, particularly those utilizing shade-grown coffee, furnish crucial ecosystem services. These services encompass biodiversity conservation, hydrological regulation, nutrient cycling, carbon sequestration, and erosion control (Muñoz-Villers *et al.*, 2020; Chazdon *et al.*, 2016; Villa *et al.*, 2020).

However, the availability of these services depends on how the system is structured and managed. This can be disrupted by poor practices or events that change the agroecosystem's structure.

According to the Agrifood and Fisheries Information Service (SIAP), Chiapas is Mexico's leading coffee-producing state, accounting for more than 37% of the country's total coffee production.

In this region, traditional coffee systems integrate native trees, polycultures, and subsistence crops, favoring soil conservation, production stability, and food security (Escamilla *et al.*, 2021).

The Frailesca region is a singular case. There, shade-grown coffee supports thousands of farming families, many of whom are indigenous, whose practices help preserve local knowledge, protect cultural and biological diversity, and mitigate the effects of climate change (Chazdon *et al.*, 2016).

Traditional coffee systems in Chiapas have undergone significant transformations driven by climatic variability, market fluctuations, changes in management practices, and pressures toward alternative land uses (Escamilla *et al.*, 2021). These changes have altered the ecological and socio-economic aspects of the agroecosystem, which has reduced its ability to recover. Therefore, a comprehensive approach is essential for understanding the complex interactions between biodiversity, management practices, ecological functions, and external pressures, as well as for assessing the Frailesca coffee system's complexity and interconnectedness.

Given the relevance of Chiapas to national coffee production, this article analyzes the current state of the traditional coffee agroecosystem in the Frailesca region in order to assess its ecological, productive, and sociocultural importance and to identify its main vulnerabilities in the face of climatic, economic, and socio-environmental pressures that threaten its continuity.

MATERIALS AND METHODS

This investigation employed a documentary review, leveraging a rational-deductive methodology (Hyde, 2000), with the objective of synthesizing and systematizing pertinent data concerning the traditional coffee agroecosystem in Chiapas and the Frailesca region. The methodological approach used was a structured narrative review. This method is well-suited for organizing different types of evidence, identifying conceptual patterns, and analyzing inconsistencies within complex socio-agroecological systems (Grant & Booth, 2009; Snyder, 2019).

The literature search, which used Google Scholar, ResearchGate, Web of Science, SciELO, and institutional repositories, was conducted from January to October 2024.

The search used keyword combinations like "coffee in Chiapas," "traditional agroecosystem," "shade-grown coffee," and "Frailesca region."

The selection process followed predefined inclusion and exclusion criteria. The analysis included a total of 42 documents published between 2000 and 2024.

These documents provided information about the ecological structure of traditional systems, their sociocultural aspects, the limitations on production, and relevant statistics at local, national, and international levels.

Duplicate studies or those not directly related to the objectives of the study were excluded.

The information was organized using thematic matrices and a comparative analysis grounded in a systemic perspective, consistent with the agroecological conception of the agroecosystem as a complex unit in which ecological, productive, and sociocultural dimensions interact. In addition, a SWOT matrix was developed to synthesize the main strengths, weaknesses, opportunities, and threats facing the traditional coffee system in Chiapas and the Frailesca region.

RESULTS AND DISCUSSION

Productive context of coffee at the global, national, and state levels

Coffee is a strategically important crop worldwide. In the 2023-2024 growing season, global production was estimated at 171.4 million bags. Brazil and Vietnam were the leading producers. In contrast, Mexico and Central America have seen production declines due to climate-related issues and pests like coffee leaf rust (Avelino & Anzueto, 2020; USDA, 2023; SIAP, 2024).

Despite the observed decline, Mexico continues to hold a significant role in organic coffee production, specialty and quality coffees, and fair trade markets, demonstrating indications of a productive rebound (Rosales *et al.*, 2023; SIAP, 2024).

Nationally, Mexico's production reached one million tons, with Chiapas maintaining its status as the foremost producing state, contributing 390 thousand tons, succeeded by Veracruz and Puebla, which produced over 253 thousand and 223 thousand tons, respectively (Figure 1). This distribution reveals a high degree of territorial concentration in coffee production, as several states contribute only modest volumes, such as Querétaro (330 t) and Morelos (35 t).

In Chiapas, the state's coffee production shows a varied pattern. Municipalities like Motozintla, which produces around 94 thousand tons, Tapachula, at nearly 83 thousand tons, and San Cristóbal de las Casas, exceeding 54 thousand tons, dominate state production. These areas benefit from favorable agricultural and ecological conditions.

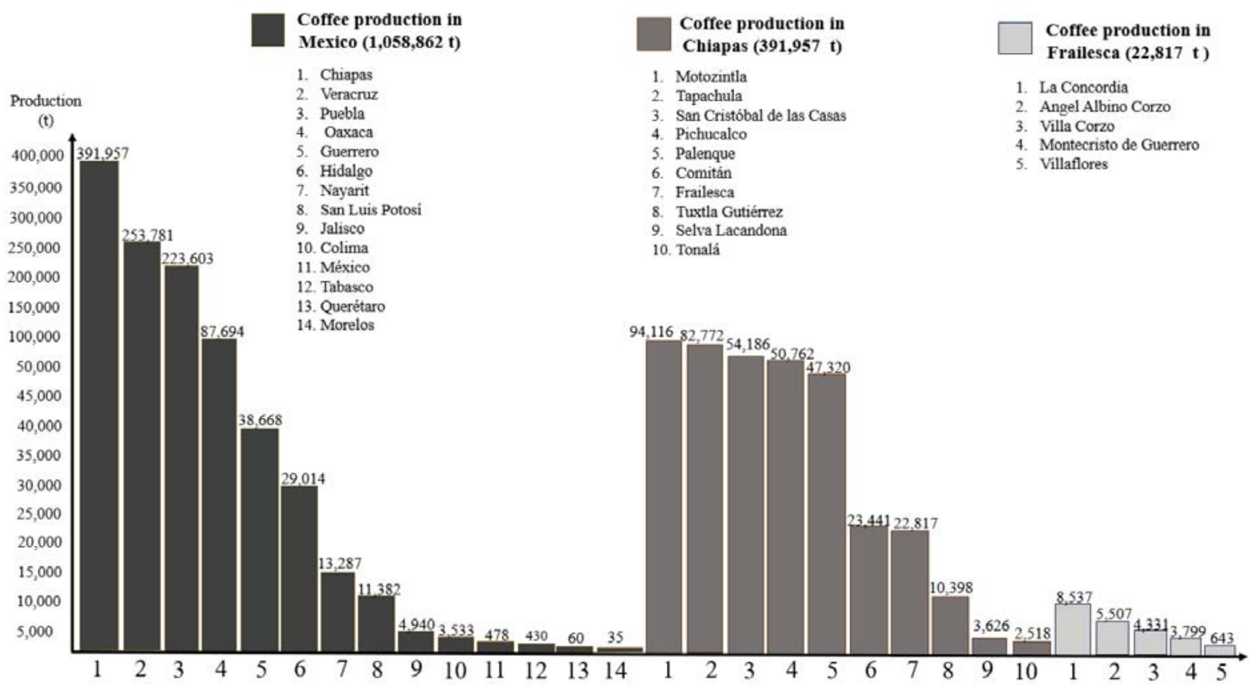


Figure 1. Coffee production in Mexico, Chiapas, and the Frailesca region. Source: elaborated based on the Statistical Yearbook of Agricultural Production (SIAP, 2024).

In contrast, municipalities like Tonalá and the Lacandon Rainforest region show low production levels.

Within this context, the Frailesca region contributes nearly 23 thousand tons, equivalent to approximately 2.2% of national production. Within the region, the municipalities of La Concordia (slightly more than 8,500 tons), Ángel Albino Corzo (around 5,400 tons), and Villa Corzo (just over 3,300 tons) concentrate most of the regional output, whereas Villaflores records considerably lower values, with slightly more than 600 tons. Although the Frailesca is not the main coffee-producing zone in the state, its relevance lies in the persistence of shade-grown agroforestry systems, characteristic of smallholder farms and diversified peasant management.

Agroecological overview of shade-grown coffee in Chiapas

Shade-grown coffee cultivation in Chiapas develops in mountainous environments characterized by diverse microclimates, volcanic-origin soils, and tree cover approaching 90%, conditions typical of the state's traditional management systems (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad [CONABIO], 2015). This production, largely organized by smallholder farmers, has substantial social, economic, cultural, and ecological importance in the region (INCAFECH, 2022).

The activity is based on small-scale landholdings: most producers, including numerous households from indigenous peoples, cultivate plots smaller than five hectares, and approximately 180,000 families depend on coffee as their primary source of livelihood (Secretaría de Agricultura y Desarrollo Rural [SADER], 2020). Varieties of *Coffea arabica* L. predominate, such as Typica, Red Bourbon, and Yellow Bourbon, adapted to altitudes between 1,000 and 1,300 m a.s.l. (Escamilla *et al.*, 2021). Family labor organization, in which women's participation is fundamental, constitutes a central axis of productive dynamics (Merlín *et al.*, 2018).

From an ecological perspective, traditional coffee plantations form highly diverse agroforestry arrangements distributed across mountainous areas, humid tropical forests, and cloud forests. Their vertical vegetation stratification promotes soil conservation, hydrological regulation, and the persistence of a wide diversity of plants, vertebrates, insects, fungi, and microorganisms (CONABIO, 2015; Libert & Paz, 2018).

The canopy observed in the Frailesca region is characteristic of traditional shade-coffee management (Figure 2).

The types of coffee plantations present in the state vary according to shade density and tree species richness, ranging from highly diverse rustic arrangements to plantations established under full sun (Table 1). In the Frailesca region, traditional polyculture (TP) and the specialized system (SS) predominate. The former integrates native species as well as local or introduced fruit trees, whereas the latter features a canopy dominated by *Inga* spp., particularly *Inga vera* (chalum) (Escamilla *et al.*, 2021).

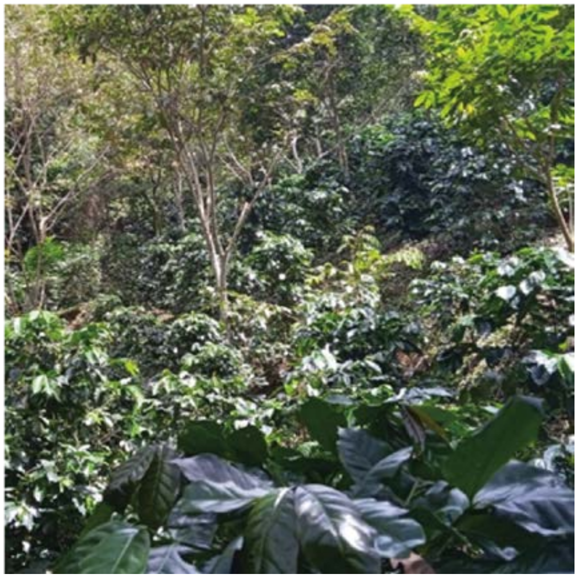


Figure 2. Multistratified traditional coffee plantation in Villa Corzo, Chiapas. Source: authors' own elaboration, 2024.

Table 1. Canopy cover, shade tree richness, and coffee plantation types.

Coffee plantation type	Canopy cover (%)	Shade tree richness (number of species)
Rustic	71-100	>50
Traditional polyculture	41-70	21-50
Commercial polyculture	31-40	6-20
Shaded monoculture	10-30	1-5

Source: table elaborated based on Harvey *et al.* (2021).

This structural diversity confers both productive and ecological resilience, while also sustaining multiple environmental benefits. Breitler *et al.* (2022) describe traditional management as having several key features. These include: (1) polycultures that combine coffee with shade trees like *Inga* and *Erythrina*, along with crops for food and fruit trees; (2) farming methods that use few resources, such as pruning, composting, and biological pest control; and (3) the positive effects on soil health, climate regulation, and the conservation of wildlife habitats.

Conversely, shade-grown coffee systems in Chiapas are currently experiencing escalating pressures. The challenges facing coffee production stem from several factors: coffee leaf rust (*Hemileia vastatrix*), climate change, deforestation, the loss of shade cover, the use of less resilient coffee varieties, a lack of public policies that support conservation, and the aging population of coffee producers (Avelino & Anzueto, 2020; Venegas *et al.*, 2021; Harvey *et al.*, 2021).

These circumstances jeopardize the system's survival, thereby highlighting the necessity of evaluating its present condition through a comprehensive lens. Despite these challenges, shade-based management continues, supported by its cultural, environmental, and economic importance.

Within this framework, endeavors like the Payments for Environmental Services initiative, championed by the Mexican Carbon Program (PMC, 2016), have become increasingly pertinent as tools to bolster the model's sustainability and to safeguard carbon reserves and agrobiodiversity.

Considering the intricacies stemming from the interplay of productive, ecological, and sociocultural elements, a systemic approach is crucial. This approach facilitates a holistic comprehension of their interrelationships and fosters progress toward a conceptualization of the coffee agroecosystem within the Frailesca region.

Conceptualization of the coffee agroecosystem in the Frailesca region

The coffee-growing environment: territoriality and productive base

The territorial configuration of the Frailesca region, comprising the municipalities of Villaflores, Villa Corzo, La Concordia, El Parral, Ángel Albino Corzo, and Montecristo de Guerrero, located between the Sierra Madre de Chiapas and the Central Depression, establishes an altitudinal gradient ranging from 279 to 2,755 m and defines a marked environmental heterogeneity (Comité Estatal de Información Estadística y Geográfica de Chiapas [CEIEG], 2021) (Figure 3).

These agroecological particularities support diverse coffee production systems in which both organic and conventional management practices are implemented, while a high level of genetic diversity is conserved. In the region, *Coffea arabica* and *C. canephora* are cultivated, with varieties such as Bourbon, Typica, Costa Rica 95, Oro Azteca, Caturra, Colombia, Sarchimor, Marsellesa, Geisha, and Guacamayo. In addition, 89% of producers maintain several of these varieties in association with fruit trees, forming multistratified systems characteristic of shade-grown coffee (Escamilla *et al.*, 2021; Venegas *et al.*, 2021; Reyes *et al.*, 2024).

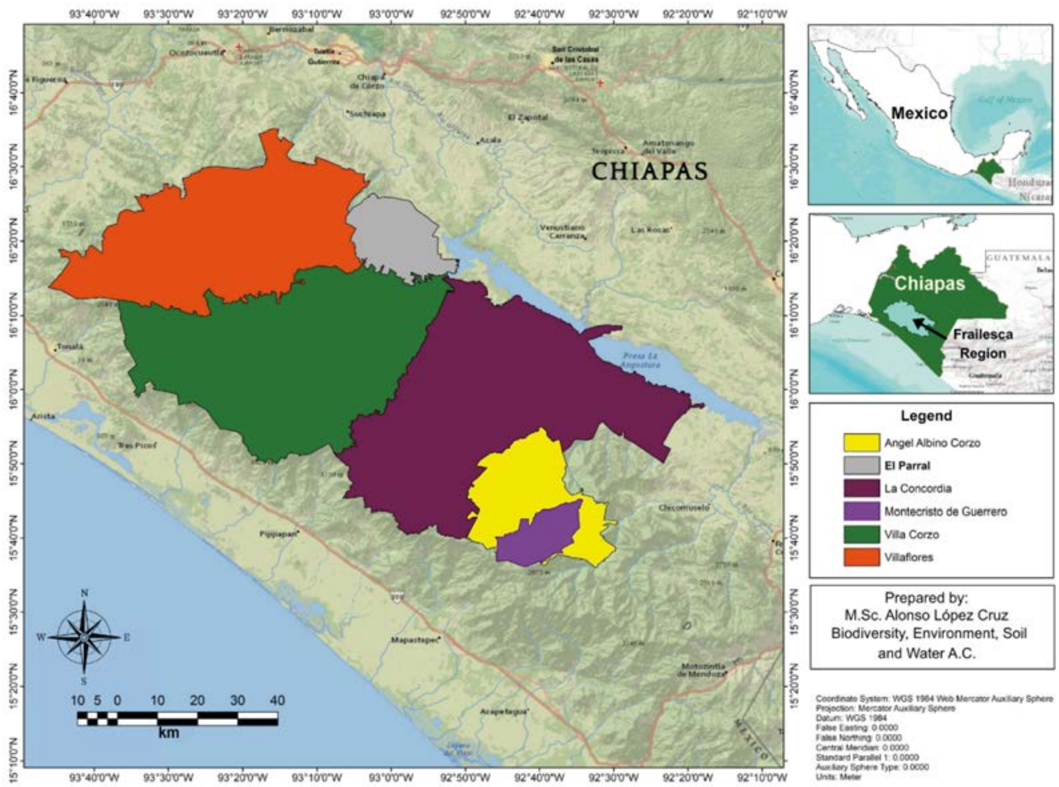


Figure 3. Frailesca region, Chiapas, Mexico.

Traditional coffee plantations incorporate a wide diversity of food and forest species that complement household diets and family incomes. These include pápalo (*Porophyllum ruderale*), purslane (*Portulaca oleracea*), black nightshade (*Solanum nigrum*), citrus species, mango, avocado, soursop, cassava, and jackfruit (CONABIO, 2015).

The prevailing tree layer, encompassing *Inga* spp. (chalum), *Casimiroa edulis* (caspirola), cedar, avocado, orange, mango, and mandarin, offers shade and facilitates crucial ecological functions, concurrently yielding timber, firewood, food, and medicinal resources (Reyes *et al.*, 2022; FAO, 2016; Benayas, 2023; Delgado *et al.*, 2018). This canopy's existence supports associated wildlife, such as migratory birds, bats, and indigenous pollinators, which are indispensable for the ecological integrity and equilibrium of the agroecosystem (Meza & Rodríguez, 2022).

Consequently, these attributes collectively illustrate a multifaceted system whose productivity and resilience are contingent upon the interplay of biological diversity, smallholder agricultural methods, and varied environmental factors, thereby establishing the Frailesca region's strategic significance within Chiapas' coffee production.

Structure of the agroecosystem

From a systemic perspective, the coffee agroecosystem of the Frailesca region can be defined as a socioecological unit oriented toward the integrated reproduction of productive, ecological, and sociocultural functions. Its general structure is organized around the following components:

Agroecosystem objectives

- Productive-economic dimension: To ensure shade-grown coffee production as the main source of household income, complemented by fruit production, timber, firewood, and other secondary products that strengthen the rural economy.
- Ecological dimension: To conserve essential processes, biodiversity, microclimatic regulation, soil fertility, and water capture, which sustain system productivity and resilience.
- Sociocultural and family dimension: To ensure peasant social reproduction through the transmission of knowledge, family-based labor organization, and the persistence of the cultural landscape.

System boundaries

- Physical boundaries: These include the coffee plot, the shade canopy, native and fruit trees, and associated polycultures. They define the biophysical space in which productive processes take place.
- Functional boundaries: These involve ecological and sociocultural relationships, microclimatic regulation, nutrient cycling, farmers' management decisions, and the conservation of local knowledge, all of which help sustain the system beyond its merely physical boundaries.
- Temporal boundaries: These correspond to the annual coffee cycle and its alternation between harvest periods (characterized by high labor demand and economic flows) and maintenance phases (dominated by family labor and coffee plantation conservation). These boundaries vary according to climatic, economic, and labor conditions.

Inputs and outputs

Inputs:

- Ecological energy: solar radiation, precipitation, volcanic-origin soils, and associated biodiversity.
- Cultural energy: local knowledge, management practices, and family labor organization.
- Labor energy: family labor and temporary labor support during the harvest season.
- Material inputs: seeds or seedlings, basic tools, agrochemical inputs, among others.

Outputs:

- Parchment coffee.
- Other products: fruits, timber, firewood, and medicinal plants.

Components or subsystems

The agroecosystem is organized into three interrelated subsystems:

- The ecological subsystem, encompassing volcanic soils, solar radiation, precipitation patterns, shade trees, and the biodiversity of both flora and fauna, functions to regulate the microclimate, nutrient cycling, water infiltration, and biological control mechanisms.

- The productive subsystem, centered on coffee cultivation as its economic foundation, also includes native fruit trees, complementary crops, and agroforestry practices. These practices encompass pruning, shade regulation, replanting, weed management, and soil conservation techniques.
- The sociocultural and labor subsystem incorporates the peasant household, its internal organization, local knowledge, management decisions, and seasonal labor participation. This subsystem is essential for cultural reproduction and the human energy metabolism of the overall system.

The dynamics of the Frailesca coffee agroecosystem are sustained by three fundamental energy flows, ecological, cultural, and labor, whose interactions determine its functioning and resilience (Figure 4).

The biophysical processes underpinning the system's functionality are delineated by this flow, encompassing light absorption, the hydrological cycle, the breakdown of organic matter, natural biological regulation, and microclimatic control. The coffee plantation's agroforestry design, characterized by its shade canopy and the biodiversity it supports, augments these processes and contributes to the system's ecological equilibrium (Odum & Barrett, 2005; Gliessman, 2015).

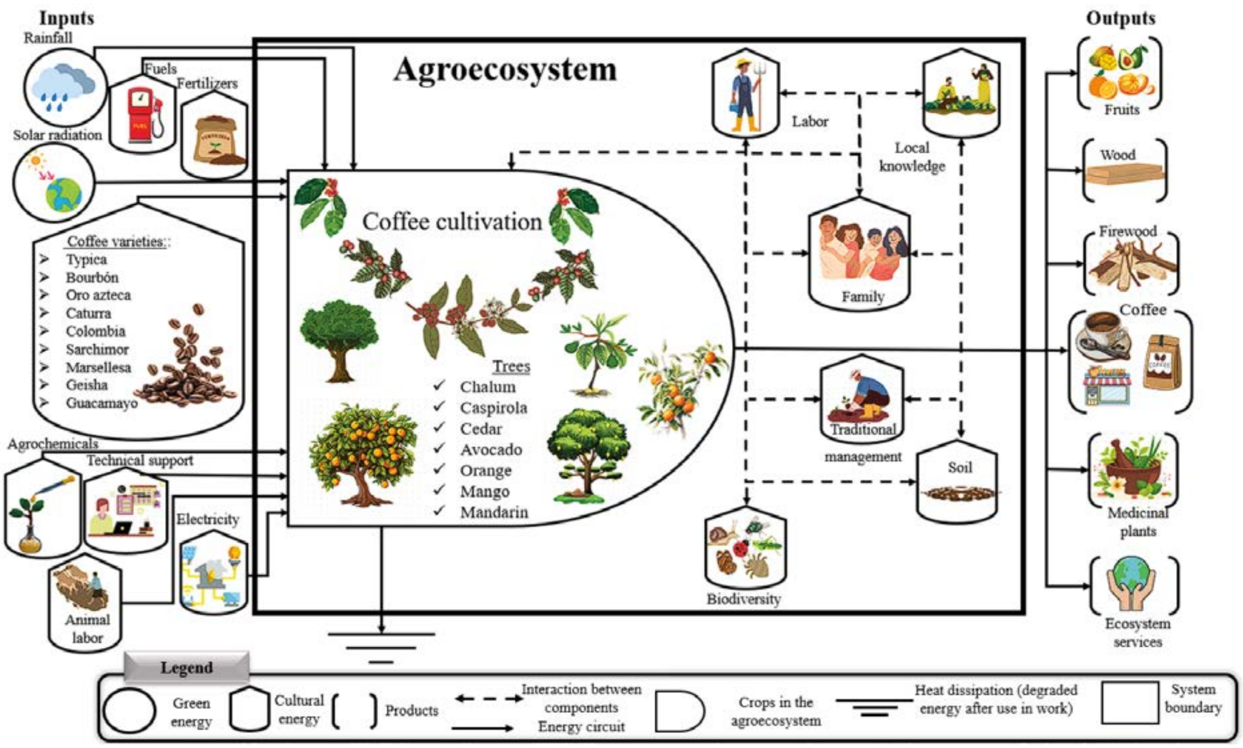


Figure 4. Functional dynamics of the traditional coffee agroecosystem in the Frailesca region, organized around ecological, cultural, and labor flows. Source: authors' own elaboration based on Odum and Barrett (2005).

Cultural flow

This flow pertains to the local knowledge, traditional practices, and social structures that inform management choices and influence the coffee plantation's configuration. It establishes the agroecological rationale of the system and its heritage aspect, thereby integrating technical, cultural, and familial knowledge (Toledo *et al.*, 2003; Altieri & Nicholls, 2017).

Labor flow

Labor flow encompasses the human effort that underpins management operations, coffee harvesting, and processing. The seasonal fluctuations inherent in this flow, characterized by labor surges during harvest periods and maintenance phases predominantly reliant on familial labor, govern the system's social metabolism and shape its productive temporality (Ruiz-Nájera *et al.*, 2016; Escamilla-Prado *et al.*, 2021).

Systemic integration

The interplay of these three flows gives rise to emergent properties that extend beyond mere productive results, including socioecological resilience, territorial stability, and adaptive capacity in response to climatic, economic, and environmental challenges.

Conceptual synthesis of the system

The coffee agroecosystem of the Frailesca region constitutes a complex socioecological unit grounded in mountain edaphoclimatic conditions and in local knowledge systems that organize coffee cultivation, the shade canopy, and associated goods. Its functioning integrates ecological, productive, and sociocultural components through flows of energy, matter, and labor that sustain community reproduction and territorial stability.

Beyond the plot scale, the system gains regional relevance by articulating productive, ecological, and cultural functions that are essential for rural well-being and territorial resilience. This configuration makes it particularly sensitive to a set of external and internal pressures that affect its adaptive capacity and continuity, while simultaneously offering opportunities derived from its biological diversity, agroforestry structure, and the strength of local knowledge.

Within this context, the factors conditioning agroecosystem stability are identified, including its weaknesses and threats, as well as its strengths and opportunities, which together define its potential for improvement and long-term sustainability.

Key aspects of the current coffee agroecosystem in the Frailesca region

The coffee agroecosystem in the Frailesca region faces structural challenges that compromise its ecological, economic, and social sustainability. Among the most relevant factors are the following:

1. **Climatic and phytosanitary pressures.**
   Variability in climate, escalating temperatures, and inconsistent rainfall patterns negatively impact both the yield and the quality of beans. These environmental

factors create conditions conducive to the spread of pests, including coffee leaf rust and the coffee berry borer, thereby causing persistent economic setbacks for smallholder farmers (Quiroga *et al.*, 2020; Prado *et al.*, 2021).

2. **Economic vulnerability.**
   Economic vulnerability stems from fluctuations in international market prices, dependence on intermediaries, and increased production costs, which collectively constrain the profitability of agricultural yields, particularly for small-scale family farms (Martínez & Manrique, 2014; Perfecto *et al.*, 2019).

3. **Productive and technological constraints.**
   The advancement of coffee systems and improvements in coffee quality are hindered by insufficient rural infrastructure, limited financial resources, and the continued use of outdated technologies (Fernández et al., 2020).

4. **Environmental degradation.**
   The ecological resilience of the system is diminished, and soil quality is compromised, due to processes like deforestation linked to land-use changes and the heavy application of agrochemicals, which subsequently impacts long-term productivity (Sosa *et al.*, 2018; Sáenz *et al.*, 2023).

5. **Social and demographic challenges.**
   A demographic aging of producers, outmigration of young people, and land fragmentation limit generational continuity and reduce local innovative capacity (Escamilla *et al.*, 2021; Henderson, 2019).

6. **Insufficient public policies.**
   Government support programs do not always reach the most vulnerable producers, and the lack of productive diversification strategies increases dependence on a single crop (Martínez & Manrique, 2014).

These factors together define socio-environmental vulnerability, which threatens regional coffee production. Addressing this issue requires a combination of strategies, including climate change adaptation, community organization, fair market access, and improvements in production methods.

Consequently, the systemic characterization and contextual analysis are integrated via a SWOT matrix, which incorporates strengths, weaknesses, opportunities, and threats, thereby facilitating the identification of critical factors for bolstering the territorial resilience of the Frailesca coffee agroecosystem.

SWOT analysis of the coffee agroecosystem in the Frailesca region, Chiapas

The Frailesca coffee agroecosystem exhibits strengths associated with its agroecological diversity, sustained by shade-grown polycultures that promote biodiversity conservation, soil protection, and community and family participation, particularly that of women. It provides essential ecosystem services, too, like capturing carbon and regulating water cycles. Beyond that, it plays a role in preserving high-quality coffee varieties, which rely on traditional knowledge to thrive.

Among the main opportunities are access to differentiated markets (organic and fair trade), Payments for Environmental Services programs, the growing global demand for sustainably produced coffee, and the availability of technological innovations aimed at improving productivity (Figure 5).

Weaknesses include an aging producer population, youth outmigration, dependence on intermediaries, high input costs, land fragmentation, and limitations in rural infrastructure.

Threats encompass increasing climatic variability, pests such as coffee leaf rust and the coffee berry borer, deforestation, volatility in international coffee prices, and the insufficiency of differentiated public policies. Taken together, these factors define a vulnerability framework that undermines the sustainability and profitability of the agroecosystem.

The SWOT analysis synthesizes the relationship between internal and external pressures. It indicates that the agroecosystem's future resilience depends on its ability to integrate ecological, productive, and sociocultural strategies. These strategies are essential for strengthening adaptation and ensuring long-term survival within the region.

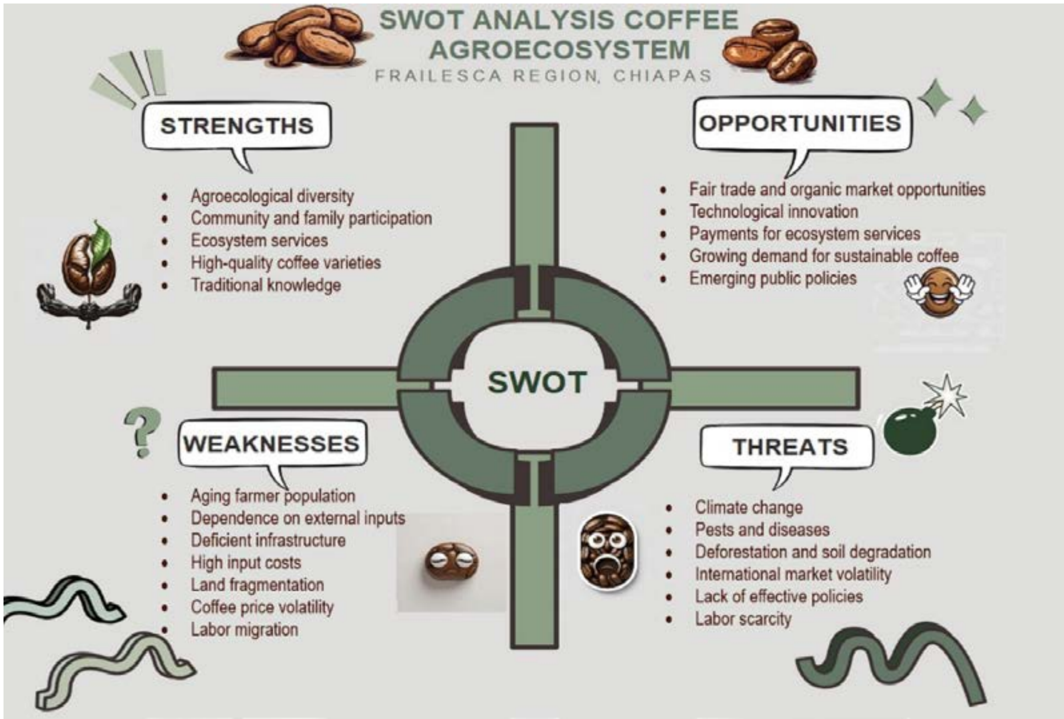


Figure 5. SWOT analysis of the coffee agroecosystem in the Frailesca region, Chiapas. Source: authors' own elaboration.

CONCLUSIONS

The systemic analysis shows that traditional coffee agroecosystems in Chiapas and the Frailesca region constitute socioecological units of high ecological, productive, and cultural relevance, sustained by biological diversity, agroforestry architecture, and local knowledge systems that confer territorial resilience.

It also identifies three critical pressures that threaten their continuity: (1) demographic vulnerability associated with aging producer populations and youth outmigration, (2) increasing climatic and phytosanitary stress, and (3) the absence of differentiated public policies tailored to small-scale coffee production.

The sustainability of these agroecosystems requires strengthening local capacities through strategies that integrate productive diversification, agroecological management, access to fair markets, and technical support. Integrating these elements is essential to ensure, in the long term, the ecological, economic, and sociocultural functions of shade-grown coffee systems in the region.

ACKNOWLEDGMENTS

The authors acknowledge the Digital Technology Agency of the State of Chiapas (ADITECH) for the support provided to the first author through the State System of Researchers.

REFERENCES

Altieri, M. A., & Nicholls, C. I. (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change, 140*(1), 33-45. https://doi.org/10.1007/s10584-013-0909-y

Avelino, J., & Anzueto, F. (2020). Coffee rust epidemics in Central America: Chronicle of a resistance breakdown following the great epidemics of 2012 and 2013. In J. B. Ristaino & A. Records (Eds.), Emerging plant diseases and global food security (pp. 185-198). The American Phytopathological Society. https://doi.org/10.1094/9780890546383.009

Benayas, J. M. R. (2023). La renaturalización del campo: Agricultura y biodiversidad pueden compartir la tierra (1st ed.). Aula Magna; McGraw Hill. https://documentacion.ceida.org/cgi-bin/koha/opac-detail.pl?biblionumber=12816

Breitler, J. C., Etienne, H., Léran, S., Marie, L., & Bertrand, B. (2022). Description of an Arabica coffee ideotype for agroforestry cropping systems: A guideline for breeding more resilient new varieties. *Plants, 11*(16), 2133. https://doi.org/10.3390/plants11162133

Chazdon, R. L., Broadbent, E. N., Rozendaal, D. M., Bongers, F., Zambrano, A. M. A., Aide, T. M., Balvanera, P., Becknell, J. M., Boukili, V., Brancalion, P. H., & Craven, D. (2016). Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. *Science Advances, 2*(5), e1501639. https://doi.org/10.1126/sciadv.1501639

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. (2015, August 13). Bosques, selvas y cafés de Chiapas: El café bajo sombra conserva la biodiversidad [Press release]. https://www.gob.mx/conabio/prensa/bosques-selvas-y-cafes-de-chiapas

Comité Estatal de Información Estadística y Geográfica de Chiapas. (2021). Anuario estadístico de Chiapas 2021. https://www.ceieg.chiapas.gob.mx/

Delgado-Matus, M., Loureiro-Sánchez, J. A., & Alcántara-Barrera, F. A. (2018). Evaluación de diversidad arbórea para selección de especies sucedáneas de reforestación en la subcuenca del Carrizal. *Mikarimin. Revista Científica Multidisciplinaria, 4*(1), 123-136.

Escamilla, E., Tinoco, J. Á., Pérez, H. A., Aguilar, Á. D. J., Sánchez, R., & Ayala, D. (2021). Transformación socioecológica en el agroecosistema café afectado por roya en Chiapas, México. *Revista Fitotecnia Mexicana, 44*(4), 643-653. https://doi.org/10.35196/rfm.2021.4.643

Fernández, C. Y., Sotto, R. K. D., & Vargas, M. L. A. (2020). Impactos ambientales de la producción del café y el aprovechamiento sustentable de los residuos generados. *Revista Producción Limpia, 15*(1), 93-110. https://doi.org/10.22507/pml.v15n1a7

Food and Agriculture Organization of the United Nations. (2016). Buenas prácticas agrícolas en el cultivo de café para reducir el impacto del cambio climático. https://www.fao.org/family-farming/detail/en/c/450200/

Food and Agriculture Organization of the United Nations. (2020). The state of food and agriculture 2020: Overcoming water challenges in agriculture. https://doi.org/10.4060/cb1447es

Gliessman, S. R. (2015). Agroecology: The ecology of sustainable food systems (3rd ed.). CRC Press.

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal, 26*(2), 91-108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Harvey, C. A., Pritts, A. A., Zwetsloot, M. J., Jansen, K., Pulleman, M. M., Armbrecht, I., Avelino, J., Barrera, J. F., Bunn, C., Hoyos, J., Isaza, C., Muñoz, J., Pérez, C. J., Rahn, E., Robiglio, V., Somarriba, E., & Valencia, V. (2021). Transformation of coffee-growing landscapes across Latin America: A review. *Agronomy for Sustainable Development*, 41, 72. https://doi.org/10.1007/s13593-021-00712-0

Hyde, K. F. (2000). Recognising deductive processes in qualitative research. *Qualitative Market Research: An International Journal, 3*(2), 82-90. https://doi.org/10.1108/13522750010322089

International Coffee Organization. (2023). Coffee report and outlook: December 2023. https://icocoffee.org/documents/cy2023-24/Coffee_Report_and_Outlook_December_2023_ICO.pdf

Merlín, Y. F., Charbonnier, A., Contreras, O. B., Herrera, H., & Soto-Pinto, L. (2018). Tipología de estrategias campesinas en la caficultura orgánica de la Sierra Madre de Chiapas. *Ecosistemas y Recursos Agropecuarios*, 5, 411-423. https://doi.org/10.19136/era.a5n15.1714

Muñoz-Villers, L. E., Geris, J., Alvarado-Barrientos, M. S., Holwerda, F., & Dawson, T. E. (2020). Coffee and shade trees show complementary use of soil water in a traditional agroforestry ecosystem. *Hydrology and Earth System Sciences, 24*(4), 1649-1668. https://doi.org/10.5194/hess-24-1649-2020

Odum, E. P., & Barrett, G. W. (2005). Fundamentals of ecology (5th ed.). Brooks/Cole.

Perfecto, I., Jiménez, M. E., & Vandermeer, J. (2019). Coffee landscapes shaping the Anthropocene: Forced simplification on a complex agroecological landscape. *Current Anthropology, 60*(S20), 236-250. https://doi.org/10.1086/703413

Quiroga, S., Suárez, C., Solís, J. D., & Martínez-Juárez, P. (2020). Framing vulnerability and coffee farmers' behaviour in the context of climate change adaptation in Nicaragua. *World Development*, 126, 104733. https://doi.org/10.1016/j.worlddev.2019.104733

Reyes, E. I., Bolaños, M. A., Escamilla, E., & Libert, A. (2024). Post-harvest practices for the production of specialty coffees in Chiapas, Mexico. *Agrociencia, 58*(5), 1-14. https://doi.org/10.47163/agrociencia.v58i5.2880

Reyes, J., Rodríguez, J. A., Pimienta, D. J., Fuentes, M. A., Marroquín, P., Merino, A., & Aguirre, J. F. (2022). Diversidad y estructura de los árboles de sombra asociados a *Coffea arabica* L. en el Soconusco, Chiapas. *Revista Mexicana de Ciencias Forestales, 13*(71), 4-27. https://doi.org/10.29298/rmcf.v13i71.1191

Ruiz-Nájera, R. E., Medina-Meléndez, J. A., Gómez-Castañeda, J. C., Sánchez-Yáñez, J. M., Gómez-Alfaro, G., & Pinto-Molina, O. (2016). Estudio del sistema de producción de café (*Coffea arabica* L.) en la región Frailesca, Chiapas. *CienciaUAT, 10*(2), 33-43. https://doi.org/10.29059/cienciauat.v10i2.550

Servicio de Información Agroalimentaria y Pesquera. (2024). Anuario estadístico de la producción agrícola 2023. https://nube.agricultura.gob.mx/cierre_agricola/

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sosa, V. J. (2018). Oportunidades de conservación del bosque de niebla a través del manejo alternativo: Los agroecosistemas cafetaleros. *Agroproductividad, 10*(1), 103-109. https://revista-agroproductividad.org/index.php/agroproductividad/article/view/940

Toledo, V. M. (2003). Ecología, espiritualidad y conocimiento: De la sociedad del riesgo a la sociedad sustentable. PNUMA/UNESCO. https://www.redalyc.org/pdf/461/46120106.pdf

United States Department of Agriculture. (2023). Coffee: World markets and trade. https://goo.su/oL5guk

Venegas, A., Soto, L., Álvarez, G., Alayón, Á., & Díaz, E. (2021). La diversificación de estrategias socioambientales en la familia campesina: Mecanismo de resiliencia ante la crisis del café en Chiapas. *Pueblos y Fronteras Digital*, 16, e510. https://doi.org/10.22201/cimsur.18704115e.2021.v16.510

Villa, P. M., Martins, S. V., de Oliveira, S. N., Rodrigues, A. C., Hernández, E. P., & Kim, D. G. (2020). Shifting cultivation and agroforestry in the Amazon: Premises for REDD. *Forest Policy and Economics*, 118, 102217. https://doi.org/10.1016/j.forpol.2020.102217