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Article

Biocultural and socioeconomic dimensions of sustainability in agroforestry systems diversified with cacao and vanilla

José M. Ramos-Prado[1]
Esteban Romero-Hernández[2]
Primo Sánchez-Morales[2]
Daniel Jiménez-García[2]
Enrique Hipólito-Romero[1§]

[1]Center for Eco-Literacy and Dialogue of Knowledge-Universidad Veracruzana. priv. Guillermo Prieto no. 2, Col. Centro, Coatepec, Veracruz. CP. 91500. Tel. 228 4116246. (jramos@uv.mx; ehipolito@uv.mx). [2]Center for Agroecology-Benemérita Autonomous University of Puebla. José de Hernández Street #15 A, Col. Obrero Campesina, Xalapa, Veracruz. CP. 91020. Tel. 228 1710899. (esteban.rohe21@gmail.com; primo.sanchez@correo.buap.mx; daniel.jimenez@correo.buap.mx).

[§]Corresponding author: ehipolito@uv.mx.

Abstract

Agroforestry systems and productive diversification are sustainable alternatives that reverse the damages and risks of conventional agriculture. There are few sustainability studies that allow them to be incorporated into projects aimed at increasing profitability and improving the welfare of producers, restoring ecosystem services. The objective was to assess the sustainability of two traditional agroforestry systems, diversified with cacao and vanilla, in the states of Veracruz and Oaxaca. Agroecological techniques and business development strategies were promoted with the families of both producers. The research was carried out during the period: February 2012 to July 2020, the plots are located in the municipalities of San Pedro Ixcatlán, Oaxaca and Papantla, Veracruz. The methodology of the framework of assessment of natural resource management systems was used. The results showed that the initial states had a low intensive management, low use of inputs, high diversification and oriented to subsistence agriculture. After diversification, agroecological management and business development, transition states have improved in most sustainability indicators. In particular, profitability (benefit-cost index), which reached 1.2 for San Pedro and 2.6 for Papantla when added value is given to vanilla and cacao. The participation of women in emerging activities derived from diversification and the interest of young people to continue with activities of transformation of raw materials and the commercialization of value-added products are relevant.

Keywords: *Theobroma cacao* L., *Vanilla planifolia* A., agroforestry, business development, MESMIS, productive diversification.

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Introduction

Cacao (*Theobroma cacao* L.) and vanilla (*Vanilla planifolia* A.), emblematic crops of economic and cultural importance in Mesoamerica, were managed in traditional agroforestry systems (TAFSs) since the pre-Hispanic period. They were grown together with bubblegum trees, rubber trees, achiote and native palms in the useful rainforests of the Olmecs and Mayans, who domesticated the Mesoamerican landrace varieties of cacao, which they used in the production of chocolate, adding vanilla as a flavoring and aromatizing agent (Gómez-Pompa *et al*., 1990; Caso-Barrera *et al*., 2006).

TAFSs play an essential role in tropical rural economies; however, although cacao and vanilla are two commercial products with a high global demand, in Mexico they are produced marginally and their productivity and profitability do not represent a contribution to local livelihoods (del Amo *et al*., 2010; González-Jácome, 2019; Hipólito and Ramos, 2020). Their diversification with species of high economic potential such as cacao, vanilla, allspice (*Pimenta dioica*), avocado (*Persea americana*), achiote (*Bixa orellana*), pacaya palm (*Chamaedorea tepejilote*), etc., would allow improving rural livelihoods, as long as there is transformation and added value of raw materials.

It is also an opportunity for women, young people and older adults to have a more equitable share of rural livelihoods; thus, young people remain in their communities and get involved in business activities (del Amo *et al*., 2010; Rojas and Rodriguez, 2019; Hipólito and Ramos, 2020). However, there are very few studies on the evaluation and benefits offered by agroecology and business development in the sustainability of diversified TAFSs, for this reason, the general objective of the study was to assess the sustainability of two traditional agroforestry systems, diversified with cacao and vanilla, in the states of Veracruz and Oaxaca. The working hypothesis proposed that the sustainability of TAFSs is increased by diversifying them with cacao and vanilla, with agroecological management, added value of raw materials and the development of business capacities.

Materials and methods

Sites and areas of study

The study was conducted in two TAFSs: a) Cerro Camarón, municipality of San Pedro Ixcatlán, Oaxaca; and b) Nuevo Ojital, municipality of Papantla, Veracruz (Figures 1a and 1b). Both have a warm-humid climate with rains in summer, the natural vegetation is evergreen and semievergreen medium rain forests, the native groups correspond to Mazatecs in San Pedro and Totonacs in Papantla. Table 1 shows the climatic characteristics, topography and soils of the two TAFSs, Papantla and San Pedro.

Figure 1a. Geographic location of the locality of Cerro Camarón, municipality of San Pedro Ixcatlán, Oaxaca (https://mapcarta.com/es/ N473375173/Mapa).

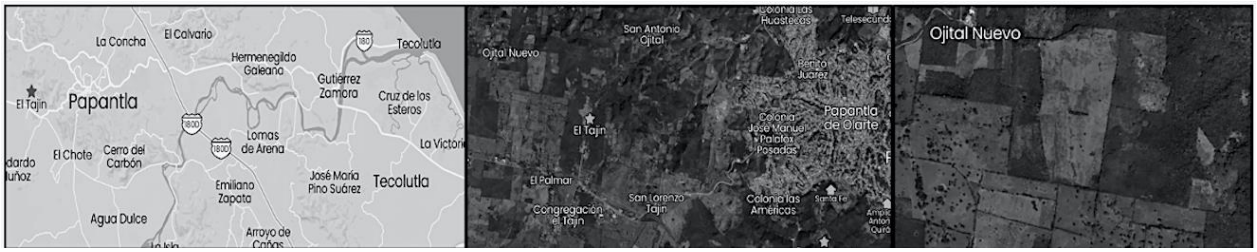

Figure 1b. Geographic location of the locality of Nuevo Ojital, municipality of Papantla, Veracruz (https://mapcarta.com/es/ N473375173/Mapa).

Table 1. Climatic characteristics, topography and soils within the two cacao-vanilla TAFSs in Papantla, Veracruz and San Pedro, Oaxaca (climate-data.org, 2018).

Municipality	Papantla	San Pedro
State	Veracruz	Oaxaca
Coordinates	20° 28’ 17” N - 97° 23’ 32” W	18° 09’ 13” N - 96° 34’ 55” W
Altitude (masl)	185	342
Precipitation	1 200	1 274
Solar radiation	392	365
Average temperature	24.2	23.7
Topography	Mountainous	Hills
Soils	Cambisol, Regosol	Leptosol, Luvisol

Average annual precipitation (mm), average solar radiation (W m^{-2} day^{-1}), average annual temperature (°C).

Productive diversification

It was codesigned with the producers in February 2012: an experimental plot of 0.5 ha was established within each TAFS. In the rainy season, June-September 2012, four clones of cacao (*Theobroma cacao* L.) of high productivity were planted: Inifap_1, Inifap_8, Inifap_9 and Neocriollo (López, 2014), 150 plants for each clone, resulting in a total of 600 plants in 0.5 ha. In both plots, a variety of mansa vanilla (*Vanilla planifolia* A.), obtained from neighboring plots, was planted with cuttings 80-100 cm long, healthy and vigorous, under tutors of orange (*Citrus sinensis*), colorín (*Erythrina americana*) and coffee (*Coffea arabica*), until having 800 and 400 cuttings in 0.5 ha, for Papantla and San Pedro, respectively.

Mixed edaphic bacterial inoculants were applied as biofertilizers at the time of planting (Hipólito *et al*., 2017), without applying any additional fertilizer. Management consisted of annual manual weeding, formation and maintenance pruning for cacao, channeling for vanilla, pest and disease control with biopreparations (IPES/FAO, 2010).

Canopy structure of the agroforestry system

Table 2 presents the records of the dominant (most frequent) trees in the upper and middle canopy: average height, diameter at breast height (DBH) and crown cover and for the upper canopy, crown richness, density and cover (Somarriba *et al*., 2018).

Table 2. Tree structure of the upper and lower canopy of the TAFSs, before diversification, for the municipalities of Papantla and San Pedro.

Municipality	Papantla	San Pedro
Dominant species of the upper canopy	*Swietenia macrophylla*, *Cedrela odorata*, *Acronomia mexicana*, *Pimenta dioica*, *Zuelonia guidonia*	*Cedrela odorata*, *Acronomia mexicana*, *Trema micrantha*
Richness of the upper canopy	10	6
Average height:upper canopy (m)	8.4 ±0.4	9.4 ±0.4
Average cover (m^2)	31.7 ±2.8	31.1 ±2.7
Average diameter (cm)	13.1 ±0.4	13.3 ±0.5
Density of trees (trees ha^{-1})	257	217
Dominant species of the lower canopy	*Citrus sinensis*, *Pimenta dioica*, *Erythrina americana*	*Musa paradisiaca*, *Coffea arabica*, *Thebroma cacao*
Lower canopy height (m)	5.2	4.6

Sustainability assessment

The methods were based on the framework of assessment of natural resource management systems (MESMIS, for its acronym in Spanish) (Astier *et al*., 2008; Speelman *et al*., 2007). A timeline was constructed for each TAFS diversified with cacao and vanilla, the ethnoecological explorations consisted of two knowledge dialogue workshops, six interviews and two surveys with producers and their families.

The workshops included the selection of the farms, the experimental design and the agroecological management program. With the participation of producers and their families, sustainability indicators and their critical points were defined. Annual activities were carried out: management training, technology transfer and business development; as well as tours, observations and direct measurements in the agroecological components of the TAFSs, family orchards and home (Altieri and Nicholls, 2002; del Amo *et al*., 2010; Alcázar *et al*., 2019; Cuevas *et al*., 2019).

Results and discussion

Critical points and indicators of sustainability

Ten indicators and their critical points were identified. Table 3 presents the methods and criteria for assessing sustainability indicators and their relationship with sustainability dimensions. Internal subsystems were also identified: the home and the family orchard; as well as external subsystems: agroecological technologies, labor, services, training, tools, equipment, materials and consumables; in their biophysical, biotic contexts, and local-regional socioeconomic aspects.

Table 3. Methods used to record and assess the sustainability indicators obtained for the critical points, by attribute and dimensions: ecological (A), economic (E) and social (S).

Attribute	C. point	Criterion	Indicator	Method	Dimension
Production	Crop diversity	Yield	Production by species (kg ha^{-1} $year^{-1}$)	Interviews and direct measurement	AES
	Price fluctuation	Change in income	Sales prices ($)	Interview and bibliography	ES
	Profitability (R)	Benefits (B) and Costs (C)	R= (B / C)	Benefits and Costs	ES
Stability-resilience	Species diversity (D)	Diversity Index	Simpson index (D)	$D = \sum (n_1/N)^2$	AES AS
	Income diversity	Species diversity	Sources of income-sale	Interview and observation	AES
Equity	Gender	Men and women	Activities carried out	Interview and observation	ES
	Interest of young people	Intergenerational change	Interest in the countryside	Interview and observation	ES
Self-management	Family labor	Independence of labor	No. of family wages	Interview and observation	ES

Dimensions. A (ecological); E (economic); and S (social); kilograms (kg); hectares (ha): profitability (R); benefits (B); costs (C); pesos ($); diversity ($D= \sum (n_1/N)^2$).

Temporal narrative of the project

From February to December 2012, the experimental plots were established within the TAFSs, researchers from the Veracruzan University (UV, for its acronym in Spanish) and technicians from the Nestlé of Mexico Cacao Plan (NMCP) carried out two workshops of diagnosis and participatory design: productive diversification of TAFS with cacao and vanilla (Hipólito and Ramos, 2020). At the beginning of the project, there were two groups of 10 women each, who made handicrafts: a) mujeres artesanas de la vainilla, SC de RL de CV, in Papantla; and b) grupo de artesanías de vainilla, Cerro Totomoztle, SC de RL de CV. The capacity of handicraft making, depending on the cultivation area of each TAFS, was 50-100 kg 3 ha^{-1}, green vanilla per year and 150-200 kg 10 ha^{-1}, respectively.

From 2013 to 2014, annual workshops on rural community strengthening were held: agroecological management, technology transfer and rural business development. The groups of artisans were dissolved due to organizational problems and continued activities at the family level, in Papantla they established the company Vanilla el Ojital, SC de RL and in San Pedro they continued at the family level without registration. In 2019 and 2020, the sustainability assessments of this study were carried out following the MESMIS methodology, the results of which are shown below.

Agroecological characteristics of cacao-vanilla TAFSs

The shade of the upper canopy was adjusted to 40-60% of cover as established in the agroecological management plan, in areas with less cover banana (*Musa paradisiaca*) and cassava (*Manihot esculenta*) were planted as temporary shade, along with allspice (*Pimenta dioica*) and red cedar (*Cedrela odorata*) as permanent shade, pruning and thinning were carried out in areas with excess cover. Organic fertilization includes covers of legumes jack beans (*Canavalia ensiformis*) and velvet beans (*Mucuna pruriens*) and keeping weedings in place. Pruning includes training, maintenance and phytosanitation, integral pest and disease control includes the use of biopreparations.

Socioeconomic and cultural dimensions

The socioeconomic and cultural dimensions for the external subsystems of the cacao-vanilla TAFSs are described in Tables 4 and 5. The most significant input variables were agroecological, technological and business training, external labor in support of farm management, and drinking water and biofuel services (Table 4). The academics of the UV and technicians of the NMCP were in charge of the advice and training, it is important to mention the activities of the whole family and occasionally day laborers (mainly men) in the agroecological management of crops within the TAFS: pruning, shade management, weeding, biological fertilization, composting, integral management of pests and diseases and harvesting.

Table 4. Socioeconomic and cultural dimensions for the external input subsystems of the TAFSs diversified with cacao and vanilla and managed entrepreneurially.

External subsystems	San Pedro	Papantla
Training: a) agroecology b) transfer of technology c) business and commercialization	a) field schools, workshops and advice b) workshops and advice (value added to cacao and vanilla) c) advice in rural business development	a) field schools, workshops and advice b) workshops and advice (value added to cacao and vanilla) c) advice in rural business development
Labor: a) agroecological management b) value added c) commercialization	a) the whole family and day laborers b) the whole family c) the whole family	a) the whole family and day laborers b) the whole family c) the whole family
Services: a) drinking water, firewood and wood	a) the whole family	a) the whole family

Table 5. Socioeconomic dimensions for the outputs (sales) of the reference TAFS (before diversification) and the alternative one (eight years later), cacao-vanilla TAFS, for San Pedro and Papantla.

External subsystems	San Pedro	Papantla
Reference TAFS products	Self-consumption and local markets as raw material	Self-consumption and local markets as raw material
Cacao-vanilla TAFS products	500 kg cacao and 75 kg vanilla ha^{-1} $year^{-1}$	150 kg cacao and 550 kg vanilla ha^{-1} $year^{-1}$
Reference TAFS sales income	74% pacaya palm, coffee (14%), banana (9%) and cacao-vanilla and cedar (3%)	Vanilla, 80-90%, orange, cacao and cedar and mahogany planks (10-20%)
Cacao-vanilla TAFS sales income	Cacao: $27 500 year (local market), $37 500 $year^{-1}$ (Tuxtepec) Vanilla processed: $37 000 $year^{-1}$ (Tuxtepec)	Vanilla processed: $1^{st.}$ $ 293 000 $year^{-1}$ $2^{nd.}$ $ 220 000 $year^{-1}$ Extract: $ 290 000 $year^{-1}$

The values of production and profits are averages of the last two years.

The construction of community capacities and the restoration of the cultural fabric was implemented through the reinforcement of social capital with the field schools for the technological and business training of the families that manage the productive systems (del Amo *et al*., 2010). The following workshops and training activities were developed: a) traditional and technified processing of vanilla fruits, for the production of vanilla of extra quality and the preparation of vanilla extracts and liqueurs; b) cacao fermentation, drying, roasting and grinding processes to prepare artisanal chocolate; and c) family and community business organization to market in fair and solidarity markets.

Table 5 shows the outflows to the external market subsystem, of TAFS products to local and regional markets and the profits derived from them. The reference TAFS refers to the products of the species that already existed and continue to be produced and marketed, the alternative TAFS is presented as cacao-vanilla TAFS, after eight years of establishment.

For San Pedro, the highest proportion of total sales correspond to pacaya palm (61%), coffee (17%) and cacao (10%), in lower proportions are cedar, vanilla and banana (12%). The average price of dried cacao in the last five years averages $55.00 kg^{-1}, with collectors and up to $75.00 kg^{-1} in the Tuxtepec market. The average annual production in San Pedro, 500 kg, corresponds to $27 500.00 $year^{-1}$ in the local market and $37 500.00 $year^{-1}$ in Tuxtepec, without considering production and freight costs. The production of green vanilla, 75 kg on average, corresponds to $15 000.00 with collectors ($200.00 kg^{-1}) and up to $30 000.00 in Tuxtepec ($400.00 kg^{-1}). By processing vanilla 15 kg are obtained, for the loss of water, in Tuxtepec it is sold at $2 500.00 kg^{-1}, corresponding to an income of $37 000.00 $year^{-1}$ without considering production costs.

For Papantla, the little cacao they produce is used for self-consumption; while the vanilla processed represent 80-90% of total sales, the other products: orange, cacao, cedar and mahogany correspond to 10-20% of income. Green vanilla is marketed in Papantla for $300.00-500.00 with collectors and already processed it reaches prices of $6 000.00 to 8 000.00 kg^{-1}, depending on the quality. The family produced 250 kg $year^{-1}$ at the beginning of the project and for the biennium 2018-20 19 it reached an average of 550 kg $year^{-1}$ on the entire farm. They obtained an average of 110 kg of vanilla processed, 2/3 parts of 1st and 2nd quality that are sold directly at an average price of $8 000.00 and $6 000.00 kg^{-1}, respectively, obtaining profits of $293 000.00 and $220 000.00. The third-quality processed vanilla (approximately 37 kg) is transformed into 370 L of extract which corresponds to $290 000.00 at an average of $800.00 L^{-1}.

For San Pedro, a benefit-cost ratio of cacao-vanilla TAFS of 1.22 was obtained, which can be interpreted as a profitable system. For Papantla, taking into account the added value of the products currently marketed by the microenterprise, the B/C ratio reaches 2.1, high enough to meet basic needs and have remnants for maintenance and investment in technology that makes the cacao-vanilla TAFS more productive and efficient.

Equity, resilience and self-management

The participation of women and young people is very important in the attributes of equity, resilience and self-management, in the two families and TAFSs assessed it is very significant in key activities of the productive and transformation chain towards a value chain. Although the fieldwork is carried out mainly by men, young people, adults and older adults, in some management activities women also collaborate, mainly in the harvest of cacao and the pollination of vanilla.

Women work mainly in domestic chores, including carrying firewood and water, they also support postharvest vanilla activities to produce and sell the processed vanilla and extracts and cacao transformation to make and market chocolate. Young people, women and men, from both families, show interest in continuing with the cacao-vanilla TAFS and continuing with value-added and business technological activities for the production and commercialization of different products derived from cacao and vanilla.

Identification of critical points for sustainability attributes

The risk factors and opportunities of the critical points (strengths and weaknesses of the cacao-vanilla TAFS), for the different areas and attributes of sustainability, are shown in Table 6. For most of the critical points, the two families have similar strengths and weaknesses, which allows establishing common criteria for improvement through strategic plans of integral management that include agroecological, technological and business aspects.

The weaknesses and risks were observed in the attributes of productivity and stability, all of them related to the greater complexity of a cacao-vanilla AFS, in relation to the reference TAFS, mainly due to the agroecological management which is more intensive, complex and requires more inputs. Practices and value-added technologies and the search for fair and solidarity regional markets are a weakness for San Pedro and are a strength for Papantla, which highlights the important role of training, advice on aspects of value-added technologies, business development and commercialization, in the attributes of stability, adaptability and organization.

Table 6. Critical points (strengths and weaknesses) found based on sustainability attributes for San Pedro and Papantla.

Attribute	Critical point	San Pedro	Papantla	DS
Productivity	High diversity of crops and products	Strength	Strength	A
		Weakness	Weakness	AES
	Greater number of inputs	Weakness	Weakness	ES
	Price fluctuation and intermediaries	Weakness	Weakness	ES
Stability and resilience	High diversity of species-income	Strength	Strength	A
		Strength	Strength	ES
	Low prices and intermediaries. Climate change	Weakness	Weakness	ES
Adaptability	Agroecological technologies	Strength	Strength	AES
	Value-added technologies	Weakness	Strength	AES
	Rescue of traditional knowledge	Strength	Strength	AS
	Search for fair regional markets	Weakness	Strength	ES
Equity	High gender participation	Strength	Strength	ES
	High participation of older adults	Strength	Strength	ES
		Strength	Strength	ES
	High interest of young people in processing and commercialization			
Organization and self-management	Availability of family and community labor	Strength	Strength	ES
		Strength	Strength	AE
	Family and community organization	Weakness	Strength	ES
	Growing local market			

The dimensions of sustainability DS correspond to: A= ecological; E= economic and S= social.

Discussions

The sustainability of the agroforestry system depends not only on its costs and benefits, but also on the risks and opportunities that the diversification means, in particular the adoption of agroecological management technologies and business strategies. However, it is an opportunity to improve their livelihoods and become more environmentally and socioeconomically resilient (Armengot *et al*., 2016; Cerda *et al*., 2019; Hipólito and Ramos, 2020). Strengths and opportunities have similarities in the high diversity of crops and products, in particular social resilience, an essential aspect of sustainable agriculture (Adger, 2000; Altieri and Nicholls, 2012; Cuevas *et al*., 2019).

The cacao-vanilla TAFSs assessed have a similar ecological structure: they are multistratified, heterogeneous, with timber and fruit trees in the upper canopy and with fruit and ornamental trees in the lower canopy, characteristics that agree with what was proposed by Cerda *et al*. (2019), on the value of environmental services of TAFSs and the need for their quantitative assessment. Agrobiodiversity increased with diversification: four varieties of cacao, banana, cassava, timber trees and fruit trees for shade. In addition, according to Resilience (2007); Priego *et al*. (2009); Altieri and Nicholls (2012), they provide habitat for wildlife species, promoting the resilience of the system.

Although the presence of cacao and vanilla in Mesoamerican TAFSs is common, they are underutilized since there is little productivity and are sold as raw material. The increase in production and its transformation and sale significantly increased some sustainability indicators, in the period of time studied. Adaptability, equity and level of family organization show a synergy with traditional knowledge, as well as the novel participation of women, young people and older adults, in all emerging activities that imply productive diversification (Hipólito and Ramos, 2020).

The socioeconomic and biocultural dimensions are strengthened by the ancient traditions of the native ethnic groups, Mazatecs in the case of San Pedro and Totonacs in Nuevo Ojital, making indispensable the study of their forms of formal and informal organization, sociocultural relationships. Aspects that need to be characterized in greater detail to assess sustainability more accurately (Adger, 2000; del Amo *et al*., 2010; Cuevas *et al*., 2019). Profitability is a necessary, but not sufficient condition of sustainability, the most sustainable agroforestry systems are those that combine a product of high value in the market, such as coffee or cacao, with agroecological practices (Hipólito *et al*., 2010; Cerda *et al*., 2019; Priego *et al*., 2019).

Conclusions

TAFSs diversified with cacao and vanilla have higher values of sustainability and resilience, in most of the indicators assessed, than the reference systems before diversification, not only because of the increase in production of vanilla and cacao, but also because of the added value of their processing and direct commercialization. The family that manages the cacao-vanilla TAFS in Papantla depends mainly on a single source of income, the vanilla processed, which makes them more sustainable in socioeconomic terms, but less resilient to climate change, compared to that of San Pedro whose main income is more diversified and directed to the local market, which limits the development of their livelihoods. In both systems there is interest of young people to continue with the activities of maintaining the agroecosystem and develop technological and business aspects, which favors the resilience and sustainability of the TAFSs, by taking advantage of the opportunity of new technologies and fair and solidarity markets.

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