Review [Revisión]

CACAO AGROFORESTRY SYSTEMS AND RESILIENCE: POTENTIAL FACTORS IN THE FACE OF THE CLIMATE CHANGE IN MEXICO †

[SISTEMAS AGROFORESTALES DE CACAO Y RESILIENCIA: FACTORES POTENCIALES ANTE EL CAMBIO CLIMÁTICO EN MÉXICO]

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SUMMARY

Background: The cacao agroforestry system (Cacao-AFS) is a small-scale design system with a great diversity and multiple functions; at the same time that is very vulnerable to the climatic variability. Through resilience is possible to see, how does a system respond and/or reorganize in the face of a perturbation like climate change. This work makes a review of Cacao-AFS and analyzes its potential resilience to climate change. **Methodology**: A review of the state of the art about the cacao system and its resilience had been organized from an analysis of 249 works consulted from bibliographic bases. The information was codified in six factors (scientific and contemporaneous knowledge, agrobiodiversity, socioecological autoregulation, capital, and social self-organization) and climate change implications, and finally evaluated through a matrix. **Results:** Through the review of the literature, it was found that there is a great adaptive capacity because scientific innovation and contemporaneous knowledge it generates different actions to solve some problems of the system. Also, it was found that there is a great agrobiodiversity in the system that allows the socioecological reproduction of the system (autoregulation). On the

† *Submitted November 29, 2021 – Accepted March 8, 2022.* http://doi.org/10.56369/tsaes.4121

ISSN: 1870-0462.
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other hand, the system is low rentable and the young people don`t want to incorporate to the activity (low capital) and the social actors don´t use to cooperate (low self-organization). **Implications:** It was found that there are some aspects that favor the resilience of cacao system and others that need to be improved. To improve the resilience of the Cacao-AFS to climate change it is necessary to create spaces for the self-organization of the different actors and the knowledge dialogue, and to make a transition to more just and agroecological schemes. There are still some parts of the systems and their resilience that had not been totally investigated, like the local responses of the communities to climate change, the immaterial life of the cacao peasants, their inter-familiar and inter-community links, the environmental history of the cacao system, the functional and respond biodiversity and holistic economic diagnostics. **Conclusions:** The cacao system had some elements that indicate some degree of resilience to the climate change. The cacao system is resilient to climate change in some factors and not resilient in others. Their investigation is a fertile field to make multi and interdisciplinary studies.
Key words: Adaptive capacity; agrobiodiversity; socioecological autoregulation; self-organization, capital.

RESUMEN

Antecedentes: El sistema agroforestal cacao (Cacao-AFS) es un sistema diseñado a pequeña escala con una gran diversidad y múltiples funciones; al mismo tiempo que es muy vulnerable ante la variabilidad climática. A través de la resiliencia es posible el conocer cómo un sistema responde y/o se reorganiza ante una perturbación como el cambio climático. Éste trabajo realiza una revisión del Cacao-AFS y analiza su potencial resiliencia ante el cambio climático. **Metodología:** Una revisión del estado del arte sobre el sistema cacao y su resiliencia se realizó a través del análisis de 249 trabajos consultados en bases bibliográficas. La información fue codificada en seis factores (Conocimiento científico, saberes contemporáneos, agrobiodiversidad, autorregulación socioecológica, capital y autoorganización) y las implicaciones ante el cambio climático, y finalmente se analizó mediante una matriz. **Resultados:** A través de la revisión de la literatura se encontró que hay una gran capacidad adaptativa debido a que tanto desde la innovación científica como desde los saberes hay diversas acciones ante problemáticas del sistema. Se encontró también una gran agrobiodiversidad en el sistema que permite la reproducción socioecológica del sistema (autorregulación). Por otro lado, el sistema es poco rentable y la juventud no le interesa incorporarse a la actividad (bajo capital) y los actores suelen no cooperar (baja autoorganización). **Implicaciones:** Se encontró que hay aspectos que favorecen la resiliencia del sistema cacao y otros que necesitan ser mejorados. Para mejorar la resiliencia del Cacao-AFS es necesario el crear espacios para la autoorganización y el diálogo de saberes, y hacer una transición hacia esquemas más justos y agroecológicos. Aún hay diversas partes del sistema y su resiliencia que no se han investigado del todo, como la vida inmaterial de los cacaoteros, sus vínculos interfamiliares e intercomunitarios, la historia ambiental del cacaotal, su diversidad funcional y de respuesta, y diagnósticos económicos holísticos. **Conclusiones:** El cacaotal cuenta con elementos que indican un cierto grado de resiliencia al cambio climático. Su investigación es un campo fértil para realizar estudios inter y multidisciplinarios.
Palabras claves: Capacidad adaptativa; agrobiodiversidad; autorregulación socioecológica; autoorganización; capital.

INTRODUCTION

The Mexican Cacao Agroforestry Systems are small-scale systems, maintained mainly by manual-familiar work and where the cacao is cultivated in association with a lot of other species with diverse functions (Córdova-Ávalos *et al*., 2001, Chávez-García, 2012, Zequeira-Larios and Ogata, 2018). With the begging and expansion of the industrial revolution humans had impacted more than ever, the biogeochemical processes of the biosphere (Malhi, 2017). In specific the climate, these impacts are manifested in low predictable alterations in the atmosphere (Arellano-Hernández, 2014), affecting at the same time biophysical and social processes that are important to a lot of communities (García-del Amo *et al*., 2020). The cacao-AFS have some characteristics that make them vulnerable to climate change, like the productivity and phenology of the cacao plants, the incidence of their plagues and associated biodiversity are correlated with climatic variables (Avendaño-Arrazate *et al*., 2011, IICA, 2017, Pérez-Sosa and Granados-Ramírez, 2020).

However, the human had historically adapted to the climate variabilities with the use of bioindicators (like changes in the shape of the clouds, the behavior of some species and others) for their prediction and the generation of systems with structures that allow them to maintain even with perturbations (Ulloa, 2014, Altieri *et al*., 2015, Rivero-Romero *et al*., 2016). Also, the peasants and other actors associated respond to the climate change in a lot of ways, being one of the most important acquisitions and development of new knowledge, along changes on their organization, creation and fortify of their support systems and/or the redesign of the productive systems (Nelson *et al*., 2009, Márquez-Serrano and Funes-Monzonte, 2013, Infante-Ramírez and Arce-Ibarra, 2019). The Socioecological complex systems

(SES) perspective allows understanding these adaptative cycles where the growth-stabilization phases are followed by cycles of change-reorganization-growth (Castillo-Villanueva and Velázquez-Torres, 2015). The SES are a theoretical-methodological approach in where human-nature relationship is conceptualized as constant but dynamic (García, 2006). A key concept of them is resilience, it is the multiple ways in which a system can absorb and/or reorganize in the face of a perturbation, maintaining at the same time their principal components and process (Engle, 2011, Salas-Zapata *et al*., 2012, Castillo-Villanueva and Velázquez-Torres, 2015, Folke *et al*., 2016).

The resilience of a system is influence by the adaptive capacity of the system, but also by their structure (García, 2006). Through a review of some theoretical works of the resilience in the socioecological systems (Bengstsson, 1998, Berkes *et al*., 2000, Hooper *et al*., 2002, Cadotte *et al*., 2011, Cabell and Oelofse, 2012, Salas-Zapata *et al*., 2012, Adenle *et al*., 2015, Castillo-Villanueva and Velázquez-Torres, 2015, Córdova-Tapia and Zambrano, 2015; Almeida-Leñero *et al*., 2016; Nwankwo *et al*. 2020) and some cases of study (Aldasoro-Maya, 2012, Márquez-Serrano *et al*., 2013, Infante-Ramírez and Arce-Ibarra, 2019, Leite *et al*., 2019, García-Jácome *et al*., 2020, Hernández-Rodríguez *et al*., 2020, Hosen *et al*., 2020, Mukhovi *et al*., 2020), it is possible to identify at least six potential factors of resilience in the socioecological systems: a) adaptative capacity: contemporaneous knowledge, b) adaptative capacity: scientific innovation, c) agrobiodiversity, d) socioecological autoregulation, e) capital and f) social self-organization.

The adaptive capacity emerges, at least in a considerable extent, from the contemporary knowledge ("saberes contemporáneos" in spanish) (Aldasoro-Maya, 2012) and the scientific knowledge (Adenle *et al*., 2015, Nwankwo *et al*., 2020). The term "saberes" is used to designate a complex system of knowledge, practices, and beliefs. Aldasoro-Maya (2012), followed by Chan-Mutul *et al*. (2019), Avilez-López *et al*. (2020) and Linares-Rosas *et al*. (2021) have proposed the use of the term contemporary knowledge, following De Sousa-Santos (2010) ideas that explain how it is urgent to improve the idea of "present" in order to consider as valid many experiences of knowing the world. These "saberes" have been named "traditional" in the academy, nonetheless, we consider this term frames them in the past, committing with this a cognitive injustice. On the other hand, the term contemporary knowledge emphasizes the continuous production and reproduction of the "saberes" to contrast with the unfortunately, very common idea that these "saberes" belong to the past and are obsolete. Therefore, these "saberes" are a key element to study resilience, because it recognizes their adaptative capacity to face actual problems.

In the other hand, there are four structural characteristics of great importance for the resilience of the SES: a) Redundancy in functional agrobiodiversity that allow the system to continue with their functionality and regenerate from perturbations; b) Socioecological autoregulation that allows the system to reproduce without overexploiting their natural and social base; c) Capital that enables to maintain the system, generates savings and be attractive to the young people; d) Self-organization between the actors linked in trust and cooperation networks (Cabell and Oelofse, 2012, Leite *et al*., 2019, Hosen *et al*., 2020, Mukhovi *et al*., 2020).

The small-scale peasants' systems, like the Mexico cacao-AFS, have been highlighted as potentially resilient to climate change (Altieri *et al*., 2015). The objective of this work was to analyze, through a literature review, if the cacao agroforestry systems of Mexico had characteristics that can make it a resilient system to climate change.

MATERIAL AND METHODS

Through a literature review, a state of the art was made to know the main functionality and resilience of the cacao systems. The state of the art is a qualitative documentary research methodology, that through a systematic and critical analysis of the literature allows creating a theoretical construction with the advances of the topic, to generate connections between the information, and to propose new lines of research (Molina-Montoya, 2005, Gómez-Vargas *et al*., 2015). To achieve that goal, the four phases methodology proposed by Gómez-Vargas *et al*. (2015) was used (Figure 1).

In the first phase, a wide search about the cacao AFSs in Mexico was conducted in international databases and scientific editorials, national journals, thesis reservoirs, congress progress and archives of government institutions (Table 1a). The journals were selected based on that at the time of searching works at the international databases they contribute with works. The keyword for the search was "cacaotal" and "cacao", in combination with their management forms, the potential resilience factors and the geographic areas (Table 1b). The words were used in Spanish and English. There were excluding works more related to the biochemistry of the products elaborated of cacao, because they don`t contribute to the objective of the work. A total of 249 papers were found (See data availability statement).

In the second phase the information was classified and codified in seven codes, they were the six potential factors of resilience (Contemporaneous knowledge, scientific innovation, agrobiodiversity, socioecological autoregulation, capital, and self-organization) and a seventh code about the implication of climate change to the cacao AFSs. That information was organized in an Excel database with the article cite, the relevant information of the paper and the corresponding code (see data availability statement).

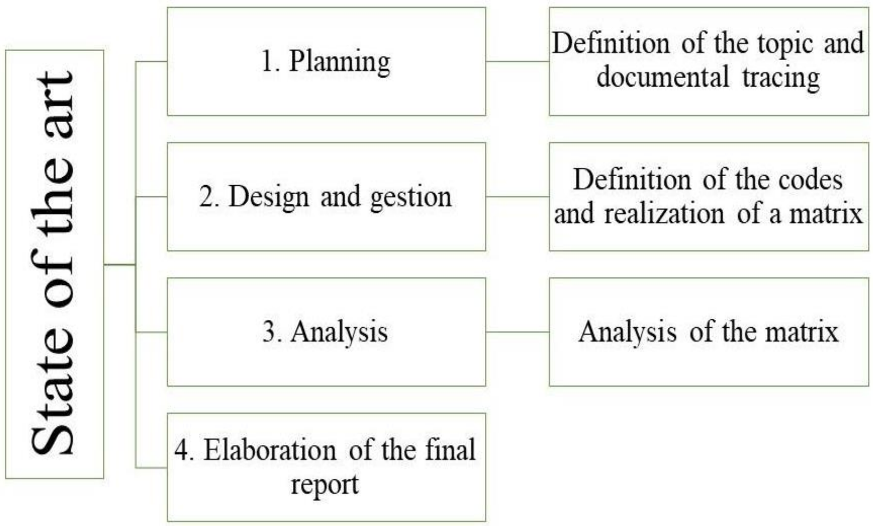

Figure 1. Methodology proposed by Gómez-Vargas *et al*. (2015) for the realization of a state of the art. Own elaboration based on Gómez Vargas *et al.* (2015).

Table 1a. Sources used for the documental research.

Sources	
International databases	Google scholar, REDALYC, researchgate
International scientific editorials	BioONE, Sciencedirect, Willey One Library, Springerlink, Jstor, Taylor & Francis, MDPI
Mexican journals	Agrociencia, Agroproductividad, Revista Mexicana de Ciencias agrícolas, Ecosistemas y recursos agropecuarios, Estudios sociales, Tropical and subtropical agroecosystems, Universidad y ciencia, Bosques y madera, Revista Chapingo serie forestales
Thesis reservoirs	UNAM, IPN, ITN, ECOSur, UACh, UJAT, UNACH, UNICACH
Government institutions	INIFAP, SAGARPA, national and regional institutions

Table 1b. Keywords used for the documental research.

Kind of keywords	Spanish keywords	English keywords
Kind of management	Intensivo, convencional, agroforestal, bajo sombra, orgánico y agroecológico	Intensive, conventional, agroforestry, shaded, organic and agroecology
Potential factors	Agrobiodiversidad, autoorganización/organización social, autorregulación socioecológica/bienes/servicios, capital/economía y saberes/conocimiento ecológico tradicional	Agrobiodiversity, self-organization/social organization, socioecological autoregulation/goods/services, capital/economy and traditional ecological knowledge
Geographic area	México, Chiapas, Tabasco, Oaxaca, Guerrero, Veracruz, and the areas with greater production of Chiapas (Soconusco) and Tabasco (Chontalapa)	

Finally, as a way to integrally analyze the resilience of the cacao-AFS, a matrix with the main factors and their indicators was elaborated (Table 3: Results), based on the six potential factors of resilience previously mentioned and the analyzed works. If the analyzed information about the cacao-AFS matches with a positive condition that favors the resilience of the system, it was taken as a positive indicator. Contrary, if the analyzed information match with a negative condition that makes more vulnerable the system, it was taken as a negative indicator. Finally, if there were no information about the condition of the system in one indicator, it was taken as unknown.

RESULTS

Based on the review of the state of art in the next sections it is shown a descriptive analysis of the seven codes used, integrated by the climate change implications to the cacao-SAFs and the six factors of resilience to climate change, and an integral analysis of the resilience of the cacao-AFS in Mexico.

Climate change and cacao agroforestry systems

The components and processes of the cacao system are highly dependent on climatic variability. The productivity, phenology and growth of the cacao depend on the temperature and the soil moisture, which had to be between 50-70% all over the year, without droughts and floods (Avendaño-Arrazate *et al*., 2011, IICA, 2017, Barrón-García *et al*., 2018). The incidence of their principal plague, the moniliasis (*Moniliophtora roreri* H. C. Evans *et al*.), depends on the precipitation, temperature and phenology of the cacao (Albores-Flores, 2017, Torres-de la Cruz *et al*., 2020). The ecosystem services like the litter fall, important nutrient source, is minor in the dry season than in the humid season (Pérez-Flores *et al*., 2018). Whereby, longer dry seasons can generate changes of the nutrition recycling rates. At the same time, this mechanism, like the partial stomatal closure, allows the plants to reduce their transpiration rates, and with that conserve water on the system and don´t generate hydraulic failures by embolism and cavitation (Bayala and Prieto, 2020), namely, it´s a resilience mechanism.

The effects of climate change are already visible on the cacao AFSs of Tabasco. The peasants had perceived an increase in the intensity and frequency of the floods, and a larger dry season. That had generated delays on the flowering and a greater incidence on the plagues and sickness (Mendéz-Sánchez *et al*., 2019, Martínez-Salvador and Martínez-Salvador, 2020). The increase of the dry season coincides with the climate change scenarios for Tabasco, in that there would be no significant decrease in the average annual precipitation (-100 mm for year, between 4.2-5% of the annual average precipitation), but with one less month of the rain season, prolonging with that, the annual drought and the evapotranspiration. These effects could generate major stress on the cacao plants generating discoloration and falling of the leaves, inhibition of the flowering, production of smaller cobs and early fructification (Pérez-Sosa and Granados-Ramírez, 2020). The reduced production in synergy with the other problems of the cacao agroforestry systems and the climate change with their gap on the rain season and lack of rain in the past years had motivated the peasants to overthrow their AFSs.

Adaptive capacity: Contemporaneous knowledge and scientific innovation

In the adaptive capacity, it was found that both, the contemporary knowledge of the peasant and other actors and the scientific innovation, in the face of different problems, had proposals, actions, and projects, that are happening and evolving at the same time that the cacao system continues evolving (Figure 2). The focus of the scientific knowledge had centered in the renovation of the cacao AFSs, to get a better organization and economic incomes, while the contemporary knowledge had a greater diversity of problems studied. They complement each other, the most successful proposals are the one in which knowledge and experience between the scientific and contemporary knowledge are shared, the ones that create spaces of co-creation of knowledge, like the participatory genetic improvement (Avendaño-Arrazate *et al*., 2013, Ramírez-González *et al*., 2014), the transition to agroecological schemes (Ogata, 2018, COLPOS, 2020, Ramos-Gamas, 2021) and the technology transfer (Peña-Aguilar and Bermudez-Peña, 2007). Contrary could be an antagonism between the scientific innovation and contemporary knowledge, when the innovation imposes over and erosion the local/indigenous/traditional knowledge, what is common under the modernization paradigm that reaches the cacao production regions of Tabasco (Chávez-García, 2012, Chávez-García and Castelán-Estrada, 2019).

Agrobiodiversity

Traditionally the cacao had been divided in tree races: The creole cacao native of Mesoamerica, forasteros native from South America and trinitarians hybrid of both (IICA, 2017). In the world and in Mexico the creole is less cultivated than the forastero and trinitarian verities (Díaz-José *et al*., 2013, IICA, 2017, Ramírez-Guillermo *et al*., 2018). This is probably because the creole cacao is less resistant to fungal pests and has lower productivity (IICA, 2017, Albores-Flores *et al*., 2018). Although the creole cacaos are reassessing and getting a higher overprice (20%), because of their great organoleptic qualities (Mendoza-López *et al*., 2011). To this genetic diversity adds a great quantity of hybrid and improvement varieties development by the INIFAP, with higher yields and resistance to the moniliasis (Mendoza-López *et al*., 2011, Avendaño-Arrazate *et al*., 2013).

Unlike other parts of the world, the cacao shade in Mexico is very diversified and not specialized (Salvador-Morales *et al*., 2020). The diversity, structure and basal areas are similar to the surrounding tropical forests (Estrada *et al*., 1994, Zárate *et al*., 2014). The plant species are a mix of typical secondary vegetation, mature rainforests and domesticated species (Salgado-Mora *et al*., 2007). This great diversity of plants allows the fauna to find refuge, food and microclimatic conditions which enables their conservation. The diversity of animals is equal, similar or slightly higher or smaller that the surrounding fragments of tropical forests, and equal or higher than other agroecosystems (Estrada *et al*., 1994, Estrada *et al*., 1998, Pérez-de la Cruz *et al*., 2007, Zárate *et al*., 2014, Oporto *et al*., 2015, Santos-Heredia *et al*., 2018).

Socioecological autoregulation

The socioecological autoregulation is the capacity to reproduce without finishing with their social and ecological basis. Apparently, the key of the reproduction of the cacao agroforestry systems appears to be the biodiversity of the system. The species associated to the cacao had multiple functions (Table 2), that make it a multipurpose system that help in many ways to the wellness of the peasant families (Chávez-García, 2012). Also, the diverse groups of plants and animals that the cacao system conserve allow to maintain the ecological ecosystem processes. Among them are the control of plague populations (Pérez-De La Cruz *et al*., 2007, Moreno-Mendoza *et al*., 2012), the dispersion of

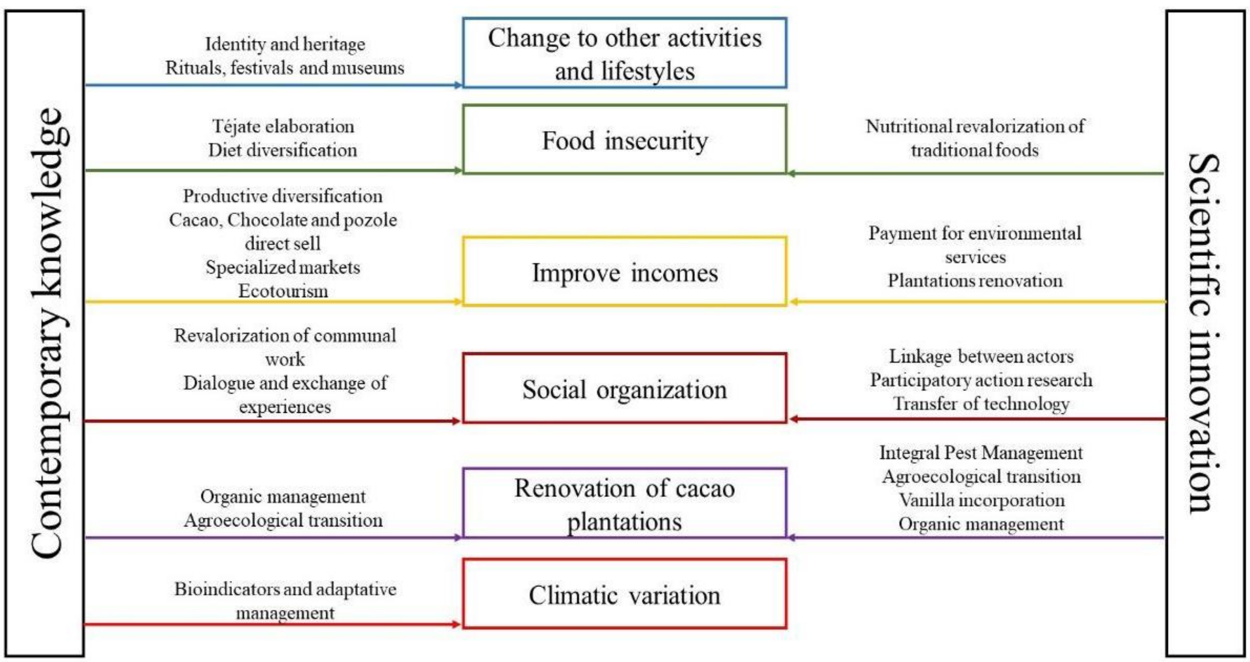

Figure 2. Contemporary knowledge, scientific innovation and the diverse problematics that they faced on the cacao system. Own elaboration based on Córdova-Ávalos *et al*. (2001), Peña-Aguilar and Bermudez-Peña (2007), Priego-Castillo *et al*. (2009), Roa-Romero *et al*. (2009), Mendoza-López *et al*. (2011), Chávez García (2012), Hernández-Gómez *et al*. (2012), Martínez-González (2012), Sotelo *et al*. (2012), Avendaño-Arrazate *et al*. (2013), Ramírez-Meneses *et al*. (2013), Cruz-Coautiño (2014), Ramírez-González *et al*. (2014), Ortíz-García *et al*. (2015), Bautista-Mora *et al*. (2016), Córdova-Avalos *et al*. (2016), Mila-Sánchez *et al*. (2016), Triano-Sánchez *et al*. (2016), IICA (2017), Ortíz-García (2017), Córdova-Lázaro *et al*. (2018), Ogata (2018), Sol-Sánchez *et al*. (2018), Chávez-García and Castelán-Estrada (2019), Córdova-Ávalos *et al*. (2019), López-Juárez *et al*. (2019), Tadeo-Sánchez (2019), Córdova-Avalos *et al*. (2020), Salvador-Morales *et al*. (2020), Ramos-Gamas (2021), Gobierno de México (2021a), Gobierno de México (2021b) and Programa de Pequeñas Donaciones (2021).

Table 2. Some of the most common species associated to the cacao and their functions.

Spanish name (Scientific name)	Functions
Cacao (*Theobroma cacao* L.)	Commercialization and edible
Mango azúcar, bellaco, durazno, manila, manililllo, pájaro, petacón, plátano, redondo, rosa y Tomy (*Mangifera indica* L.)	Commercialization, edible, food for wildlife and wood
Cedro (*Cedrela odorata* L.)	Commercialization, handicraft elaboration and wood
Naranja dulce y de jugo (*Citrus x sinensis*)	Edible and wood
Aguacate (*Persea americana* Mill.)	Edible
Guarumo (*Cecropia obtusifolia* Bertol.)	Food for wildlife, medicinal and wood
Cocoite, cocohite o yaite (*Gliricidia sepium* (Jacq.))	Food for wildlife, nitrogen fixative, soil improvement and wood
Macuili, macuíli o macuilí (*Tabebuia rosea* (Bertol.) Bertero ex A. DC.)	Commercialization and wood
Mulato o palo mulato (*Bursera simaruba* (L.) Sarg.)	Food for wildlife, medicinal and wood
Mamey o zapote (*Pouteria sapota* (Jacq.) H.E. Moore & Stearn)	Commercialization and edible

Own elaboration based on Muñoz *et al*. (2006), Salgado-Mora *et al*. (2007), Chávez García (2012), Bautista-Mora *et al*. (2016), Sol-Sánchez *et al*. (2018), López-Cruz *et al*. (2021) and Zequeira-Larios *et al*. (2021).

seeds by the fauna (Medellin and Gaona, 1999, Zárate *et al*., 2014), the reincorporation of nutrients by the litter fall (Roa-Romero *et al*., 2009, Pérez-Flores *et al*., 2018) and the cycling and reincorporation of nutrients by the soil fauna (Uribe-López *et al*., 2006, Santos-Heredia *et al*., 2018).

Despite the great socioecological autoregulation capacity the biodiversity give to the system, there are diverse processes that are experiencing an impoverishment of their socioecological basis: a) The advanced age of the AFSs that cause lower productivity and capacity to maintain the system; b) The advance age of the cacao farmers, that makes them more dependent of the external workforce; c) The no maintaining or no realization of the pruning, thinning and drains, that increase the attack of diverse fungal pests like the moniliasis or frosty pod (*Moniliophthora roreri*), black pod (*Phytophthora sp.*) and the branch galls (*Fusarium sp.*) (Córdova-Ávalos *et al*., 2001, Díaz-José *et al*., 2014, Hernández-Gómez *et al*., 2015).

Capital

If it is only considerate the production and sale of cacao, the plantations would be operating with losses, because to cover only the costs it is necessary a minimal production of 770 kg/ha (Espinosa-García *et al*., 2015), a very high production considering the national average of 502.26 kg/ha (SIAP, 2021). The rentability of the system in fact varies according to the strategy that the producer follows. The exportation of organic cacao makes more rentable the system (Priego-Castillo *et al*., 2009), at a point that is rentable only with a production of 317 kg/ha (Venegas-Mancera, 2017). The direct sale of artisanal chocolates also allows having better profits (Mila-Sánchez *et al*., 2016, Córdova-Ávalos *et al*., 2019). There are other species with a great price and local market like the mango (*Mangifera indica* L.), the mamey zapote (*Manilkara zapota* (L.) P. van Royen) or the allspice (*Pimenta dioica* (L.) Merr.), the last one even generates higher earnings than the cocoa in Tabasco (Roa-Romero *et al*., 2009, Sol-Sánchez *et al*., 2018). Nevertheless, there are other peasants that don´t use those biotic resources for self-consumption or sale even if they know their uses (Bautista-Mora *et al*., 2016). Finally, the incomes generated by the cacao production can be complemented with other activities, like other crops, salaried work on the cities and the commerce (Chávez-García, 2012, Díaz-José *et al*., 2014, Hernández-Gómez *et al*., 2015, López-Cruz *et al*., 2021).

In the social capital, nowadays the cocoa producers have a low scholarity and advanced age, which implies a depleted physical capacity and extra costs by having to hire workforce (Díaz-José *et al*., 2014, Hernández-Gómez *et al*., 2015, Ortíz-Garcia, 2017). In communal lands (“ejidos”) the young people prefer to not incorporate to the activity, because they have another life expectative, different from working on the field, or they don´t find possibilities to get land, capital to invest or salaried work (Priego-Castillo *et al*., 2009, Chávez-García, 2012, López-Cruz *et al*., 2021, Ramos-Gamas, 2021). But field data shows that in the private owners with bigger farms, like in Comalcalco, the situation is very different, and the young people incorporate to the activity.

Self-organization

The cacao producers have a great social web, where different local, regional, and international actors interact in a lot of ways (Figure 3). There have been valuable initiatives to connect between the different actors, like the participatory action research (Avendaño-Arrazate *et al*., 2013, Ramírez-González *et al*., 2014, Ogata, 2018, Ramos-Gamas, 2021), the farmer field schools (Zequeira-Larios *et al*., 2012), the woman cooperatives that revalorize the communal work (Martínez-Salvador and Martínez-Salvador, 2020) and the generation of museums and festivals of chocolate (Martínez-González, 2012).

Nevertheless, in general, the cacao producer works isolated and with a little sharing of knowledge-innovation (Ballesteros-Possú *et al*., 2007). The local actors are in vertical and low participative schemes, in where few actors had the power over the financial aid and the commercialization the cocoa (Ramírez-Martínez, 2007). Between the diverse actors of the cocoa-chocolate chain there are a lot of dislocation and low confidence, coordination and cooperation between them, reason why the innovation processes are slow or don`t exist (Ballesteros-Possú *et al*., 2007, Díaz-José *et al*., 2013, Martínez-Becerra, 2018).

An integral analysis of the Cacao-AFS resilience

The integral analysis of the Cacao-AFS resilience shows that it is heterogeneous, with some strong characteristics like the adaptative capacity of the contemporaneous (75.00% of the indicators have a positive diagnostic) and scientific knowledge (66.67% positive), the agrobiodiversity (66.67% positive) and they socioecological autoregulation capacity (100% positive). In the other hand, there are some factors that make more vulnerable the system, like the capital (66.67% not positive) and the social self-organization (100.00% not positive). It is also interest that there an important number of indicators that are partially or totally unknown (26.6%) and shows the gaps of information necessary to investigate for a more complete understanding of the Cacao-AFS resilience.

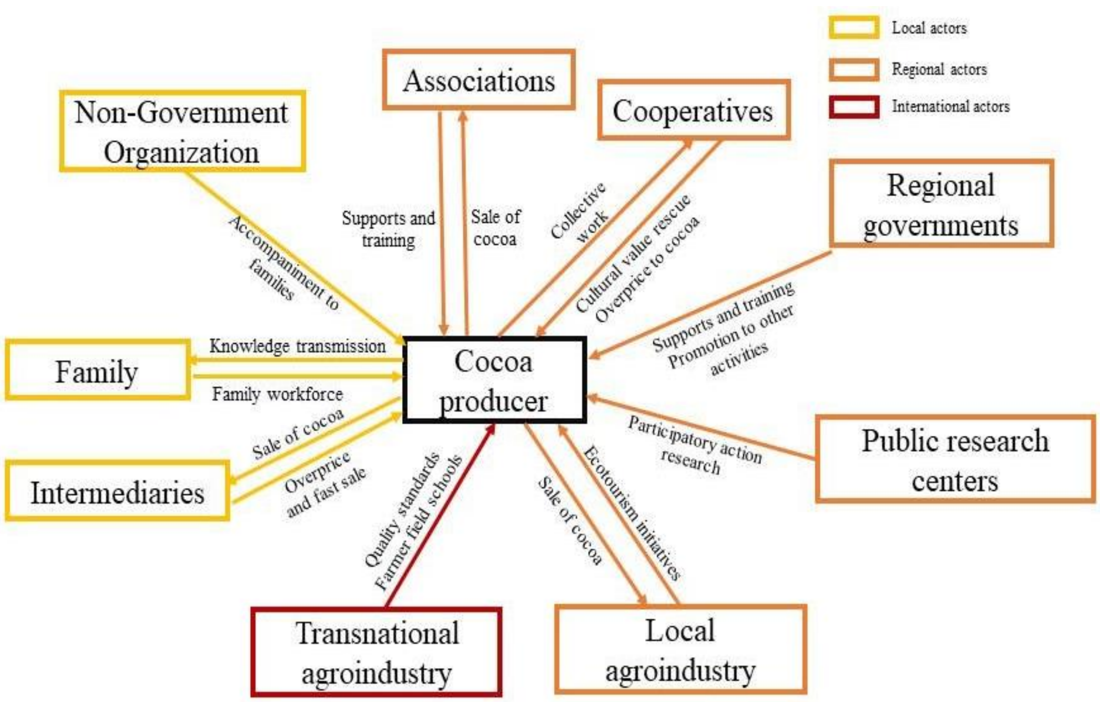

Figure 3. Social web of the different actors that interact with the cacao producer. Own elaboration based on Córdova-Ávalos *et al*. (2001), Ramírez-Martínez (2007), Córdova-Avalos *et al*. (2008), Ramírez-González (2008), Priego-Castillo *et al*. (2009), Mendoza-López *et al*. (2011), Martínez-González (2012), Zequeira-Larios *et al*. (2012), Avendaño-Arrazate *et al*. (2013), Hernández-Gómez *et al*. (2015), IICA (2017), Larrondo-Posadas (2017), Martínez-Becerra (2018), Tadeo-Sánchez (2019), Martínez-Salvador and Martínez-Salvador (2020), Salvador-Morales *et al*. (2020), López-Cruz *et al*. (2021), Ramos-Gamas (2021) and Horizontes Creativos (2021). (See supporting data).

Table 3. Integral diagnostic of the cacao-AFS resilience in Mexico (The complementary sources of every condition can be found at the appendix).

Factors	Favorable condition indicators	Cacao condition	Diagnostic
Adaptative Capacity: Contemporaneous knowledge	The peasants had a strong identity with the activity	Diverse studies show that the peasants, and even other actors, had a strong identity linked with the cacao and cacao-AFS (Ramírez-Martínez, 2007 and other 12 studies)	Positive
	The contemporaneous knowledge understands the dynamic of nature and had some strategies to deal with that	This kind of study had yet not been done. But field data shows that the cacao farmers adapt the systems to climate variability and other environmental perturbations.	Unknown-Positive
	The contemporaneous knowledge gives continue solutions to the socioecological problematics of the system	The cacao farmers and other actors are giving solutions and implementing actions to deal with different socioecological problems (Martínez-Salvador and Martínez-Salvador and other 63 studies)	Positive
	The contemporaneous knowledge is valued and taken into account in the innovation process	Historically, the contemporaneous knowledge hasn´t been taken into count in the rural development and innovation processes (Chávez-García, 2012). But more recently there are participatory investigation processes that do it (Avendaño-Arrazate *et al*., 2013 and other five studies)	Negative, transitioning to positive
Adaptative Capacity: Scientific knowledge	The scientific community give continue solutions to the socioecological problematics of the system	The scientific community are giving solutions and implementing actions to deal with different socioecological problems (Ortíz-García *et al*., 2015 and other 105 studies)	Positive
	The scientific community is connected to other actors and shared their knowledge	Different scientific institutions are having projects with a participative perspective (Ramos-Gamas, 2021 and other five studies)	Positive
	The contemporaneous knowledge is valued and taken into account in the innovation process	Historically, the contemporaneus knowledge hasn´t been taken in count it the rural development and innovation processes (Chávez-García, 2012, Chávez-García and Castelán-Estrada, 2019). But more recently there are participatory investigation processes that do it (Avendaño-Arrazate *et al*., 2013 and other five studies)	Negative, transitioning to positive
Agrobiodiversity	The system conserves diverse groups of species	Diverse studies had demonstrated that the cacao AFS conserve more diversity than other agroecosystems, and the same or almost the same diversity that the rainforests fragments (Zárate *et al*., 2014 and other 33 studies)	Positive

Factors	Favorable condition indicators	Cacao condition	Diagnostic
	The system conserves diverse functional groups	Little information about the functional groups of the cacao-AFS is known but that the ecological processes and services continue (Santos-Heredia *et al*., 2017 and other 18 studies), it´s an indirect signal that they are at the system. In the case of Arachnida had been described some functional groups based on their hunting strategies and the use of space in the habitat (Lucio-Palacio, 2015).	Unknown-Positive
	The system conserves diverse species that had different responses to different perturbations, and allow the system to continue without affecting the ecological processes-services	This kind of study had yet not been done	Unknown
Socioecological autoregulation	The system reproduces the social and ecological bases at the same time that the ecological processes-services continue	The cacao conserve ecological processes-services better than other agroecosystems and equal or almost equal that the rainforest fragments (Santos-Heredia *et al*., 2017 and other 18 studies)	Positive
	The system had different resources that help to the peasant subsistence	The biodiversity of the cacao AFS had different functions that help to the well-being of the cacao producer (Zequeira-Larios *et al*., 2021 and other 12 studies)	Positive
Capital	The system is rentable and allows the peasant to continue with them	If it´s only take into count the sale of cacao, cacao-AFS is not a rentable system. But it´s rentability can be improved by selling other products of the systems, by dabbling in markets with overprices and/or by transforming/selling direct the cacao, chocolate, pozol or other products (Roa-Romero *et al*., 2009 and other five studes)	Not positive in general. Positive in some cases.
	The rentability of the system is attractive to the young people	Young people, in general, are not attracted by the activity (Chávez-García, 2012 and other three studies)	Not positive
	The different resource of the system and the other activities that the peasant had allows it to continue been rentable perhaps the perturbations	This kind of study had yet not been done. But the cacao farmers use to have multiple resources and activity strategies (Chávez-García, 2012 and other ten studies).	Unknown
Self-Organization	The actors self-organize to cooperate	There are some various efforts to cooperate between the different actors (Martínez-Salvador and Martínez-Salvador and other five studies). But in general, the actors do not cooperate (Díaz, 2013 and other ten studies)	Not positive

Factors	Favorable condition indicators	Cacao condition	Diagnostic
	The relationships between actors are based on confidence and reciprocity	There are a lot of distrust between actors (Ramírez-Martínez, 2007)	Not positive
	The social organization allows that the information and innovations is sharing and reach all the actors	The sharing of innovations and information is low and not effective (Martínez-Becerra *et al*., 20182013 and other 2 studies)	Not positive

DISCUSION

Potential resilience to climate change in the Mexico cacao plantations

Historically, the cacao system had been cultivated in more regions of Mexico than now (Ogata, 2003, Powis *et al*., 2008, Powis *et al*., 2011). Now their distribution is only limited to the states of Tabasco, Chiapas and a little more in Oaxaca and Guerrero (Avendaño-Arrazate *et al*, 2011), this is a very restricted distribution considering the historical (Bergmann, 1969) and potential (Espinosa-García *et al*., 2015) distribution in areas with adequate soil, geography and climate of the cacao plantations in Mexico that used to include states so far north as Nayarit and Tuxpan, Veracruz. These decline in zones that produce cacao have a lot of reasons, between them, the low prices of the cocoa y and their fungal plagues that cause a low rentability and low management of the plantations, the lack of public policies that cause hard access to capacitation and their replacement for other crops that are more incentive by the public policies and the lack of competitiveness to face the great international producers of Africa and their low prices (Córdova-Ávalos *et al*., 2001, Mendoza-López *et al*., 2011, Hernández-Gómez *et al*., 2015, Zequeira-Larios and Ogata, 2018). The six factors used in this article to study the resilience of the cacao-AFS can give a deeper understanding of the elements and processes that allow the system to continue (resilience) or to disappear (vulnerability) in Mexico.

In the adaptive capacity the interplay of contemporary knowledge and scientific innovation, gives us a lot of actions and solutions to the problems that the cacao system is confronting. More specifically, in contemporary knowledge there is a strong identity of the peasants and other actors to the cacao and the cacao plantations. This is manifested in a series of festivals in which the cacao is the center, and that helps to the cultural reproduction of the cacao. In other systems, a strong identity allows the actors to continue with their systems despite the problematics (Leite *et al*., 2019, Hernández-Rodríguez *et al*., 2020), this also happens to the cacao actors. The contemporary knowledge also generates a diversified agroecosystem, which at the same time fortifies another two factors: agrobiodiversity and socioecological autoregulation. The above makes the contemporaneous knowledge not only a resilience factor, but also a source of resilience. Despite this great adaptive capacity, there is a barrier between the contemporaneous knowledge and the scientific innovation that doesn´t allow the system to have greater adaptability to the change and that is at least in the case of Tabasco (Chávez-García, 2012) had generated the erosion of the contemporaneous knowledge.

Going to the structural factors, there is a rich genetic diversity of cacaos and of species associated with them. The great diversity of cacaos is compound of creoles, forasteros, trinitarians and improved varieties that are a source of resilience. This is because, different studies in other parts of the world had found that the different varieties of cacao had different stress thresholds to perturbations related to climatic variabilities, whereby the different varieties of cacao vary in their answers like in the percentage of stomatic closure under hydric stress and the photochemical efficiency of the photosystem II under hydric stress and light intensities (Barrera-Avellaneda, 2006) or the variability of the photochemical efficiency of the photosystem II and chlorophyll concentration under different temperatures (Daymond and Hadley, 2005). If the improvement programs were very intensive, this rich diversity will be lost because of the genetic homogenization. On the other hand, the associated diversity to cacao is composed of domesticated and wild biodiversity of flora and fauna. This is a good indicator of resilience because the most biodiverse systems take less time to regenerate from climatic variabilities (Adolf *et al*., 2020).

The biodiversity also fortifies another factor, the socioecological autoregulation, because it helps to provide a series of resources and ecological services important to the peasants. This is not a surprise, because the cacao plantations (Mortimer *et al*., 2018) and other agroforestry systems (Jose, 2009, Moreno-Calles *et al*., 2016) had been remarked for the double role that plays of conserving a great diversity while providing valuable goods and services. Both, biodiversity and socioecological autoregulation are factors that are positive helping to the resilience to climate change of the cacao plantations. However, the low management of the cacao-AFS put in risk this socioecological reproduction because some important ecophysiological processes of the cacao and microclimatic conditions of the system (Jaimez *et al*., 2008; Jiménez-Pérez *et al*., 2019) and the incidence of plagues like the moniliasis (Krauss *et al*., 2003; Ortíz-Garcia *et al*., 2015) depend on the management of the system.

In the case of the capital, the story is totally different. In general, the cacao plantations are not rentable or operate with a little margin of gain, and cacao production is not the principal economic activity of the peasants. The rentability can be improved if all the biotic resources of the cacao plantations are exploited or if the cacao is exported to specialized markets of be sold directly to the consumer. But this appears to be the exception more than a rule, a proof of it is that the young people can´t or don´t want to incorporate to the activity. The mean age reported for the cacao farmers are between 57.5 years (Díaz-José *et al*., 2014) and 59 years (Hernández-Gómez *et al*., 2015), while the median age for Mexico for 2020 was 29 years, and in the states where those studies were carried out the median age was 24 years (for Chiapas) and 29 years (for Tabasco) (INEGI, 2022). This is clear evidence of the aging of the workfare, which makes the cacao plantations less rentable because it becomes necessary to contract laborers, generating at the same time a more vulnerable economic and social capital to the climate change.

Finally, in the self-organization perhaps there are valuable efforts to generate links between the different actors, the diagnostics still indicates that there is a vertical social structure, a great distrust, a lack of cooperation and innovation between the actors of the cacao chain. The lack of self-organization makes that contemporary knowledge and scientific innovations don´t reach to all the actors. An example of this is that despite the great variety of solution that are for the technical problems of the cacao plantations like the low productivity and fungal pests' control, the yield of cacao in México have recovered neither gotten the levels reported in the scientific innovations, except for the Chiapas irrigate plantations or the plantations of Guerrero, since the arrival of the moniliasis (*Moniliophtora roreri* H. C. Evans *et al*.) in 2005 (Figure 4: Appendix).

This low rate of acceptance of innovations from scientific and contemporaneous knowledge can also be because of the low rentability of the cacao plantations. In other parts of the world had been documented that the cacao plantations can be more rentable with high losses by diseases, with an adequate control if the price of cacao is too low (Krauss *et al*., 2003), which makes any kind of control inaccessible to the cacao producers (Krauss *et al*., 2003, Phillips-Mora and Wikinson, 2007, ten Hoopen and Krauss, 2016). It´s important to mention that the prices of the cacao tend to vary a lot in the last 17 years (2005-2012) with an average of 2464.5±540.25 and a minimum at January of 2007 of 1,138.66 (USD/Ton) to a maximum of 3,525.12 (USD/Ton) at January of 2010, with two pikes at the average monthly prices between July 2007 (2953.68 USD/Ton) to August 2011 (3064.31) and between January 2014 (2819.43 USD/Ton) to November 2016 (2500.48), and two depressions from January 2005 (1549.13 USD/Ton) to March 2007 (1276.28 USD/Ton) and between February 2017 (2034.08 USD/Ton) to January 2018 (1951.57 USD/Ton) (ICCO, 2022).

At the same time, if the development programs only take in count the scientific knowledge and are very aggressive to the contemporaneous knowledge and the local agroecosystems and livelihoods, the agrobiodiversity and contemporaneous knowledge can be affected, like in the case of Plan Chontalpa at Tabasco (Chávez-García, 2012). The agrobiodiversity at the cacao-AFS had multiple roles that benefit the reproduction of the system, only for Mexico it had been reported 98 species with different direct uses (food, medicine, fuel, construction materials, handcraft, industrial, interchange or sale) and other 35 species that benefit the system in other ways like providing shade for the cacao or like fertilizer (Fisher-Ortíz *et al*., 2020). In other parts of the world had been demonstrated how the more diversified systems are less vulnerable to the attack of pests like termites (Djuideu *et al*., 2020). So, the loss of agrobiodiversity by the intensification of the system negatively affects a lot of processes of the system.

With the past arguments, it is evident the interconnection that the resilience factors have. In theory, good self-organization and capital would fortify the resilience of the cacao system. But in the case of México cacao plantations these factors negatively affect other factors. At the same time agrobiodiversity and contemporary knowledge positively affect other factors. The above demonstrates that the resilience factors can be analyzed one by one, but they continue to be a complex and dynamic system with multiple connections, a reason why the negative or positive affectations in one factor would affect another (Figure 5: Appendix).

Study limitations, information gaps and new ways in the study of Mexico´s cacao plantations

This work had two main limitations to analyzing the resilience to climate change. The first limitation of this study is that all the analyzed studies had different objectives, methodologies, study units and methodologies, which makes that all the results and data are very heterogeneous and do not allow to make a quantitative and statistical analysis. So, the only way to analyze this heterogeny information was through a qualitative analysis without a complementary quantitative analysis.

The Second limitation is that the documental and bibliographic analysis in this work is more centered on general resilience than the resilience to climate change. This is because there are not a lot of works that address how does climate variability affect the six factors analyzed. In fact, there are only 11 studies that analyze the effect of climate on different parts of the cacao SAFs, and are mainly concentrated on the population ecology of insects (Capetillo-Concepción *et al*., 2014, Gerónimo-Cruz *et al*., 2020, Hernández-Lara *et al*., 2020) and in least amount the phenology of the cacao (Barrón-García *et al*., 2014), the leaf fall at different seasons (Pérez-Flores *et al*., 2018), the infestation of moniliasis (Torres-De La Cruz *et al*., 2020), the prediction of the effects of the climate change (Pérez-Sosa and Granados-Ramírez, 2020), the effect of different kinds of management over the physiology of the cacao and the microclime (Jiménez-Pérez *et al*., 2019) and only superficially the local perception of the cacao producers to the climate change (Larrondo-Posadas, 2017, Méndez-Sánchez *et al*., 2019; Martínez-Salvador and Martínez-Salvador, 2020). This little quantity of works related to the effects of climate variability it´s an important limitation to this review, and the reason why this work analyzes the general resilience of the system more than the resilience to climate change.

Despite these two limitations the qualitative analysis of the six factors is good enough to give us an idea of the potential resilience to the climate change of the cacao-AFS. The following section shows a gap analysis and new research lines that would help to better understand the general and climatic resilience of the cacao plantations.

Around the world it had been documented that the communities adapt to climate change in all the biomes of the world (Schlingmann *et al*., 2021), these local responses are a research line that can be tackled with an anthropological perspective. Another great input that this perspective can contribute with, is a comprehension of the contemporary knowledge and the social self-organization, the study of immaterial life, the interfamilial and intercommunity webs and environmental history, three phenomena that affect the continuity of the systems and that can´t be aboard from a technical-ecological perspective (Escalera-Reyes and Ruíz-Ballesteros, 2011).

The agrobiodiversity and the socioecological autoregulation are highly related, it’s not a surprise that there is a research line that correlates them. The species affect in different magnitudes and ways the ecological process and services (Bengstsson, 1998, Córdova-Tapia and Zambrano, 2015, Almeida-Leñero *et al*., 2016), reason why it is possible to differentiate the species based on their biological, biochemical, physics and behavior traits, and correlate them with their habitat requirements, environmental tolerance and ecosystem function, denominated functional groups (Cadotte *et al*., 2011, Córdova-Tapia and Zambrano, 2015). These functional groups affect more the ecological process than the species richness (Bengtsson, 1998, Hooper *et al*., 2002, Cadotte *et al*., 2011).

If the different functional groups would have different tolerance to the perturbation, the systems could continue whit the ecological process and services despite the perturbations (Cabell and Oelofse, 2012, Salas-Zapata *et al*., 2012). Whereby, in the face of climate change determinate the functional and tolerance groups of the cacao plantations agrobiodiversity is an important theme, to create systems resilient to the perturbation and that can continue with their process. But the biodiversity had a third role in the cocoa plantations, because the species had different roles for the cacao producer, whence it is possible to determinate social roles of the biodiversity. It is important to understand this triple role of biodiversity (social, functional and tolerance groups), because it would let us to understand and redesign systems that can continue with their socioecological function perhaps the perturbations. Interesting works in Mexico and other parts of the world have beginning to explore these multiple biodiversity roles in the cacao plantations (Jiménez-Pérez *et al*., 2019, Djuideu *et al*., 2020, López-Cruz *et al*., 2021).

Finally, the cacao plantations had multiple biotic resources that help to complement the economy of the peasants apart from the cacao production. The cacao producer also realizes another activity (cultivate other crops, salaried work, between others) that help to complement that economy. This multiple resource strategy had been documented as resilient in the face of multiple perturbations (García-Jácome *et al*., 2020). To achieve holistic economic diagnostics including all the resources and activities that the cacao producer makes, and how does different perturbations, including the climatic, affect the system economy, would help to better understand the capital resilience of the cacao plantations.

Actions in the face of the climate change

With the actual knowledge about the cacao plantations, it is possible to suggest two important action lines: a) To promote the self-organization of the actors, and b) to promote more justice and agroecological schemes. The organization of peasants in groups and with other actors had been demonstrated as a key factor of resilience, and a detonator of a series of processes that fortify the other resilience factors (Escalera-Reyes and Ruiz-Ballesteros, 2011, Márquez-Serrano and Funes-Monzote, 2013, Mukhovi *et al*., 2020). The reason why, it is necessary to impulse from the academy, the public policies and ONGs the creation of spaces for a dialogue exchange that can help to coordinate efforts and share contemporary knowledge and innovations. The knowledge dialogue enables to break the asymmetrical and excluding power-knowledge relationships, and allows to create collective ideas, experiences, discussions, and interpretations that can help to create endogenous development processes (Argueta-Villamar, 2011, Delgado and Rist, 2016, Martínez-Torres and Rosset, 2016). This is an effective way to put to service of the peasants the external agents and knowledge, and not just to use the peasants as a fount of scientific knowledge, like in other approaches. In other parts of the world there are experiences that prove that self-organization and knowledge sharing help to strengthen the resilience of cacao plantations (Jacobi *et al*., 2017).

In the other hand, the modernization development processes had been based for decades in the “total control” of the nature through science as the unique valid knowledge and the commodification of the land and foods. This process had generated the erosion of cultural and knowledge diversity, genetic and species homogenization, soil erosion and “top-down” social webs where the transnational companies control the system in many ways (Sevilla-Guzmán, 2006). In other words, the modernizations processes expressed on investigation institutions, scientific innovations, public policies, mass media, and others affect negatively almost all the resilience factors of the socioecological systems. In Tabasco, the state that most cacao produces, development processes like the plan Chontalpa, the urbanization and industrialization, had eroded the local knowledge, the community structures and had promoted conventional agriculture based on agrochemicals and monocultures (Chávez García, 2012, Chávez-García and Castelán-Estrada, 2019).

Contrary to the modernization development processes, agroecological schemes had been proposed to fortify the resilience of the agriculture systems to climate change. Because these systems enable to conserve the functional groups, soil and water and promote the use of local supplies. The above allows the systems to reduce the losses in the face of diverse climatic events (droughts and hurricanes), maintain the production, recover fast and conserve their natural base (Altieri and Nicholls, 2013). Agroecology also implies the revalorization of the local knowledge, the search of more justice food systems, the collective action and maintenance of the socioecological bases of agroecosystems (Altieri and Nicholls, 2013). All these allow the agroecological schemes to fortify the resilience to climate change.

The agroecological management of the cacao plantations had been documented as successful to reduce the incidence of plagues and improve the production and fertility of the soil (Castillo-Gámez and Ortiz-Gómez, 2019, Chávez-García and Castelán-Estrada, 2019, Cribe-Suárez *et al*., 2019). At the same time, the agroecological management had improved the quality of life of the producers in many ways (Ramos-Gamas, 2021). The research about the scaling up of agroecology identified the main factors that are crucial for this to happen: how to get out of a crisis, initiatives of self-organization, favorable markets and policies, and constructivist learnings processes that allow the impulse of agroecological practices (Mier y Terán Giménez-Cacho *et al*., 2018). In Mexico, we can find some points that could indicate that the agroecological massification of the cacao plantations is already happening. These are the participatory action investigation from the COLPOS and INIFAP, the emergency of technical and social innovative associations, the impulse of the organic production by state governments and public research centers, the support of integral projects by civil and international associations and the search of diverse companies and consumer for fine cacao products. By these reasons, it is necessary to continue boosting and articulating efforts that can result in a more justice and resilient food system.

CONCLUSIONS

The study of the cacao-SAF resilience to climate change it´s a clear example of the multiple and complex ecological and social interactions that a system has, and how it is necessary for the cooperation of diverse disciplines to analyze this kind of phenomes. The holistic diagnostic made in this review through the proposal of the six potential factors of resilience had let at the same time: a) to analyze from a holistic way the resilience of the cacao-AFS; and b) To analyze the factors and their specific contribution to the resilience, what make possible to detect elements and process of the system that make it more vulnerable or resilience. Diverse investigation lines in multi, inter and transdisciplinary works are necessary to continue understanding the cacao-AFS as a complex system and it´s resilience.

The cacao system had maintained over the last 4000 years in Mexico, which is a clear proof of resilience. In the face of climate change, the six factors of resilience show us that the cacao-AFS had a good adaptive capacity and some structural factors (agrobiodiversity and socioecological autoregulation) that are beneficial to the resilience of the system. However, it´s necessary to work on the factors that make it vulnerable (capital and social self-organization), and to improve its adaptive capacity through the incorporation of contemporaneous knowledge in the innovation processes. To get this, it´s very important to continue with the efforts of some institutions like the PNUD and COLPOS to make a transition to more justice and agroecological schemes it´s necessary, and also to generate a horizontal knowledge dialogue.

The factors interact between them in negative, positive and/or both ways, this is also an important result of the review because perhaps the factors are very holistic, there is still a great complexity of the system that connect them and make them interact in unexpected ways, what at the same time make the system and resilience more complex than expected. Participative research including considerable field work and especially long-time studies, as well as modeling, could help us to understand these complex webs of characteristics and connections, and help to answer some other interesting questions like Do the factors weigh the same in the face of the climate change and other perturbation? Do the factors and resilience are the same in different socioecological contexts and/or other systems? There are other important factors of resilience?

Other future studies are also necessary for other small-scale and agroforestry systems are necessary to know if the resilience of the system it´s something intrinsic of these kinds of studies, if the same factors make these systems vulnerable or resilience, or if the resilience of the system change depending on the socioecological context and system. Undoubtedly, the study of the resilience of the socioecological systems from different fields it´s an important and fertile field of investigation.

Acknowledgement
To El Colegio de la Frontera Sur (ECOSur) and the Consejo Nacional de Ciencia y Tecnología (CONACYT) for the master scholarship that allow the elaboration of this paper.

Funding. This research was partially funding by CONACYT through a master scholarship and by ECOSur through the Programa de Apoyo de Tesis de Maestría (PATM-2020). Rodríguez-Robles appreciates the support provided by the project "Capacidad Adaptativa de la Agricultura Campesina en el Paisaje Rural (UDG-PTC-1592)".

Conflict of interests. The authors hereby declare that they have no conflict of interest.

Compliance with ethical standards. The authors have nothing to declare, due to the nature of the work.

Data availability. The references (supporting data) are presented in Fisher-Ortiz, R.A, Rodriguez-Robles, U., Aldasonoro-Maya, E.M., Soto-Pinto, M.L. and Chavez-Garcia, E., 2022. Supporting data. Fisher-Ortiz *et al*. [Data set]. Zenodo. https://doi.org/10.5281/zenodo.6339573

Author contribution statement (CRediT): R.A. Fisher-Ortíz: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft. **U. Rodríguez Robles:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **E. M. Aldasoro Maya:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **M. L. Soto Pinto:** Conceptualization, Formal analysis, Writing – review & editing. **E. Chávez-García:** Conceptualization, Formal analysis, Writing – review & editing.

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APPENDICES

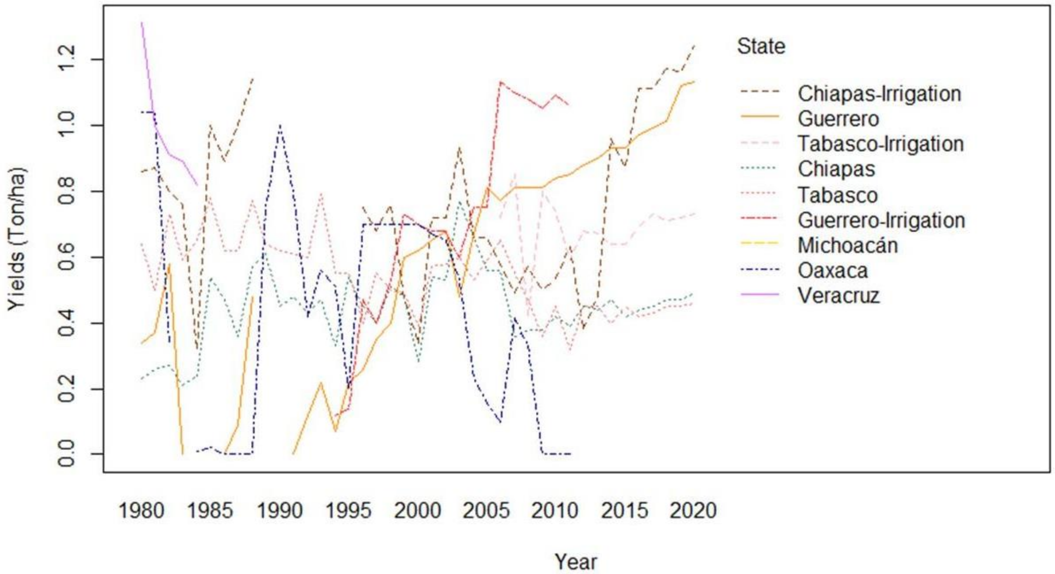

Figure 4. Yield of the cacao plantations in México from 1980 to 2020. Own elaboration with data of SIAP (2020).

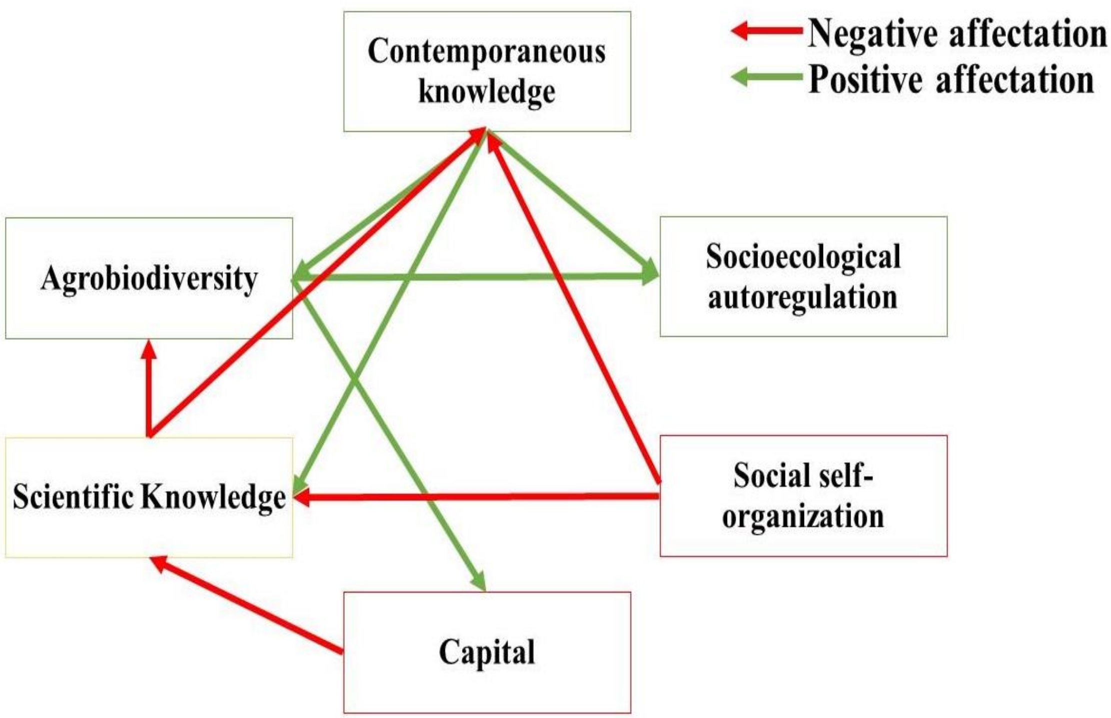

Figure 5. Interconnection between the resilience factors on the cacao plantations of Mexico. Own elaboration.