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ANALYSIS OF AGROFORESTRY RESEARCH IN MEXICO: A BIBLIOMETRIC APPROACH

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ABSTRACT

The world is currently confronted with a complex task involving the sustainable balance of food production and long-term consumption. One way to face this challenge is through agroforestry systems (ASF). At the national level, there is relevant information on the subject; however, few studies have attempted to analyze trends in agroforestry scientific development over time. In this sense, it was proposed that the number of ASF publications related to food security and natural resource conservation increase on an annual basis. The objective of the present study was to perform a quantitative analysis of agroforestry research published between 1990 and 2022 from Web of Science in Mexico with a bibliometric approach. There were 204 publications related to agroforestry systems, recording an increase of 86 % in the last decade. Among the scientific journals analyzed, Agroforestry Systems and Journal of Ethnobiology and Ethnomedicine registered the highest number of publications and citations. The most frequent terms mentioned in publications over 32 years were the relationship between the effects of ASF on crops, traditional management, local knowledge, and the conservation of natural resources. The Universidad Nacional Autónoma de México (UNAM) is the institution with the highest number of research works on the subject, mainly by scientists Alejandro Casas Fernandez and Isabel Moreno Calles, both individually and collaboratively. In conclusion, the number of publications on ASF increased during the time period studied, primarily in the area of food security.

Keywords: Ecosystem services, VOSviewer, co-occurrence networks, databases, production-conservation.

INTRODUCTION

Modern agriculture is characterized by the large-scale intensification of monocultures such as corn, beans, wheat, barley, soybeans, and sugarcane in order to achieve higher production levels globally (Mukherjee, 2022). This focus has been evident over the

past 50 years due to the increase in human population worldwide (Lovrić *et al*., 2018). However, such food production has had negative effects on soil, such as acidification, eutrophication, and soil fertility, accelerating ecological degradation in general (Wilson *et al*., 2020). One of the main challenges of modern agriculture is to reduce external inputs and environmental impacts by finding a balance between production and consumption in the long term (Springmann *et al*., 2018). In this sense, agroforestry can be an alternative to these problems through the integration of trees in crops (Jemal *et al*., 2018).

Agroforestry systems (ASF) are defined as the combination of trees and shrubs in croplands and rural landscapes with or without livestock (Pantera *et al*., 2021). This includes trees both in landscapes and along forest margins (ICRAF, 2023). Interactions between trees and other agricultural components are important at multiple scales, including agricultural fields (where trees and crops are associated generating income from the sale of products), on farms (where trees can provide livestock fodder, fuel, food and shelter) and landscapes (where agricultural and forest land uses combine to determine the provision of ecosystem services) (Anderson and Sinclair, 1993; Kohli *et al*., 2008). Therefore, agroforestry is recognized as a sustainable practice in the ecological, economic, and social sense (Garrity, 2012). Several studies have been conducted to document the effects of agroforestry in solving social, environmental, and conservation problems, such as socioeconomic changes in the rural sector from ASF (Montambault and Alavalapati, 2005), greenhouse gas sequestration (Zhang *et al*., 2019a), as well as conservation agriculture and the use of green manures (Gondim *et al*., 2021). Similarly, approximately 46 % of agricultural land in the world has a tree cover of more than 10 %, influencing about 30 % of local rural populations with short- and medium-term benefits (Liu *et al*., 2019).

ASF research in Mexico has focused on biocultural diversity (Moreno-Calles *et al*., 2013), agro-food products (Moreno-Calles *et al*., 2016), ecosystem services (Casanova-Lugo *et al*., 2016), and atmospheric carbon sequestration (Bustamante-González, 2018). Although there is relevant information on the positive effects of agroforestry practices at the national level, there is no general analysis of knowledge on ASF that allows understanding their initiation and development over time, where questions such as, when, where, what, and with whom can be answered from the literature generated by different institutions and researchers in Mexico (Moreno-Calles *et al*., 2013). The former is key to establish new lines of research and generate public policies that allow visualizing the development of the topic in order to make a more comprehensive analysis and reach more relevant conclusions. In this sense, adopting a bibliometric analysis can provide a new perspective on the state of knowledge, characteristics, and trends in a specific field, i.e., it allows people who are unfamiliar with the field but are interested to quickly understand the information and the state of development of the field in question. Currently, bibliometric analysis has been widely applied in research related to agriculture, forestry, greenhouse gas emissions, and some other fields (Liu *et al*., 2019; Uribe-Toril *et al*., 2019; Zhang *et al*., 2019a).

The objective of this study was to carry out a quantitative analysis of research on agroforestry systems in Mexico over the last 32 years. It is hypothesized that there will be an increase in the number of publications on ASF related to food security and natural resource conservation issues. A bibliometric approach was used, which comprises a set of quantitative methods to analyze published literature in order to identify, classify, and quantify thematic, methodological, and conceptual trends, while taking into account their variations over time in a given discipline (van Eck and Waltman, 2010; Zhang *et al*., 2019b). Through this methodology, we set out to answer the following questions: *i*) How is the temporal distribution of the studies, and how have the topics changed over time, *ii)* Which are the main journals that address these topics, *iii)* Which research institutes publish the most on the topic, *iv)* Which authors publish the most, and *v)* What are the most frequent terms mentioned in publications during the period 1990 to 2022.

MATERIALS AND METHODS

The research was conducted using a bibliometric and data mining approach, which included the selection of the database, as well as the identification of search terms and filters. The titles and abstracts of the articles were selected to identify and eliminate unrelated articles. The selected subset of data was then analyzed in detail to quantify the different criteria to be evaluated.

Bibliographic base

Data collection for this study was extracted from the Web of Science database (https://www.webofknowledge.com) hereafter WoS (Pranckutė, 2021). WoS is the largest multidisciplinary database of abstracts and references of scientific literature in the world. It is considered one of the most comprehensive databases in global research compilation (Singh *et al*., 2021b).

A systematic search of publications related to agroforestry systems was carried out in the WoS database for the last 32 years (1990–2022). In this search, the more general logical operators TI= Agroforestry systems* OR TI= Agroforestry* were used to extract all possible publications related to the topic, where TI = does not restrict to those studies whose title includes any of the variants of the keywords. All the resulting articles were exported as a plain text file with their complete record and references cited. All information was classified according to ID, author, year, title, journal, abstract, and keywords. Each record was standardized and carefully reviewed to exclude those items that were not in accordance with the objective of the work. Reviews, book chapters, and conference proceedings were not considered, since these can be published more than once in different media (Vasconcelos *et al*., 2020).

Time distribution of studies

To define the temporal behavior of agroforestry scientific production from 1990 to 2022, an exponential regression model was fitted using the least squares method. This

method finds the equation of the exponential function that best fits a set of data and plots the values of the dependent variable (Bingham and Fry, 2010). It was verified that the statistical assumptions of the linear fit were met (Su *et al*., 2012). On the other hand, a Pearson correlation was performed to find out if there is a relationship between the number of publications and the topics registered between 1990 to 2022. All analyses were performed in GraphPad Prism (2019) version 8.2.1.

Bibliometric analysis

VOSviewer software was used to provide the visual network representation of the data (van Eck and Waltman, 2010). VOSviewer is a bibliometric analysis tool that is used to explore and analyze data filtered from searches performed in Web of Science, Dimensions, PubMed, and Scopus, among others (McAllister *et al*., 2021). In general, it can be used to create networks of different topics such as scientific publications, journals, researchers, and research institutions as keywords. These elements can be connected through co-authorship links, co-occurrence of words, citation, and bibliographic coupling.

Elements in a semantic network are represented by nodes and edges. Nodes are objects such as co-authorship or co-occurrence of keywords or institutions, while an edge can exist between any pair of nodes, i.e., an edge is a connection or relationship between two nodes (Santos *et al*., 2022). The distance between two nodes in the graph indicates the approximate relationship between the search terms and the relationship between the respective terms. In contrast, smaller distances point to a larger number of co-occurrences (McAllister *et al*., 2021). The size of a label at a node is determined by the weight of an item within a network (sizes have a direct correlation with frequency), and the color represents a group in the network visualization maps (Sood *et al*., 2021). All articles extracted from the search were analyzed in terms of their bibliographic and textual data.

Bibliographic data

Bibliographic coupling (linkage × journal sources)

The network was developed using only with journals with at least five publications, resulting in only nine journals and two clusters. The VOSviwer software generates clusters by considering individual publications at a focus or main point. However, for this study, each source was analyzed individually and then grouped into a cluster based on the relevance of each variable (van Eck and Waltman, 2010).

Research institutions

For the institutions, a selection criterion was established that included a minimum of five published papers and a minimum of 30 citations for all institutions based on similar studies (Figueroa-Rodríguez *et al*., 2019; Zhang *et al*., 2019b; Santos *et al*., 2022), in order to obtain only those with the highest scientific representation in the area.

Authors, citation, and co-citation

To learn whether ASF topics tend to be concentrated in authorship, the most productive authors and their citations were individually analyzed. To create the linkage network, authors were required to have at least five publications and 30 citations (Zhang *et al*., 2019b).

Textual data

Co-occurrences between terms (in article titles and keywords)

Based on the textual data found in the keywords of the articles and using the frequency of co-occurrence to analyze the data, only terms repeated at least five times were considered, with repeated terms having been identified and adjusted for. Limiting the terms considered for article titles and keywords reduced the risks of terms being repeated in different parts of the same recorded documents (Mourao and Martinho, 2020).

Finally, the construction of a map is a three-step process. In the first step, a similarity matrix was calculated based on the co-occurrence matrix. In the second step, a map is constructed by applying the VOS mapping technique to the similarity matrix, and finally, the map is translated and reflects the information. All clusters were constructed based on the methodology described by van Eck and Waltman (2010).

RESULTS AND DISCUSSION

Time distribution

A total of 204 ASF-related articles from 1990 to 2022 were analyzed. The regression model revealed an exponential trend in the behavior of the number of publications over time ($R^2 = 0.807$) (Figure 1). That is, in the 1990s, the number of publications per year ranged from one to two. For the period from 2000 to 2010, the number of publications increased with an erratic pattern; however, from 2012 to 2022, there was sustained growth in the number of publications, with 2020 being the year with the most publications, 35 (17 %). The production of research articles in the period 2012–2022 represented 86 % (175 studies) of the total number of publications analyzed.

The increase in scientific research since the 2000s is related to the inadequate management of agricultural production systems in Mexico (Caicedo-Aldaz *et al*., 2020). In particular, these models have been oriented towards the intensification of production systems through monocultures, the use of chemical fertilizers, pesticides, and genetically modified varieties, resulting in technological dependence and the devaluation of traditional peasant production systems (Lovrić *et al*., 2018). In this context, agroecological and agroforestry studies have seen a significant increase in the last decade because they integrate new approaches, both analytical, holistic, and production indicators that allow the development of new management techniques that help in the conservation of natural resources to produce food in a sustainable

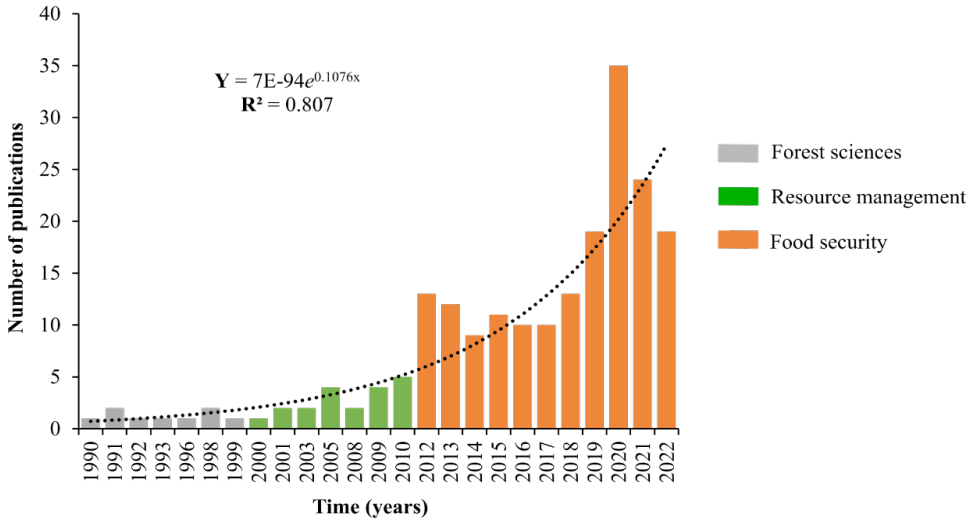

Figure 1. Exponential regression model describing the time evolution of publications on agroforestry systems in Mexico from 1990 to 2022.

manner (Casanova-Lugo *et al*., 2016; Moreno-Calles *et al*., 2016; Cadena-Zamudio *et al*., 2022).

Of the 204 publications, 175 (86 %) presented a moderate correlation with food security by integrating the cultivation and use of timber species for germplasm conservation ($R^2 = 0.499$; $p = 0.02$); 18 (9 %) to resource management with species of agroecological interest in agroforestry systems, and 10 (5 %) to ecological and forestry sciences ($p \geq 0.05$). In particular, the emphasis on agricultural production for food in the last decade has been primarily related to national problems and commitments signed by Mexico for food production, with a special emphasis on socially and economically depressed areas (Santillán-Fernández *et al*., 2023). Currently, the federal government's current programs (Estrategia de Acompañamiento Técnico del programa Producción para el Bienestar and Sembrando Vida) seek to formulate strategies in the agricultural sector to produce basic food for society in a sustainable manner (CEDRSSA, 2020). In this sense, the implementation of projects with agroforestry approaches that integrate first-line species has allowed a significant increase in grain production for food security and contributed to the solution of environmental problems, such as the conservation of natural resources (Singh *et al*., 2021a).

Bibliographic linking and journal sources

The relationship between the journals and the number of references they share (bibliographic linkage × journal sources) is shown (Figure 2). In general, the Agroforestry Systems journal registered the most hits in the search, representing 70 % of the publications. Similarly, the analysis showed strong relationships between the journals Journal of Ethnobiology and Ethnomedicine and Botanical Sciencies.

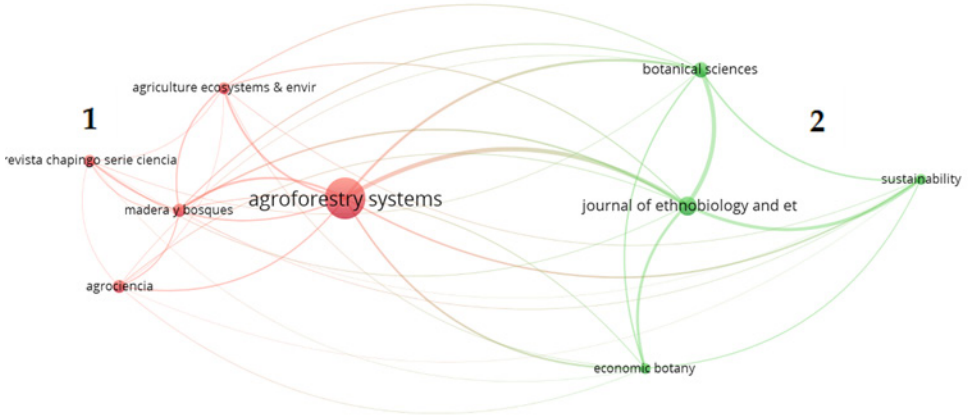

Figure 2. Visualization of the network based on bibliographic data (bibliographic linkage and journal sources).

In this study, each source was analyzed individually before being combined into a single source based on the relevance of each variable. This resulted in nine items divided into two clusters (Figure 2). Ninety-four (94) items were grouped in cluster one, which could indicate some editorial preference among journals, or that journals publish articles citing other papers within specific groups of journals, especially those with high impact factors with multidisciplinary approaches (Mourao and Martinho, 2020). For example, the journal Agroforestry Systems registered an impact factor of 2.5, while for Journal of Ethnobiology and Ethnomedicine it was 3.0 in 2022, which makes them a focus of attraction for scientists in the field who seek to publish the results of their research with greater impact and international character (Selmer, 2018).

Research institutions

Ten institutions grouped into four clusters (Table 1). The Universidad Nacional Autónoma de México (UNAM) was the institution with the highest number of publications (73, 41.9 %), followed by the Universidad Autónoma Chapingo (23, 13.2 %), Colegio de Postgraduados (16, 9.1 %), and the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias 15 (8.5 %) (Table 1).

The teaching and research institutions with the most studies on agroforestry systems in Mexico was UNAM. In 2012, this institution initiated a project supported through the Ethnoecology and Biocultural Heritage Network of the National Council of Science and Technology (CONACyT) with the objective of characterizing the main agroforestry systems of the peoples of Mexico. This resulted in a significant amount of research on the various regions of Mexico, which has generated several courses and undergraduate and graduate theses, publications in indexed journals, and several refereed chapters up to the creation of the Bachelor's Degree in Agroforestry Sciences at UNAM (Moreno-Calles *et al*., 2020). Similarly, the Universidad Autónoma Chapingo

Table 1. Institutions with the most scientific publications on agroforestry systems in Mexico. The information is grouped by cluster and from most to least articles published by each research center.

Research institution	Publications	Cluster	Link number
Universidad Autónoma Chapingo	23 (13.2 %)	1	20
Colegio de Postgraduados	16 (9.1 %)	1	13
Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias	15 (8.5 %)	1	12
Universidad Veracruzana	13 (7.4 %)	1	8
El Colegio de la Frontera Sur	8 (4.5 %)	1	21
Universidad Autónoma de Chiapas	7 (4 %)	1	12
Universidad Nacional Autónoma de México	73 (41.9 %)	2	265
Universidad Autónoma del Estado de México	8 (4.5 %)	2	16
Instituto de Ecología A.C	12 (6.8 %)	3	8
Universidad Autónoma del Estado de Morelos	7 (4 %)	3	42
Universidad Autónoma Metropolitana	7 (4 %)	4	7

through the Division of Forestry Sciences and the International Center for Agroforestry for Sustainable Development (CADS), and the Colegio de Postgraduados (CP) in its campuses located in the tropical zone also stand out for their contributions in the research of agroforestry systems with socioeconomic and ecological approaches, as well as the evaluation of carbon sequestration (CONAFOR, 2013). The Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) has made significant contributions to the development of new technologies and their transfer through books, technical brochures, leaflets, and articles on their application in rural areas.

In general, UNAM, Chapingo, CP, and INIFAP, as well as non-governmental organizations, civil associations, and peasant groups, seek to develop strategies based on scientific, technical, and cultural knowledge that allow for the revaluation and improvement of ASF in order for it to be recognized as part of the peoples of Mexico (González-Valdivia *et al*., 2018).

Authors, citation and co-citation

The network visualization map (Figure 3) reveals that several authors were grouped into a single cluster.

In relation to the authors with the most publications, UNAM researcher Alejandro Casas Fernández has the most studies on agroforestry systems in Mexico. Dr. Casas has focused on the study of sustainable management of non-timber forest resources during domestication processes, as well as the *in-situ* management of genetic resources. He has been a strong supporter of ethnoecology and the conservation of biocultural diversity in different regions of Mexico, as well as the traditional management of agroforestry systems. Dr. Moreno Calles has also contributed to several studies, including ethno-agroforestry, family, urban, and peri-urban agriculture. She is currently responsible for

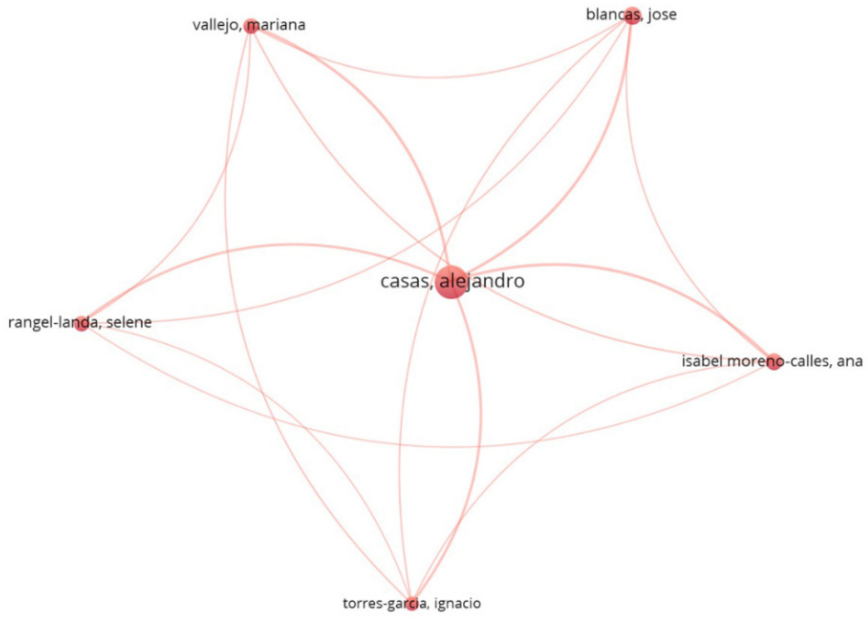

Figure 3. Network visualization map based on bibliographic data (authors and citations).

CONACyT's Thematic Network of Agroforestry Systems in Mexico (www.red-sam.org); she coordinated the creation of the Bachelor's Degree in Agroforestry Sciences in the State of Michoacán and is editor of the book "Etnoagroforestería en México" and "Sistemas Agroforestales de México" (Moreno-Calles *et al*., 2020). Both authors stand out for their scientific-academic collaboration in the number of times they have been cited together (Table 2).

Table 2. Authors recording the highest number of times cited in publications on agroforestry systems.

Author	Citations	Co-citations	Cluster	Link number
Casas-Fernández A	555	157	1	798
Moreno-Calles AI	379	71	1	502

Main terms

The research topics were classified into three groups, represented by different colors of the full set of 32 years (1991 to 2022) (Figure 4).

For the period studied, a network with three clusters is shown, where the size of each node (point) and link (line) is proportional to the intensity of the link of the node or line. Red cluster = 1, green cluster = 2 and blue cluster = 3. The former reveals

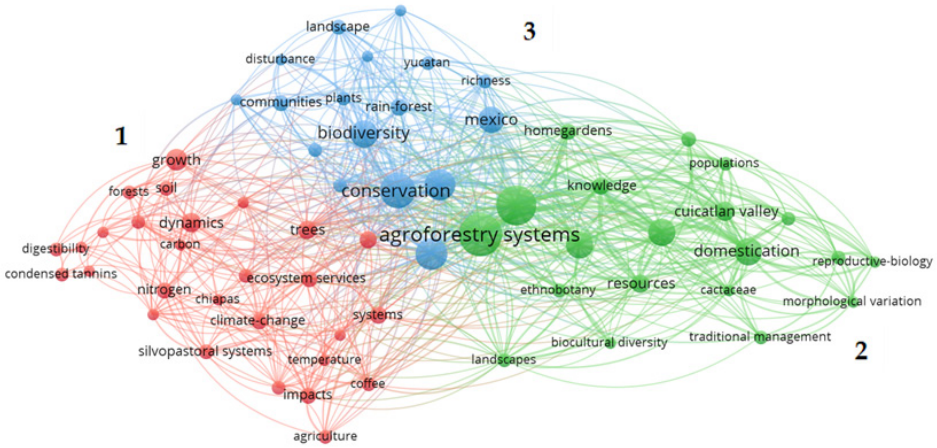

Figure 4. Visualization of the keyword co-occurrence network of all articles published over a period of 32 years (1990–2022, 1282 terms analyzed).

the consolidation of terms and exposes a clear conceptual framework for studies on agroforestry systems in Mexico. The clusters identified covered the entire period studied (1990–2022): (1) "growth", "dynamics", "trees", "ecosystem, services", "nitrogen", "soil" and "biomass"; (2) "agroforestry systems", "diversity", "biodiversity conservation", "plant management", "domestication", "knowledge" and "resources"; (3) "conservation," "management", "biodiversity", "forest", "Mexico", "plants", and "communities".

Cluster one shows the emergence of research topics related to the use and combination of nitrogen-fixing species and their positive effects on the soil through leaf litter residues (biomass) that serve as a source of nutrients and organic matter when decomposed, contributing to the maintenance and fertility of the soil (Petit-Aldana *et al*., 2012). Cluster two focuses on research topics related to the potential of agroforestry systems in the conservation of resources and ecosystem biodiversity through the local knowledge and traditional management of native peoples (Moreno-Calles *et al*., 2013; Santos *et al*., 2022). Cluster three addresses issues associated with the management of agroforestry systems under the concept of biological conservation in order to maintain ecosystem function and restore biodiversity through live fences for agricultural and/or fruit production with timber species (Santos *et al*., 2022).

CONCLUSIONS

The bibliometric analysis focused on ASF publications in Mexico over the last 32 years. The results show an increase in the number of publications over time, indicating a growing community interest in food security and conservation of natural resources. In particular, the most frequent indicators of publications from 1990 to 2022 were tree cultivation and their nutritional effects on the soil, the potential of ASF in natural

resource conservation through traditional management and local knowledge, and ecosystem functionality and restoration.

This work has certain limitations such as the use of different databases (Dimensions, PubMed, and Scopus, among others) where there may be variations in the number of articles present in the databases, as well as the use of qualitative tools for the analysis.

AUTHOR CONTRIBUTIONS

Conceptualization, data analysis, and writing of the original draft, CZ-DA; Data review and follow-up of results, CZ-DA, CI-P and AV-JL; Data analysis and writing of the final manuscript, CZ-DA, NC-DH, and AT-R; Drafting, revising, and editing of the final manuscript, CZ-DA, CI-P and HM-J. All authors have read and accepted the published version of the manuscript.

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