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Global trends in sustainable cocoa (*Theobroma cacao* L.) production: A bibliometric analysis (2019–2025)

UNIVERSIDAD NACIONAL DE COLOMBIA

Tendencias globales en la producción sostenible de cacao (*Theobroma cacao* L.): un análisis bibliométrico (2019–2025)

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ABSTRACT

Keywords:
Agroindustry
Circular economy
Fair-trade
Green practices

Currently, there is global concern about rising temperatures, which, together with the food risk, is causing climate change. In addition, cocoa (*Theobroma cacao* L.) production is questioned because of its production method, which generates deforestation and high energy and water consumption in the process. These environmental problems cause a bad image in the sector, and uncertainty in the overall production of the cocoa industry, which has been striving to implement sustainable practices to mitigate the effects of climate change. However, solutions to this environmental issue have received little attention from the scientific community, and the need has arisen to investigate sustainable solutions for the cocoa industry. This study aims to conduct a bibliometric analysis to identify global sustainable trends that have been researched in the cocoa industry. For this purpose, a search strategy was designed and applied in the Scopus and Web of Science (WoS) databases, to collect information, filtering the results, in the categories of articles related to the agriculture and business groups in the 2019-2025 period, published in journals cataloged in quartiles one and two. Using the R programming language for information processing, 56 documents were found. Eleven sustainable practices were identified in the industry to improve social, economic, and environmental performance, through waste valorization, soil improvement, reduction of water and energy consumption, and the adoption of green certifications. Finally, a framework is proposed for integrating the links in the supply chain with the practices for making them most sustainable.

RESUMEN

Palabras clave:
Agroindustria
Economía circular
Comercio justo
Prácticas verdes

En la actualidad, existe preocupación mundial por el aumento de las temperaturas que, junto con el riesgo alimentario, provoca el cambio climático. Además, la producción de cacao (*Theobroma cacao* L.) se cuestiona por su método de producción, que genera deforestación y un elevado consumo de energía y agua en el proceso. Estos problemas medioambientales causan mala imagen en el sector e incertidumbre en la producción global de la industria del cacao, que se ha esforzado por aplicar prácticas sostenibles para mitigar los efectos del cambio climático. Sin embargo, las soluciones a este problema ambiental han recibido poca atención por parte de la comunidad científica y ha surgido la necesidad de investigar soluciones sostenibles para la industria. Este estudio tiene como objetivo realizar un análisis bibliométrico para identificar tendencias globales sostenibles que se han investigado en la industria del cacao. Para ello, se diseñó una estrategia de búsqueda aplicada en las bases de datos Scopus y Web of Science (WoS), con el propósito de recopilar información, filtrando los resultados, en las categorías de artículos relacionados con los grupos de agricultura y negocios en el periodo 2019-2025 publicados en revistas catalogadas en los cuartiles uno y dos. Utilizando el lenguaje de programación R para el tratamiento de la información, hallando 56 documentos. Se identificaron 11 prácticas sostenibles en la industria, con el objetivo de mejorar el rendimiento social, económico y medioambiental, mediante la valorización de los residuos, la mejora del suelo, la reducción del consumo de agua y energía y la adopción de certificaciones verdes. Por último, se propone un marco para integrar los eslabones de la cadena de suministro con las prácticas para hacerla sostenible.

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There is currently a drop in world cocoa bean harvests, according to figures reported according to data presented by the International Cocoa Organization (ICCO 2025a). The 2023-2024 production is estimated at 4.3 million tons, with a 14% decrease over the previous year, in which production was 5 million tons. This is a consequence of the 16% drop in the African continent, which produces 70% on average worldwide, the most affected African country was Ivory Coast with a 25% decrease (ICCO 2025a). This problem in production has not been alien to the American context, where the drop in production was 6%, going from a production of 1,046 million tons in the 2022-2023 period to 980 million tons in the 2022-2023 period (ICCO 2025a). In addition, a 5% drop in cocoa beans grindings worldwide in the same period (2023-2024) compared to the previous year, with reported figures of 1,792 million tons, with the European continent being the major player with the processing of 36% of the world's grindings, Africa saw a 10% drop in milling, with Côte d'Ivoire being the most affected country with a 6% drop, between these two continents, approximately 60% of world production is milled in the Americas the drop in the grindings of cocoa beans was 14% from reported figures in the 2022/2023 timeframe of 979 million tons to 891 million tons. (ICCO 2025a).

On the other hand, the food industry is one of the main sectors that pollutes the environment, negatively impacting society (Keller et al. 2022). This has led to the rise of environmentally friendly agriculture in the food industry in order to promote sustainable development (Silva et al. 2017). The cocoa industry is adding to this global cleaner production approach (López del Amo and Akizu-Gardoki 2024). Also, the decision-making power of the demand focused on the acquisition of healthy and environmentally friendly products has generated pressure on cocoa farmers to incorporate green practices in their production processes in order to meet market requirements (Fayaz et al. 2024), with the transformation of cocoa waste into secondary raw materials for applications becoming a challenge (Puyana-Romero et al. 2022). Therefore, cocoa agro-industrial companies that incorporate green practices in their processes can reduce costs and ecosystem impacts to achieve the sustainability of the industry (Girón-Hernández et al. 2024). Also, environmental regulations are public mechanisms applied by governments in order to control environmental pollution, becoming an important issue for different stakeholders and especially for industrialists and their production (Chen and Haoa 2025)Europe has implemented strong regulations for the care of the environment, such as the regulation against deforestation (EUDR) (EU 2023/1115), which aims to counteract the deforestation of imported products, especially cocoa. This regulation generates global policy innovation for the management of global chains (Urugo et al. 2025), therefore, understanding and complying with the new EU regulations has become a challenge for the cocoa industry, especially for smallholder farmers (Moluh Njoya et al. 2025). Voluntary sustainability standards, which are also called certifications, are non-governmental tools aimed at reducing the environmental, economic, and social impacts of the production of crops such as cocoa (Dröge et al. 2025), most of the cocoa exported is Fairtrade or Rainforest Alliance certified (RA) (Steinke et al. 2024). Fair trade is a global trend that promotes sustainability and fair trade for farmers, prohibits the use of toxic pesticides and trains farmers in the management of agrochemicals, creating more balanced forms of economic and social development (Quach et al. 2025). RA was designed to certify farms that comply with social and environmental standards, which must take care of the soil and water sources as well as treat workers with dignity, without neglecting financial profitability (Tischner et al. 2017).

However, the indiscriminate use of chemical fertilizers to improve production, and the increase of inadequately treated waste that negatively impacts the environment, the economy and society, place the concept of sustainability in the cocoa sector in question (Mariatti et al. 2021; Perez et al. 2022), generating concern in cocoa production processes, which leads to questioning the impacts on the economic, environmental and social dimensions (García-Herrero et al. 2019). Moreover, climate change, the fall in production and the global increase in cocoa prices (which have reached historic highs) has caused farmers to abandon their crops and has led to alarm in the sector, by jeopardizing the sustainability of the industry (Bandanaa et al. 2025). Nonetheless, important research has been conducted previously, relating cocoa to sustainable practices, using the review of literature in the last five years as a research method, with the following being found.

Rathgens et al. (2020) presented the problem of child labor in the cocoa sector, which is a deepening in the assessment of the impact of the certifications, the main challenge for academics. Mariatti et al. (2021) identified the processes successfully implemented in the management of cocoa husk and corncob residues, in addition to the contribution of technologies associated with Industry 4.0 as an input to circular economy practices, so that this constructive collaboration between technologies and practice strengthens economic and environmental performance.

Ribeiro-Duthie et al. (2021) found the relevant literature on fair trade certification of staple foods, including cocoa. The importance of this certification is that it informs the consumer about the fairness of producers' wages and the democratization of production and sustainability. Perez et al. (2022) identified the main challenges related to the sustainability of the chocolate industry, such as the complexity of monitoring the cocoa and chocolate supply chain, the limited training of farmers in good environmental practices, the slow adaptation to the certification process required by European markets for the export of the product from 2020, and the environmental costs associated with packaging.

Fernández-Ríos et al. (2022) found 15 superfoods with environmental performance measurements, with the existing literature on cocoa being the most cultivated, processed, and consumed superfood, and its supply chain being the most studied. Barrios-Rodríguez et al. (2022) studied the process of transforming cocoa pods into biomass as a circular economy strategy that minimizes environmental impact and refines energy costs and extraction time. Suri and Basu (2022), through a literature review, found the fundamental variables that impact the resistance of chocolate to heat, the difficulties presented in the texture, and the obstacles presented in storage, which have generated an important opportunity for research in sustainability. Previous research has made relevant contributions to cocoa and sustainability. However, there are no studies that propose an integrative route between sustainable cocoa practices and the supply chain to achieve a balance between the three pillars of sustainability (environmental, social, and economic). Also, previous studies did not address the thematic evolution of knowledge to know the next research agenda, hence the importance of this research.

This work aims to perform a bibliometric analysis to identify global trends in the world cocoa industry related to sustainability practices in scientific literature. The above process will be a fundamental input to answer the following research questions: Which are the leading countries in research on cocoa and sustainability? Which are the high-impact journals of scientific publication? What are the global research trends in established cocoa and sustainability issues? What are the main sustainable practices in the cocoa industry? This paper has been divided into four parts: 1) deals with the introduction, including the challenges of the cocoa industry in relation to sustainability. 2) concerned with the methodology used for this study, Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) approach. 3) deals with the results of the scientific data mining that will provide answers to the questions posed in the introduction, and 4) deals with the discussion from the metaphorical approach of the tree of knowledge.

MATERIALS AND METHODS

Type of research

Bibliometrics provides insight into the important factors of the academic dimensions of research on a large scale by studying them at the national level or by individual academic discipline (Siao et al. 2022). The resources applied in bibliometric studies make it possible to estimate publications and citations by relating productivity to the influence and quality of scientific papers (Madeira et al. 2023), allowing the identification of research scopes and existing gaps by reducing scientific subjectivity (Salihu et al. 2022). The R open-source software, with its R Studio extensions, the Bibliometrix library and related Biblioshyne interface were used. The importance of programming languages and their tools is recognized by the scientific community (Aziz et al. 2024). The databases used for the analysis process were Scopus and Web of Science (WoS), because these are databases with an enormous collection of material and quality scientific analysis tools (Tsilika 2023).

Data analysis

Keywords and similar terms were explored in topics delimited by the research, classifying the level of importance according to the number of records. The first one was called Cocoa, a topic that covers the terminology on this crop, in which the term with the highest result was “cocoa” with

15,873 records in Scopus, and 8,936 in WoS, for a total of 38,315 and 15,875 in the respective databases. Secondly, the dimension of green practices was explored, where the term sustainability is the most used by the scientific community, with 1,410,997 and 776,214. This group is the most influential in the research, with a total result of 1,413,913 and 777,875, which integrates all the terminology associated with this group. Finally, in the integration using the selection mechanisms represented in the Boolean operators for the design of a search strategy to capture data with the topics related to the research ("Green label") OR ("green certification") OR ("Sustaina*") OR ("green practi*") AND ("*Theobroma cacao*") OR ("Cocoa") OR ("Cacao"). On July 10, 2025, 1,591 and 1,060 documents were identified documents related to cocoa integrating green practices. This exploration was performed on the main structure of the documents (title, abstract, and keywords). Table 1 presents the results of the two databases.

Table 1. Keyword research.

Topic	Scopus	WoS
"Theobroma cacao"	7,693	2,745
"Cocoa"	15,873	8,936
"cacao"	14,749	4,176
Total, topic cacao	38,315	15,875
"Sustaina"*	1,410,997	776,214
" Green label"	286	101
"Green certification"	368	168
"Green practi"*	2,262	1,402
*Total, Topic Gree*n	1,413,913	777,875
Final cross-checking of information	1,591	1,060

The PRISMA method was used as input for the research approach to provide a clear and concise systematic approach to data mining (Agyei et al. 2024). The following classification parameters were used to classify information search focused only on articles in areas related to research, such as agriculture and business, in Scopus. The following subject areas were selected: Agricultural and Biological Sciences, Environmental, Social Sciences, Economics, Econometrics, and Finance. Also, in WoS, the selected research areas were Environmental Sciences, Ecology, Agriculture, and Science Technology. Other topics were Food Science Technology, Forestry, Business Economics, and Biodiversity Conservation, to identify global scientific trends. The search was limited to the production of the last six years only (2019-2025). For greater quality in the processing of the information, only articles belonging to quartiles one and two (Q1 and Q2) were selected for a final result in the two databases of 48 and 42 (Figure 1). Finally, to end duplicates, processes were conducted to verify the information, in the R open-source software, R Studio version 4.3.2, in BibTex format, in the two databases. The result was 34 duplicate documents eliminated for a net resulting of the unification of 56. This research did not

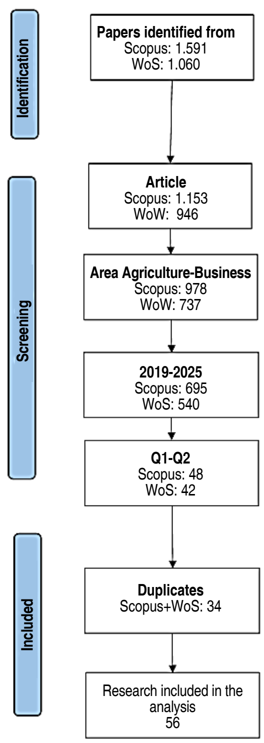

Figure 1. Prism method.

include articles classified in quartiles 3 and 4 (Q3-Q4), and databases other than Scopus and WoS were not used, which may introduce limitations in the results.

Figure 2 illustrates the geographical dissemination of research papers. The methodology used to determine geographical representation was the location of the research institutions to which the authors belong. On the other hand, the intensification of the color blue shows the scientific strength of the country according to the number of records, for graphic analysis, the five main countries will be studied, which in their respective order are: Spain and United Kingdom (17), Ghana and (16) Italy, finally, Ecuador with (15) records. This research has been carried out in partnership with different countries. The strongest collaborations, according to the number of frequencies represented in Figure 3 by the weight of the line, there is a triangulation of collaboration between Finland with China, and the United States, as well as a reported network between China and the USA. Finally, there is a strong collaboration between China and Ghana (Figure 3).

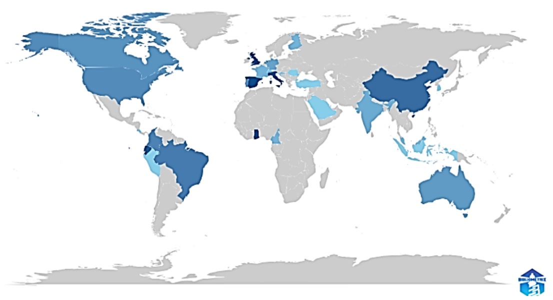

Figure 2. Countries' scientific production.

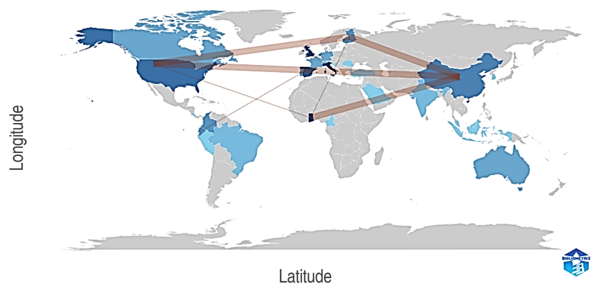

Figure 3. Countries' collaboration.

Figure 4 analyzes citations by country; the top 5, according to total citations, is led by China (177), the United Kingdom (154), Switzerland (129), and Italy (144). It is worth noting the representation of Colombia in this ranking: (46).

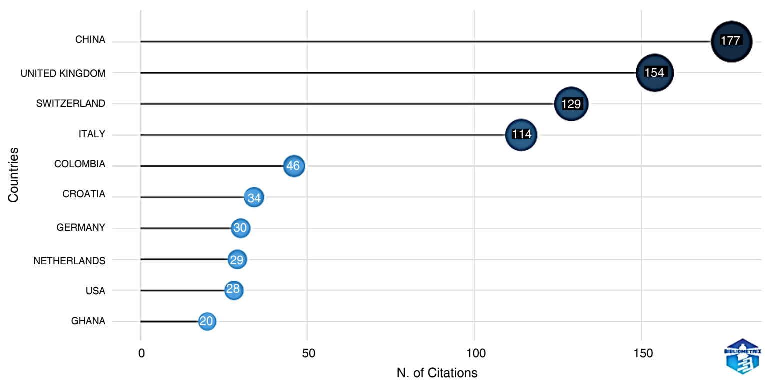

Figure 4. Most cited countries.

Figure 5 presents the ranking according to Multiple Country Publications (MCP) and Single Country Publications (SCP). According to the combination of these variables, the UK leads, followed by Italy and China. In the case of Colombia, research has been carried out only in this country. Figure 6 shows the historical production by country over the last 5 years, which was initiated by Ghana, the UK, and Italy. Among the new scientific actors, Colombia appears with recent publications in the year 2023 (5) and 2024-2025(10), respectively (Figure 6).

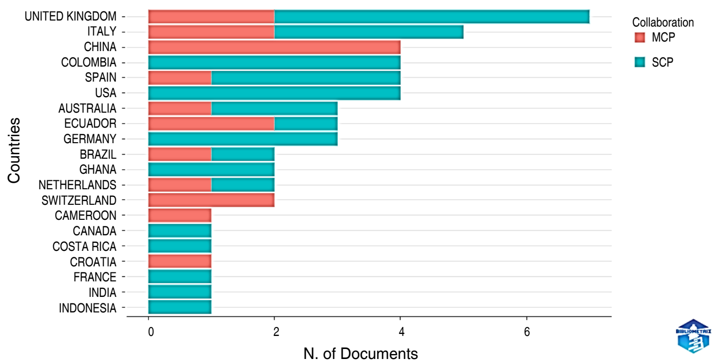

Figure 5. Corresponding author's countries.

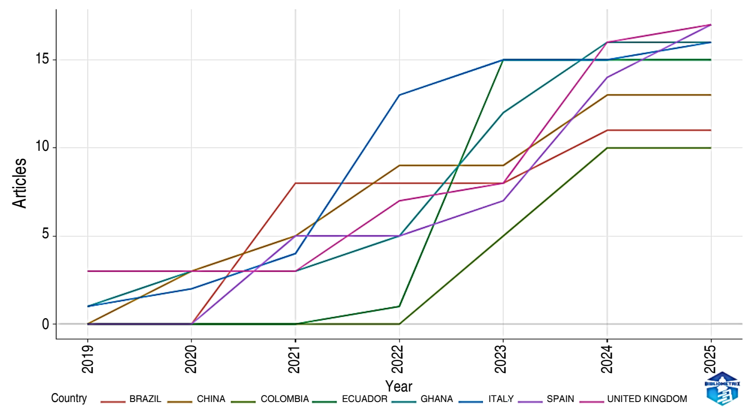

Figure 6. Countries' production over time.

Preferred journals

Figure 7 shows the top 5 sources according to the number of published articles. Important classifications are highlighted according to the number of records: Journal of Cleaner Production (13); Innovative Food Science (4); Sustainable Production and Consumption (3). Finally, there are the Applied Geography, Food and Bioprocess Technology, the Journal of International Food and Agribusiness Marketing, and the Supply Chain Management: An International Journal with two registrations, respectively.

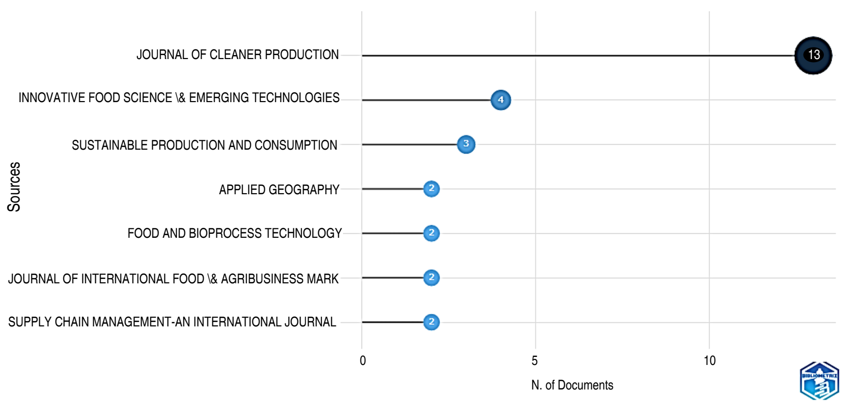

Figure 7. Most relevant sources.

Table 2 shows the main policies of Journals. It should be noted that all of them are of open access, according to the Citi Score bibliometric metrics of the Scopus database, Sustainable Production and Consumption leads (22.5). However, according to the bibliometric metric, the Impact factor of the WoS database Journal Cleaner Production (10) is the highest among the journals.

Table 2. Main bibliometric metrics and journal policies.

Journals	Open access	Article processing charge (USD)	Submission for acceptance	Cite score	Impact factor	Thematic relevance
Cleaner Production	X	4,660	145	20.7	10	Sustainability
Innovative Food Science	X	4,470	85	12.5	6.8	Innovation
Sustainable Production and Consumption	X	3,770	105	22.5	9.6	Technology, consumption and sustainability

Research trends

Figure 8 presents the historical distribution of publications, starting in 2019 with 5 papers, reaching historical highs in 2022 with 11 papers, in 2023 there was a 9% decrease in the number of queries. In 2024, there were the same number of papers as in 2022. In the first half of 2025, the figure is 5 research.

The analysis of references by spectroscopy shows the evolution of citations over time, showing their importance in scientific research (Nica et al. 2024). According to Figure 9,

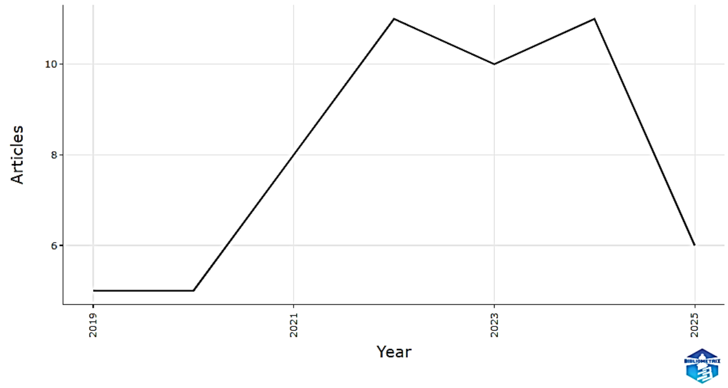

Figure 8. Historical evolution of publications.

the first reference found was the research of Nevinson (1906), with one citation. The historical maximum occurred in the 2020s, with 322, taking Adesanya et al. (2020) and LeBaron et al. (2020) as a ranking. According to Google, academic citations for these papers were 120 and 101, respectively (Figure 9).

In this regard, keyword analysis represents the study of the most important words of the authors, revealing important fields in the scientific community (Pesta et al. 2018). In this order of ideas, Figure 10 shows the thematic map of research, this figure allows to identify the important topics of study according to the keywords of the authors, presenting the weight of the internal importance reflected in the growth of the dimensions and the external importance that is the relationship of the research in a specific field grouped in four segments (Bagdi et al. 2023). Driving topics are relevant topics and have a significant impact on other topics; they are considered topics with restricted progress, niche topics may lack weight and importance, and core topics are fundamental topics but need further research (Serter and Gumusburun 2024).

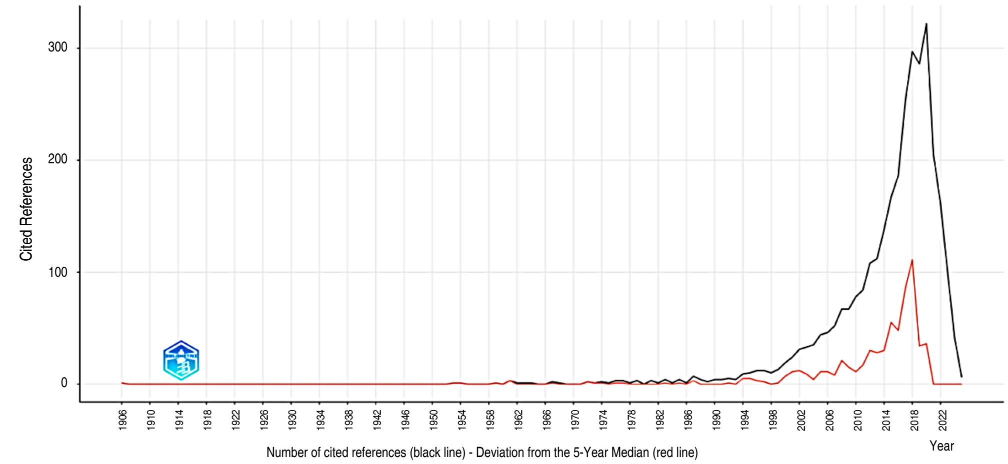

Figure 9. Historical evolution of citation.

The following parameters were used to configure the analysis: Number of words: 70, Minimum frequency of clusters (per thousand documents): 5, Number of labels: 3, Label size: 0.3, Community repulsion, and Clustering algorithm Walktrap. The research agenda can be approached from four quadrants: 1) Basic: issues with work that relates to circular economy, cocoa byproducts and agritourism; 2) Emerging themes: bioactive compounds, polyphenols pretreatment, biochar, cocoa beans, cocoa pod husk; 3) Niche topics are studies related to adoption, agroforestry, agroforestry systems and competitive advantages and 4) Motor topics: sustainability, cocoa, agriculture, life cycle assessment, food and sustainable development.

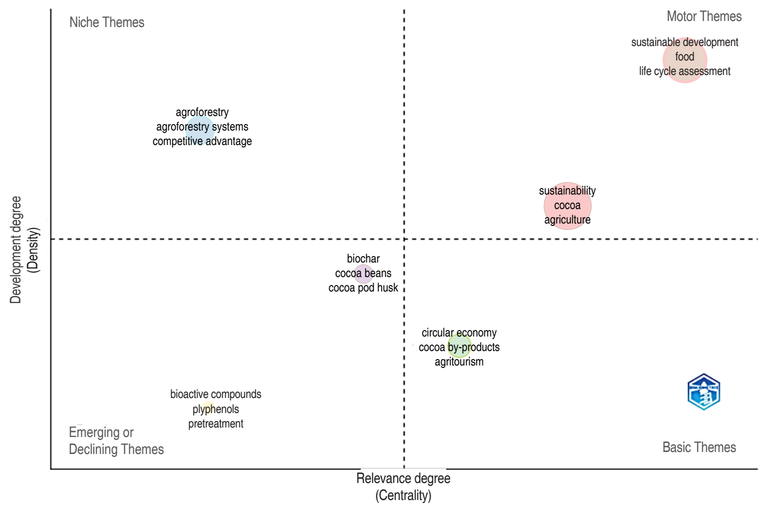

Figure 10. Thematic map.

The factorial reduction technique is applied to reduce dimensions and group similarities in scientific topics (Talero-Sarmiento et al. 2025). In this context, by using the multiple correspondence analysis technique (MCA), which represents the data as a point in a low-dimensional Euclidean space (Abafe et al. 2022). The K-means method was applied to study the association of the co-citation matrix with K=3; the variance of the information in the two dimensions was 86.05%. The first research trend in the green group is related to life cycle assessment in food. The second blue trend focuses on the sustainable development of supply chains. Finally, the third red trend is related to cocoa, certifications, sustainability, and supply chain management (Figure 11).

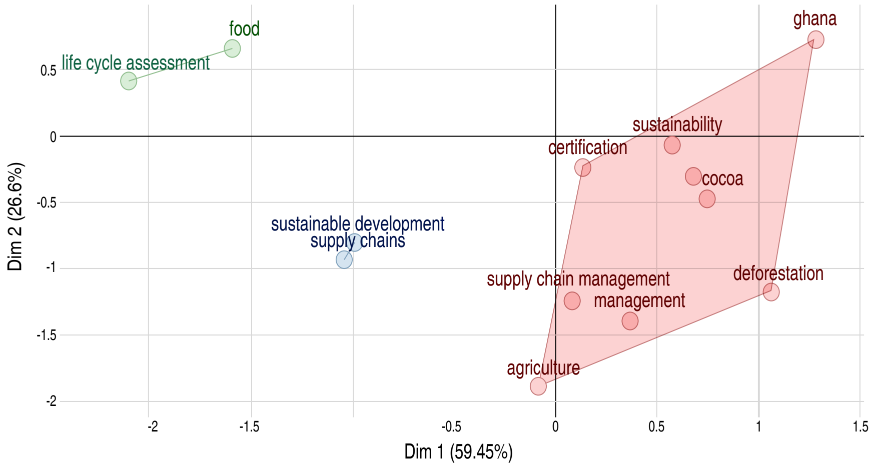

Figure 11. Factorial analysis map.

The keyword clouds figure are a visual scheme of the most relevant words in the research, represented by the size of the word (Turki and Roy 2022). In this line, and according to Figure 12, taking as a reference the five most relevant according to the records in their respective order, the following were found:

Figure 12. Keywords cloud.

Sustainability (18), Cocoa (11), sustainable development (10), life cycle assessment (7), agriculture, environmental impact, food and management (6), respectively. Figure 13 shows the rectangle diagram, where the size of the geometrical figure represents the importance of the Word (Purna Prakash et al. 2024) and their percentage of use frequency. The following stand out in the same classification, with 40% of the total number of records: Sustainability (10), Cocoa, sustainable development, life cycle assessment, agriculture, environmental impact and food and management (6), respectively (Figure 13).

The co-occurrence analysis studies the relationship between keywords. The size of the node and closeness between words allow it to determine the degree of association between them (Det Udomsap and Hallinger 2020). The Walktrap algorithm is recognized for its

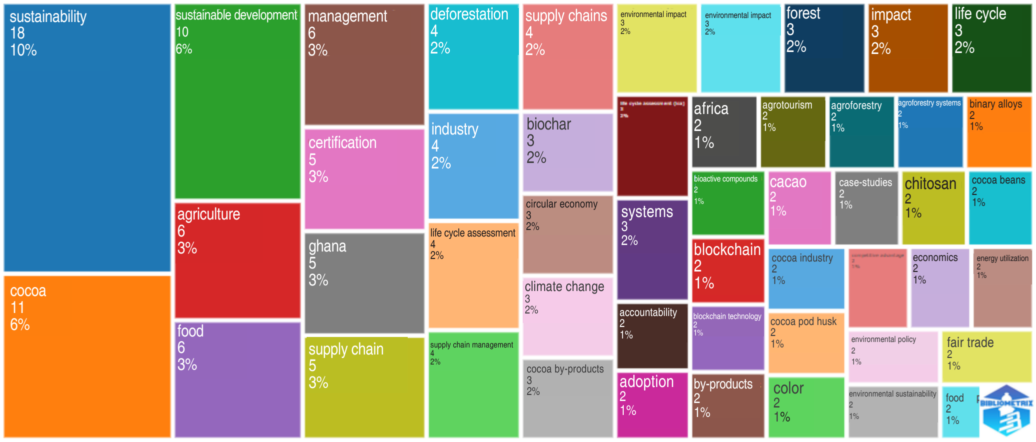

Figure 13. Keywords tree map.

efficiency in the clustering of key terms and the design of the visualization of the mapping of fields (Pons and Latapy 2005). According to Figure 14, three important word clusters were identified. The first red cluster focused more on sustainability and was related to agro-tourism, agro-forestry, forestry, and certifications, especially fair trade, the cocoa industry, and emerging technologies such as the blockchain. The second, the green color, is more focused on sustainable development related to climate change, global warming, supply chain, life cycle assessment, and environmental impacts. Finally, the purple cluster focuses more on the circular economy and cocoa byproducts. In order to identify the research trends, a density map was used, where the intensity of red color represents the most important scientific currents. According to the above, in the cluster focused on sustainability, most of the research is done in environmental policies, deforestation, and management, and the cluster led by sustainable development, environmental impacts, climate change, and life cycle assessment (Figure 15) (Sun et al. 2023).

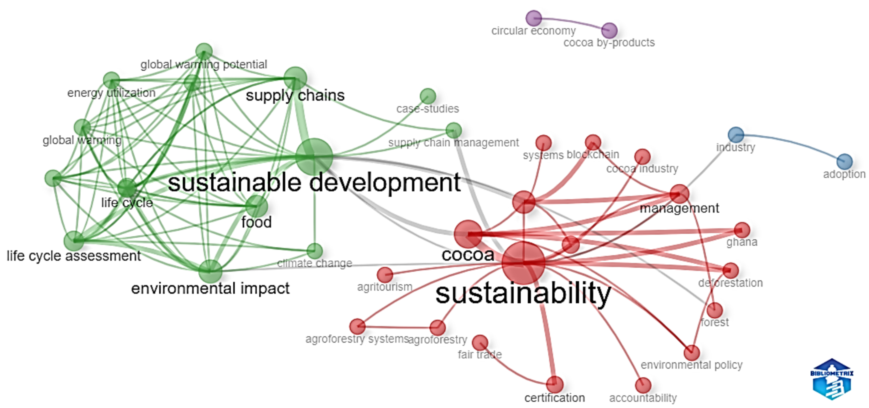

Figure 14. Keywords co-occurrence.

Figure 16 shows an integrative conceptual framework, using the metaphorical figure of a cocoa tree for the relevance of the research. The roots are the 10 identified sustainable practices: Agroforestry, Agrotourism, Circular Economy, Fair Trade, Biomarkers, LCA, Fluidized Bed Roasting, Extrusion, Green Suppliers and Buyers, and

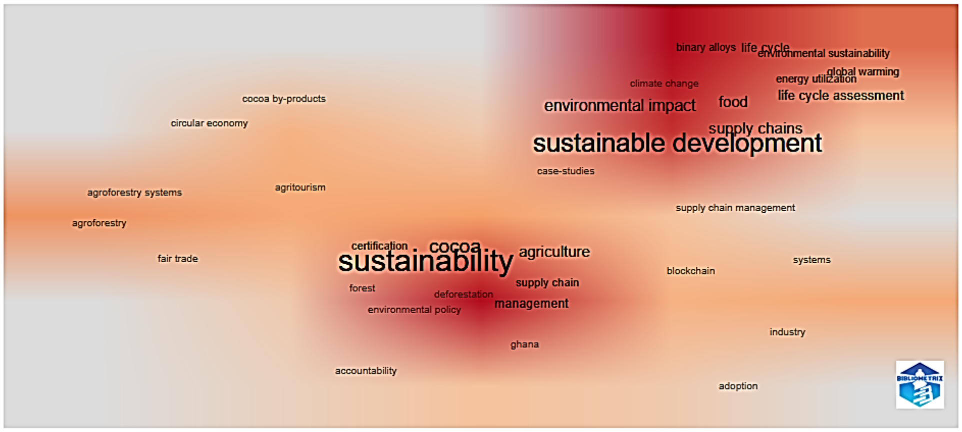

Figure 15. Keywords: density map.

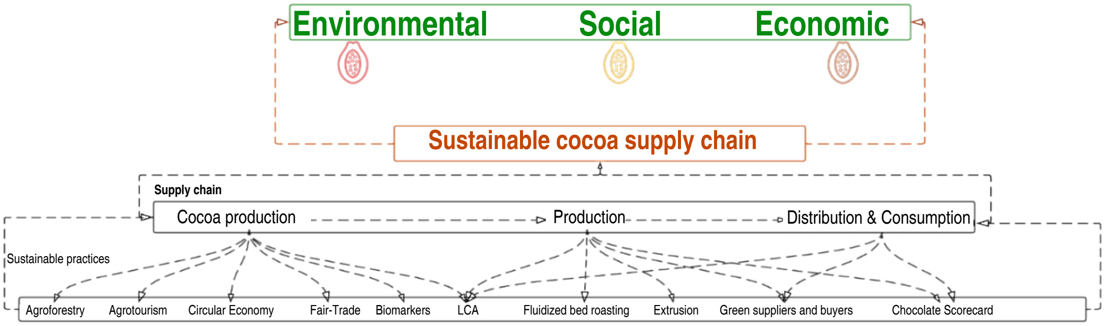

Figure 16. Framework on sustainable cocoa industry practices.

Chocolate Scorecard, which connect to the supply chain. The above provides support represented in the trunk to the sustainable supply chain. These previously presented relationships will bear fruit, illustrated as three cocoa pods in the balance of the three pillars of sustainability (environmental, social, and economic).

The following are the most relevant results of this research, reflecting on the conceptual and methodological assumptions that underpin the review. From the definition of sustainability by the Brundtland Commission, as the coverage of current needs without sacrificing the coverage of future needs (Brundtland and Khalid 1987), along with the triple bottom line sustainability model developed by John Elkington defined as the balance between profit, social welfare, and environmental impact (Elkington and Rowlands 1999). As it analyzes the concept of sustainable cocoa, it can be defined as the production chain that generates economic and social benefits while reducing the impact on ecosystems related to the cocoa industry. The definition above is consistent with that (ICCO 2025b). However, according to the same organization, there are problems in the sustainability of the cocoa industry, such as farmers with low economic returns, in addition to the precision exercised by the different stakeholders concerning environmental and social care. Concerning the first topic, the review also revealed the leading research countries as European, which demand high standards for exports related to sustainability and environmental matters. Additionally, Europe plays an important role in the world cocoa trade (Siddiqui et al. 2024). An interesting fact is that as it analyzed the origin of the main journals, these are also European, which ratifies the greater scientific influence of this region, leading the scientific agenda around the sustainability of the cocoa industry. Also, the main papers are open access, which allows a democratization of knowledge, reaching important studies to groups and interests of little economic development, such as small and medium enterprises (SME), as well as small farmers in the cocoa industry. With respect to research trends, the central topics are certifications, environmental impacts, and dynamic agricultural systems, among which agroforestry systems were identified. This finding is consistent with Olarte and Muñoz (2025).

This research identifies the main sustainable practices in the cocoa industry. The green labels generate benefits for the cocoa supply chain. Farmers can sell their products in European markets, which have the purchase of only sustainably certified cocoa as a restriction since 2020, which motivates exporting companies to certify farmers, generating greater sustainability in their processes. Input purchasing companies guarantee the green traceability of the product, and finally, consumers can enjoy chocolate without remorse of negative impacts on tropical ecosystems (Perez et al. 2022). An important finding was that fair-trade certification generates direct income to farmers by eliminating intermediaries between raw materials and globalized markets, generating higher profits, gender equity, and climate resilience (FairTrade 2025).

Agroforestry emerges as a sustainable system that allows generating benefits to cocoa cultivation, such as planting shade trees to improve production performance and pest control, also minimizing environmental impacts by eliminating the use of chemical insecticides. Also, biomass produced by trees increases the stock of carbon and nutrients in the soil, which improves production yields, which can be transformed into income in carbon payment systems (Krause et al. 2025). However, these agroforestry systems compete with the resources of cocoa monocrops, with the analysis of the compensation system between the consumption of water, space, and light of the trees versus the performance in cocoa production being important (Abdulai et al. 2025; Ariza-Salamanca et al. 2024).

Life Cycle Assessment (LCA) allows for the analysis of the environmental impacts of a production system along the supply chain (Dominguez et al. 2023). In a global context, the cocoa industry presents high consumption of resources, such as water, electricity, and energy in the production, manufacturing, and transportation stages, generating toxic effects on sources of seawater and human consumption, as a result of wastewater and material waste. In the stage of international transportation from factories to distribution points, fuel consumption produces polluting metals such as mercury and chromium, generating negative impacts on ecosystems (Wang and Dong 2025). Nevertheless, the environmental impact can be mitigated with the following system improvement options: In production, with the use of organic fertilizers and the reduction of pesticides in processing, by switching from diesel to natural gas systems (Ntiamoah and Afrane 2008). Finally, the circular economy has been used in the waste generated by cocoa, such as the cocoa pod, which can be transformed into a reassessment of this waste, such as compost to produce organic fertilizers and pectin for potential use in the biomedical industry (Dachs et al. 2025).

Table 3 presents six authors who investigated the reassessment of cocoa byproducts: Cocoa bean shells (CBS) and pod husks (CPH), from which biochar, polyphenols, advanced materials, improved fertilizers, compost, and hydrocarbons can be obtained.

Table 3. Circular economy research.

Authors	Result
Mariatti et al. (2021)	Analyzed the reassessment of waste CBS, CPH, identifying the extraction of polyphenols relevant compound for the biomedical industry.
Mwafulirwa et al. (2024)	Applying the circular economy to identify the extraction of biochar and compost from the CPH.
Girón-Hernández et al. 2024)	Biomass extraction from CPH, studied to extract advanced materials to improve human health.
Hoof et al. (2024)	Biomass reduction of CPH with applied vermicomposting was studied.
Andoh-Mensah et al. (2023)	CBS and NPK fertilizer blend investigated to improve performance in coconut crops.
Landázuri et al. (2023)	Investigated the hydrothermal carbonization of lignocellulosic wastes to produce hydrocarbon from CPH. Materials produced by this process are highly insulating, and can be used by the electrical industry.

Table 4 presents three authors who did research on LCA, which is more focused on studying energy consumption on farms.

Table 5 presents two authors' research on the Sustainable supply chain, which relies on the blockchain to map the supply chain, guaranteeing its sustainability and transparency.

Table 4. LCA Research.

Authors	Result
Caicedo-Vargas et al. (2023)	Identified the volume of cocoa production by smallholder farmers under 10 hectares, the non-cumulative demand for non-renewable energy, carbon footprint, and the net margin.
Armengot et al. (2021)	Studied the relationship between food production and energy, and water consumption using LCA in cocoa farms.
Tagne et al. 2022)	CPH analysis for biomass and bioethanol production.

Table 5. Research Sustainable supply chain.

Authors	Result
Quayson et al. (2021)	Applied technologies, such as blockchains, to improve the vulnerability resistance of small producers in the supply chain and make it more sustainable.
Bai et al. (2022)	Analyzed the application of emerging technologies, such as blockchain, to improve supply chain transparency and solve problems, such as a lack of social responsibility and decreasing environmental performance.
Quayson et al. (2024)	Analyzed the barriers that occur in emerging economies in the implementation of blockchain technology in supply chain sustainability.

Table 6 features the works related to green labels, which focus on Fair-Trade certification, which combines the social and environmental approach on farms.

Seven research projects were carried out studying non-conventional sustainable practices such as Biomarkers, Fluidized bed roasting, Extrusion, Green suppliers and buyers, Chocolate Scorecard, and Agrotourism (Table 7).

Table 6. Green Labels.

Authors	Result
Miglietta et al. (2022)	Studied the discussion of the scope of Fair Trade in ecological sustainability in the economic productivity of the water obtained by the Fair-Trade premium.
Knößlsdorfer et al. (2021)	Investigated the impact of Fair-Trade certification on food security, concluding that it has an improvement in the standard of living of cocoa farmers and a negative impact on food security.

Table 7. Agroforestry.

Authors	Result
Krause et al. (2025)	Studied how to improve the sequestration of soil carbon dioxide gas reserves by generating tree biomass.
Ariza-Salamanca et al. (2024)	Investigates the variables that drive performance in young cocoa crops compared to agroforestry, where increasing the height of the trees in the agroforestry system may have a decreasing effect on cocoa performance.
Abdulai et al. (2025)	Analyzed how the phenology of leaves in agroforestry systems influences the climate resilience and yield of cocoa.

Table 8 presents studies that explored additional types of sustainable practices.

The practical implications of this work are the identification of a set of sustainable practices in the cocoa industry, along with the design of an integrative framework that allows the different links in the supply chain to generate strategies for the implementation of practices to achieve sustainability. For example, the government can generate public policies and programs to encourage the implementation of the practices in industry. Additionally, the farmers' cooperatives will have a portfolio of sustainable practices, which will allow them to improve their sustainability strategies and generate green income.

Table 8. Research that addressed other types of sustainable practices.

Authors	Practices	Result
Lafargue et al. (2022)	Biomarkers	Created a biomarkers library, which allows sustainable traceability of the cocoa supply chain, enabling audits for compliance with standards.
Peña-Correa et al. (2022)	Fluidized bed roasting	Study of cocoa roasting techniques, oven roasting, and fluidized bed roasting. The latter method is more productive, generating efficiency in energy and water consumption.
Valverde et al. (2021)	Extrusion	Investigated extrusion, which is a more sustainable processing method compared to the traditional alkalization method, where extrusion allows generating an alkalinized product with high sensory properties more efficiently and sustainably.
Amoako et al. (2023)	Green suppliers and buyers	Investigated how a strong relationship between green buyers and suppliers improves sustainability through recruitment strategies and rewards.
Perkiss et al. (2025)	Chocolate Scorecard	Used the Chocolate Scorecard sustainability accounting tool to improve sustainability in the company.
Little and Blau (2020)	Agrotourism	Investigated how agritourism can improve the standard of living of communities and strengthen them in the face of climate change.

For this research, the authors conducted a rigorous search of scientific literature. However, the following limitations are presented: only English language documents from Scopus and WoS databases classified in Q1 and Q2 in the period 2019- 2024 were analyzed. This may lead to the exclusion of relevant documents published in other databases, outside the analyzed period, and journals of minor categories in languages other than English.

CONCLUSION

According to the literature, the recent increase in global temperatures, surpassing levels recorded in the 19th century, is expected to cause more frequent droughts, food shortages, and a decline in the nutritional quality of food. By defining sustainable cocoa production as an environmentally friendly agricultural process that generates economic gains and benefits families, the above corresponds to only one link in the sustainable supply chain, which covers production, manufacturing, and marketing, in which balance must be maintained in the three pillars (Environmental, Economic, and Social) for sustainable supply chain holders.

Geographical analysis showed Spain, the UK, and Ghana, together with Ecuador, lead the research; the strongest scientific clusters are those related to the China-US network, and finally, there is a strong collaboration between China and Ghana. Research on sustainable cocoa production is concentrated in Europe. This leadership arises because of the restrictive measures imposed on cocoa exports to this region.

Analyzing the submission policies and trends of the journals (high-impact journals), all of which are Open Access, generates greater visibility of the research, as there is no charge for accessing the document. This allows the development of a democratization of knowledge by providing access to information to various stakeholders, including cocoa cooperatives and small and medium-sized enterprises, which face budgetary constraints.

About the global research trends in the established topics in cocoa and sustainability, the thematic analysis was able to demonstrate that the trend in research revolves around certifications in sustainability and environmental impacts, together with dynamic farming systems, in addition to the decrease of the environmental impacts through the assessment of the residues of the cocoa production process, in this case the cocoa pod. Regarding the supply chain, to guarantee sustainability in all the links of the production, manufacturing and commercialization chain.

Finally, according to the bibliometric analysis, sustainable agroforestry systems provide an important opportunity to enhance sustainability in the cocoa production process by reducing environmental impacts through carbon sequestration, which can be translated into income for producers. However, a cost–benefit relationship was identified between the profitability of the system and resource consumption, so farmers should assess whether the benefits of adopting sustainable agroforestry systems outweigh the resources used. Sustainable certifications, such as those identified in the Fair-Trade study, also serve as a competitive advantage when entering European markets and generate direct income for farmers by reducing the influence of intermediaries. Life Cycle Assessment (LCA) analysis enables producers to implement improvement measures aimed at reducing environmental impacts related to energy and water use, as well as enhancing environmentally friendly transportation systems to prevent the discharge of heavy metals into water sources for both marine and human consumption. Additionally, residues from cocoa production, such as cocoa pods, can be converted into compost through circular economy practices, replacing chemical fertilizers, improving profitability, and making production more environmentally friendly. Moreover, these residues can be processed into pectin, a key component in the biomedical industry. Future research could further explore the relationship between sustainability, Industry 4.0 technologies, and cocoa—an area that remains underexplored—such as the use of precision agriculture tools and blockchain traceability. It could also address how technology adoption in the cocoa industry can improve enterprise sustainability and contribute to sustainable development, as well as expand geographical studies to regions such as Central Africa and Southeast Asia, where cocoa production is significant but underrepresented in the literature.

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CONFLICT OF INTERESTS

Researchers state that they have no conflict of interest.

REFERENCES

Abafe EA, Bahta YT and Jordaan H (2022) Exploring biblioshiny for historical assessment of global research on sustainable use of water in agriculture. Sustainability 14: 10651. https: //doi.org/10.3390/su141710651

Abdulai I, Hoffmann M, Kahiluoto H et al (2025) Functional groups of leaf phenology are key to build climate-resilience in cocoa agroforestry systems. Agric Ecosyst Environ 379: 109363. https://doi.org/10.1016/j.agee.2024.109363

Adesanya A, Yang B, Bin Iqdara FW and Yang Y (2020) Improving sustainability performance through supplier relationship management in the tobacco industry. Supply Chain Management: An International Journal 25: 413–426. https://doi.org/10.1108/SCM-01-2018-0034

Agyei V, Adom-Asamoah G and Poku-Boansi M (2024) Sustainable transportation in Africa: A bibliometric, visualisation and thematic analysis. Journal of Cleaner Production 462: 142727. https://doi.org/10.1016/j.jclepro.2024.142727

Amoako DK, Zakuan MN, Okyere-Kwakye E and Tetteh FK (2023) Effect of Training and Reward on Social Sustainability in Ghana's Cocoa Supply Chain: The Role of Green Buyer-Supplier Relationship. Journal of International Food & Agribusiness Marketing 35: 212–243. https://doi.org/10.1080/08974438.2021.1981511

Andoh-Mensah E, Anthonio CK, Sossah FL et al (2023) Integrated soil fertility management using cocoa bean shells improves soil chemical properties, coconut yield and mitigates environmental pollution. Journal of Cleaner Production 428: 139418. https://doi.org/10.1016/j.jclepro.2023.139418

Ariza-Salamanca AJ, Navarro-Cerrillo RM, Crozier J et al (2024) Drivers of cocoa yield and growth in young monoculture and agroforestry systems. Agric Syst 219: 104044. https://doi.org/10.1016/j.agsy.2024.104044

Armengot L, Beltrán MJ, Schneider M et al (2021) Food-energy-water nexus of different cacao production systems from a LCA approach. Journal of Cleaner Production 304: 126941. https://doi.org/10.1016/j.jclepro.2021.126941

Aziz F, Li C, Khan AU and Khan A (2024) Emerging trends and insights in sustainable innovation performance: A two decade literature review (2002–2022). Journal of Cleaner Production 467: 142805.

https://doi.org/10.1016/j.jclepro.2024.142805

Bagdi T, Ghosh S, Sarkar A et al (2023) Evaluation of research progress and trends on gender and renewable energy: A bibliometric analysis. Journal of Cleaner Production 423: 138654. https://doi.org/10.1016/j.jclepro.2023.138654

Bai C, Quayson M and Sarkis J (2022) Analysis of Blockchain's enablers for improving sustainable supply chain transparency in Africa cocoa industry. Journal of Cleaner Production 358: 131896. https://doi.org/10.1016/j.jclepro.2022.131896

Bandanaa J, Asante IK, Annang TY et al (2025) Social and environmental trade-offs and synergies in cocoa production: Does the farming system matter? Sustainability 17: 1674. https://doi.org/10.3390/su17041674

Barrios-Rodríguez YF, Salas-Calderón KT, Orozco-Blanco DA et al (2022) Cocoa pod husk: a high-pectin source with applications in the food and biomedical fields. ChemBioEng Reviews 9: 462–474. https://doi.org/10.1002/cben.202100061

Brundtland GH and Khalid M (1987) Our common future. Oxford University Press, Oxford, GB.

Caicedo-Vargas C, Pérez-Neira D, Abad-González J and Gallar D (2023) Agroecology as a means to improve energy metabolism and economic management in smallholder cocoa farmers in the Ecuadorian Amazon. Sustainable Production and Consumption 41: 201–212. https://doi.org/10.1016/j.spc.2023.08.005

Chen W and Haoa H (2025) Environmental regulation and Outward FDI of Chinese listed companies: The role of technological innovations. Economic Analysis and Policy. https://doi.org/10.1016/j.eap.2025.07.023

Dachs I, Rülke J and Franz M (2025) Bringing a circular economy perspective into global production networks: Cocoa pod husk-based compost production in Ghana. Journal of Cleaner Production 519: 145955. https://doi.org/10.1016/j.jclepro.2025.145955

Det Udomsap A and Hallinger P (2020) A bibliometric review of research on sustainable construction, 1994–2018. Journal of Cleaner Production 254: 120073. https://doi.org/10.1016/j.jclepro.2020.120073

Dominguez Aldama D, Grassauer F, Zhu Y et al (2023) Allocation methods in life cycle assessments (LCAs) of agri-food co-products and food waste valorization systems: Systematic review and recommendations. Journal of Cleaner Production 421: 138488. https://doi.org/10.1016/j.jclepro.2023.138488

Dröge S, Makmun Jusrin MJ, Verbist B et al (2025) No effect of rainforest alliance cocoa certification on shade cover and bird species richness in Sulawesi, Indonesia. Journal for Nature Conservation 84: 126849. https://doi.org/10.1016/j.jnc.2025.126849

Elkington J and Rowlands IH (1999) Cannibals with forks: The triple bottom line of 21st century business. Alternatives Journal 25: 42.

FairTrade (2025) Cocoa. https://www.fairtrade.net/en/products/Fairtrade_products/cocoa.html

Fayaz G, Mhamadi M, Rodrigue D et al (2024) Mapping approach for selecting promising agro-waste dietary fibers as sustainable and functional food ingredients. Food and Bioprocess Technology 17: 1797–1813. https://doi.org/10.1007/s11947-023-03223-w

Fernández-Ríos A, Laso J, Hoehn D et al (2022) A critical review of superfoods from a holistic nutritional and environmental approach. Journal of Cleaner Production 379: 134491. https://doi.org/10.1016/j.jclepro.2022.134491

García-Herrero L, Menna F De and Vittuari M (2019) Sustainability concerns and practices in the chocolate life cycle: Integrating consumers' perceptions and experts' knowledge. Sustainable Production and Consumption 20: 117–127. https://doi.org/10.1016/j.spc.2019.06.003

Girón-Hernández J, Rodríguez YB, Corbezzolo N et al (2024) Exploiting residual cocoa biomass to extract advanced materials as building blocks for manufacturing nanoparticles aimed at alleviating formation-induced oxidative stress on human dermal fibroblasts. Nanoscale Advances 6: 3809–3824. https://doi.org/10.1039/D4NA00248B

Hoof B Van, Solano A, Riaño J et al (2024) Decision-making for circular economy implementation in agri-food systems: A transdisciplinary case study of cacao in Colombia. Journal of Cleaner Production 434: 140307. https://doi.org/10.1016/j.jclepro.2023.140307

ICCO (2025a) Data on production and grindings of cocoa beans. https://www.icco.org/statistics/

ICCO (2025b) Sustainability of the world cocoa economy. https://www.icco.org/economy/#sustainability

Keller J, Jung M and Lasch R (2022) Sustainability Governance: Insights from a cocoa supply chain. Sustainability 14: 10763. https://doi.org/10.3390/su141710763

Knößlsdorfer I, Sellare J and Qaim M (2021) Effects of Fairtrade on farm household food security and living standards: Insights from Côte d'Ivoire. Global Food Security 29: 100535. https://doi.org/10.1016/j.gfs.2021.100535

Krause H-M, Saj S, Rüegg J et al (2025) Successional agroforestry promotes biomass carbon storage in cocoa production systems: results from a long-term system comparison experiment on organic and conventional systems. Agriculture, Ecosystems & Environment 393: 109820. https://doi.org/10.1016/j.agee.2025.109820

Lafargue P, Rogerson M, Parry GC and Allainguillaume J (2022) Broken chocolate: Biomarkers as a method for delivering cocoa supply chain visibility. Supply Chain Management: An International Journal 27: 728–741. https://doi.org/10.1108/SCM-11-2020-0583

Landázuri AC, Prócel LM, Caisaluisa O et al (2023) Valorization of ripe banana peels and cocoa pod husk hydrochars as green sustainable "low loss" dielectric materials. Journal of Cleaner Production 426: 139044. https://doi.org/10.1016/j.jclepro.2023.139044

LeBaron T, Singh R, Fatima G et al (2020) The effects of 24-week, high-concentration hydrogen-rich water on body composition, blood lipid profiles and inflammation biomarkers in men and women with metabolic syndrome: A randomized controlled trial. Diabetes, Metabolic Syndrome and Obesity Volume 13: 889–896. https://doi.org/10.2147/DMSO.S240122

Little ME and Blau E (2020) Social adaptation and climate mitigation through agrotourism: A case study of tourism in Mastatal, Costa Rica. Journal of Ecotourism 19: 97–112. https://doi.org/10.1080/14724049.2019.1652305

López del Amo B and Akizu-Gardoki O (2024) Derived environmental impacts of organic fairtrade cocoa (Peru) compared to its conventional equivalent (Ivory Coast) through life-cycle assessment in the basque country. Sustainability 16: 493. https://doi.org/10.3390/su16020493

Madeira C, Rodrigues P and Gomez-Suarez M (2023) A bibliometric and content analysis of sustainability and smart tourism. Urban Science 7: 33. https://doi.org/10.3390/urbansci7020033

Mariatti F, Gunjević V, Boffa L and Cravotto G (2021) Process intensification technologies for the recovery of valuable compounds from cocoa by-products. Innovative Food Science & Emerging Technologies 68: 102601. https://doi.org/10.1016/j.ifset.2021.102601

Miglietta PP, Fischer C and De Leo F (2022) Virtual water flows and economic water productivity of Italian fair-trade: The case of bananas, cocoa and coffee. British Food Journal 124: 4009–4023. https://doi.org/10.1108/BFJ-03-2020-0265

Moluh Njoya H, Cristóbal Reyes S, Hien KA et al (2025) Can cooperative membership foster compliance with New European Union regulations on deforestation-free production? Evidence from cocoa farmers in Western Côte d'Ivoire. Trees, Forests and People 20: 100897. https://doi.org/10.1016/j.tfp.2025.100897

Mwafulirwa L, Sizmur T, Daymond A et al (2024) Cocoa pod husk-derived organic soil amendments differentially affect soil fertility, nutrient leaching, and greenhouse gas emissions in cocoa soils. Journal of Cleaner Production 479: 144065. https://doi.org/10.1016/j.jclepro.2024.144065

Nevinson HW (1906) A modern slavery. Harper & Brothers, United Kingdom.

Nica I, Georgescu I and Chiriță N (2024) Simulation and Modelling as Catalysts for Renewable Energy: A bibliometric analysis of global research trends. Energies (Basel) 17: 3090.

Ntiamoah A and Afrane G (2008) Environmental impacts of cocoa production and processing in Ghana: Life cycle assessment approach. Journal of Cleaner Production 16: 1735–1740. https://doi.org/10.1016/j.jclepro.2007.11.004

Olarte Libreros MM and Muñoz Maya CM (2025) Sustainable practices in the cocoa value chain: A systematic literature review. Tendencias 26: 191–215. https://doi.org/10.22267/rtend.252601.270

Peña-Correa RF, Ataç Mogol B, van Boekel MAJS and Fogliano V (2022) Fluidized bed roasting of cocoa nibs speeds up processing and favors the formation of pyrazines. Innovative Food Science & Emerging Technologies 79: 103062. https://doi.org/10.1016/j.ifset.2022.103062

Perez M, Lopez-Yerena A and Vallverdú-Queralt A (2022) Traceability, authenticity and sustainability of cocoa and chocolate products: a challenge for the chocolate industry. Critical Reviews in Food Science and Nutrition 62: 475–489. https://doi.org/10.1080/10408398.2020.1819769

Perkiss S, Dumay J, Bernardi C et al (2025) Accountability to tackle sustainability challenges in the cocoa supply chain. Accounting, Auditing & Accountability Journal. https://doi.org/10.1108/AAAJ-05-2024-7069

Pesta B, Fuerst J and Kirkegaard E (2018) Bibliometric Keyword Analysis across Seventeen Years (2000–2016) of Intelligence Articles. Journal of Intelligence 6: 46. https://doi.org/10.3390/jintelligence6040046

Pons P and Latapy M (2005) Computing communities in large networks using random walks. pp 284–293. https://doi.org/10.1007/11569596_31

Purna Prakash K, Venkata Pavan Kumar Y, Himajyothi K and Pradeep Reddy G (2024) Comprehensive bibliometric analysis on smart grids: Key concepts and research trends. Electricity 5: 75–92. https://doi.org/10.3390/electricity5010005

Puyana-Romero V, Iannace G, Cajas-Camacho LG et al (2022) Acoustic characterization and modeling of silicone-bonded cocoa crop waste using a model based on the gaussian support vector machine. Fibers 10: 25. https://doi.org/10.3390/fib10030025

Quach S, Roberts RE, Dang S et al (2025) The interaction between values and self-identity on fairtrade consumption: The value-identity-behavior model. Appetite 206: 107826. https://doi.org/10.1016/j.appet.2024.107826

Quayson M, Bai C and Sarkis J (2021) Technology for social good foundations: A perspective from the smallholder farmer in sustainable supply chains. IEEE Transactions on Engineering Management 68: 894–898. https://www.semanticscholar.org/paper/Technology-for-Social-Good-Foundations%3A-A-From-the-Quayson-Bai/f71de9e08fc48d8bdebf569c1cdf0072c230d7ad

Quayson M, Bai C, Sarkis J and Hossin MA (2024) Evaluating barriers to blockchain technology for sustainable agricultural supply chain: A fuzzy hierarchical group DEMATEL approach. Operations Management Research 17: 728–753. https://doi.org/10.1007/s12063-024-00443-x

Rathgens J, Gröschner S and von Wehrden H (2020) Going beyond certificates: A systematic review of alternative trade arrangements in the global food sector. Journal of Cleaner Production 276: 123208. https://doi.org/10.1016/j.jclepro.2020.123208

Ribeiro-Duthie AC, Gale F and Murphy-Gregory H (2021) Fair trade and staple foods: A systematic review. Journal of Cleaner Production 279: 123586. https://doi.org/10.1016/j.jclepro.2020.123586

Salihu C, Hussein M, Mohandes SR and Zayed T (2022) Towards a comprehensive review of the deterioration factors and modeling for sewer pipelines: A hybrid of bibliometric, scientometric, and meta-analysis approach. Journal of Cleaner Production 351: 131460. https://doi.org/10.1016/j.jclepro.2022.131460

Serter M and Gumusburun Ayalp G (2024) A Holistic analysis on risks of post-disaster reconstruction using RStudio Bibliometrix. Sustainability 16: 9463. https://doi.org/10.3390/su16219463

Siao H-J, Gau S-H, Kuo J-H et al (2022) Bibliometric analysis of environmental, social, and governance management research from 2002 to 2021. Sustainability 14: 16121. https://doi.org/10.3390/su142316121

Siddiqui SA, Karim I, Shahiya C et al (2024) A critical review of consumer responsibility in promoting sustainable cocoa production. Current Research in Food Science 9: 100818. https://doi.org/10.1016/j.crfs.2024.100818

Silva AR de A, Bioto AS, Efraim P and Queiroz G de C (2017) Impact of sustainability labeling in the perception of sensory quality and purchase intention of chocolate consumers. Journal of Cleaner Production 141: 11–21. https://doi.org/10.1016/j.jclepro.2016.09.024

Steinke J, Ivanova Y, Jones SK et al (2024) Digital sustainability tracing in smallholder context: Ex-ante insights from the Peruvian cocoa supply chain. World Development Sustainability 5: 100185. https://doi.org/10.1016/j.wds.2024.100185

Sun J, Zhang D, Peng S et al (2023) Insights of the fate of antibiotic resistance genes during organic solid wastes composting based on bibliometric analysis: Development, hotspots, and trend directions. Journal of Cleaner Production 425: 138781. https://doi.org/10.1016/j.jclepro.2023.138781

Suri T and Basu S (2022) Heat resistant chocolate development for subtropical and tropical climates: A review. Critical Reviews in Food Science and Nutrition 62: 5603–5622. https://doi.org/10.1080/10408398.2021.1888690

Tagne RFT, Santagata R, Tchuifon Tchuifon DR et al (2022) Environmental impact of second-generation biofuels production from agricultural residues in Cameroon: A life-cycle assessment study. Journal of Cleaner Production 378: 134630. https://doi.org/10.1016/j.jclepro.2022.134630

Talero-Sarmiento LH, Parra-Sanchez DT and Lamos-Diaz H (2025) A bibliometric analysis of computational and mathematical techniques in the cocoa sustainable food value chain. Heliyon 11: e43015. https://

doi.org/10.1016/j.heliyon.2025.e43015

Tischner U, Stø E, Kjærnes U and Tukker A (2017) System innovation for sustainability 3: Case studies in sustainable consumption and production—food and agriculture. Routledge.

Tsilika K (2023) Exploring the contributions to mathematical economics: A bibliometric analysis using bibliometrix and VOSviewer. Mathematics 11: 4703. https://doi.org/10.3390/math11224703

Turki T and Roy SS (2022) Novel hate speech detection using word cloud visualization and ensemble learning coupled with count vectorizer. Applied Sciences 12: 6611. https://doi.org/10.3390/app12136611

Urugo MM, Worku M, Tola YB and Gemede HF (2025) Ethiopian coffee: Production systems, geographical origin traceability, and European Union deforestation regulation directive compliance. Journal of Agriculture and Food Research 19: 101695. https://doi.org/10.1016/j.jafr.2025.101695

Valverde D, Sánchez-Jimenez V, Barat JM and Pérez-Esteve É (2021) The effect of extrusion on the physical and chemical properties of alkalized cocoa. Innovative Food Science & Emerging Technologies 73: 102768. https://doi.org/10.1016/j.ifset.2021.102768

Wang S and Dong Y (2025) Analyzing the environmental footprint of the chocolate industry using a hybrid life cycle assessment method. Cleaner Engineering and Technology 25: 100912. https://doi.org/10.1016/j.clet.2025.100912