Reducing Cadmium and Lead Contamination in Cacao: A Bibliometric Analysis of 10 Years of Research Using Bibliometrics

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Abstract. *Theobroma cacao* L., a special crop, is used to make famous culinary products like chocolate that are distributed all over the world. However, heavy metals like cadmium (Cd) and lead (Pb) can taint cacao, posing health risks to farmers and consumers. Scientists and researchers are examining ways to lessen the toxicity and uptake of Cd and Pb in cacao and are putting forth prospective strategies to restrict their uptake and accumulation in cocoa. This study aims to examine the literature from the last ten years of scientific research on preventing Cd and Pb absorption into cocoa using bibliometrics from RStudio. We collected 446 articles with 2118 authors from Scopus and Web of Science, published between 2014 and 2023. Food Research International and Science of The Total Environment are the two journals with the most relevant publications about Cd and Pb contamination in cacao. The findings of the bibliometric analysis revealed that not only Cd and Pb but also other heavy metals were present in cocoa. Several studies have explored ways to prevent or reduce metal uptake by cacao, such as biochar and organic matter, lime and micronutrients, and cacao genotypes with low accumulation. Postharvest handling, such as fermentation and winnowing, is also potentially used to reduce Cd and Pb content.

1 Introduction

Cacao is a significant agricultural commodity for culinary products worldwide worldwide [1]. Cacao is the primary ingredient in chocolate production, with high economic and nutritional value. Nevertheless, cacao can also be contaminated with heavy metals which are harmful to health such as cadmium (Cd) and lead (Pb) [2]. Cd and Pb can cause kidney damage, bone demineralization, lung cancer, and other adverse effects [3]. Therefore, it's critical to monitor and reduce the cadmium and lead concentrations in cacao and cacao-related goods.

Cd and Pb are elements known to possess carcinogenic properties [4]. However, their impact on plant growth and development is not shown to be substantial. Cd and Pb originate from natural and manufactured causes, including geological formations, volcanic eruptions,

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air deposition, mining operations, the plastics manufacturing sector, waste disposal, and chemical fertilizers [5]. Cd and Pb have the potential to collect within the soil and afterward be absorbed by the roots of cacao plants. These heavy metals can then be transported to various other parts of the plant, including the seeds of the cacao plant [6].

The presence of Cd and Pb contamination in cacao has garnered the attention of researchers and scientists, who have undertaken studies to remove the toxicity and absorption of Cd and Pb in cacao and provide possible methods to reduce the digestion and aggregation of Cd and Pb in cacao. It is imperative to use a remediation approach to reduce the Cd and Pb contents of the contaminating cocoa beans. Some remediation approaches have been studied, such as using lime or biochar as soil amendments [5][7] or using organic amendments [8]. Liming is the addition of lime to the soil to increase its pH and decrease its acidity. Lime is an inorganic substance composed of calcium, magnesium, or carbonate. Liming has numerous advantages for soil and plants, including reducing Cd contamination by forming insoluble compounds with Cd [9].

Some research and experiments have been executed and scientifically reported. In order to examine the state of the art of Cd and Pb contamination within cacao plants, and cocoa beans, including their derivative products, and to support the development of related policies, a comprehensive analysis of those scientific reports needs to be developed. Bibliometric analysis is a scholarly methodology to assess scientific publications on a specific subject matter. The bibliometric analysis allows for examining patterns, impacts, trends, and research networks within specific knowledge domains [10]. Using bibliometric analysis can assist researchers in identifying areas of knowledge that need to be adequately explored, evaluating their research endeavors' effectiveness, establishing research priorities, and enhancing the visibility and impact of their scholarly work [11].

Bibliometric employs mathematics and engages statistical methods to evaluate all knowledge sources statistically [10]. It is a technique extensively used to assess how a certain topic is progressing [11]. Primarily, bibliometrics offers significant advantages that allow academics to conduct in-depth analyses of a particular field of study by looking at word frequency, geographic distribution, co-citations, and citations and then drawing beneficial conclusions. Until now, bibliometrics has been extensively utilized in mapping the expansion of research topic areas, co-authorship analysis, co-citation analysis, and hotspot research.

The objective of this research is to conduct a bibliometrics analysis of scholarly literature regarding the mitigation of cadmium and lead content in cocoa. This paper will analyze the number, distribution, citations, keywords, affiliations, countries, journals, and authorship of these scientific publications. This paper will also identify the main topics, essential issues, challenges, and opportunities in research on Cd and Pb content in cacao and its mitigation. We used Scopus and Web of Science as our two sources of literature data for this investigation. These two databases, which include a large variety of scientific literature, such as journal articles, conference proceedings, and books, are among the most popular for bibliometric analysis. The constraints of utilizing a single database can be mitigated, and a more comprehensive view of the research landscape can be obtained by combining data from both databases [12].

2 Materials and Methods

According to the multiphase process presented, studying papers has four phases (see Figure 1). First, we explore the Web of Science (WoS) using Boolean operators, which contain: cocoa OR cacao (All Fields) and cadmium OR Pb (All Fields) and explore Scopus using cocoa OR cacao (Title, Abstract, Keywords) and cadmium OR Pb (Title, Abstract, Keywords) with limits for conference papers and publications within the 2014–2023

timeframe. For the search for "lead", we use the keyword "Pb" because lead tends to mean supremacy, as in the word leadership.

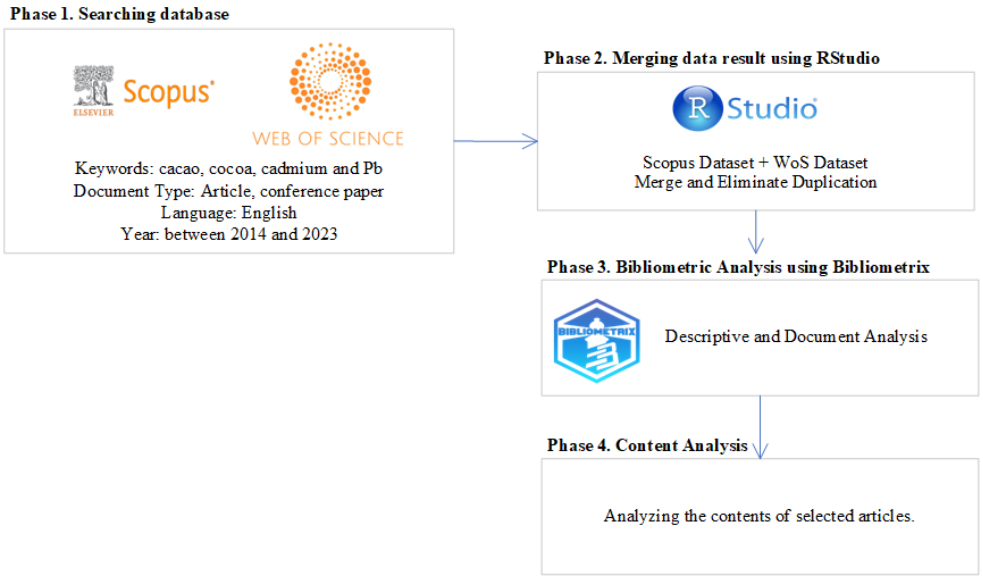

Fig. 1. Multiphase Action in Studying the Papers

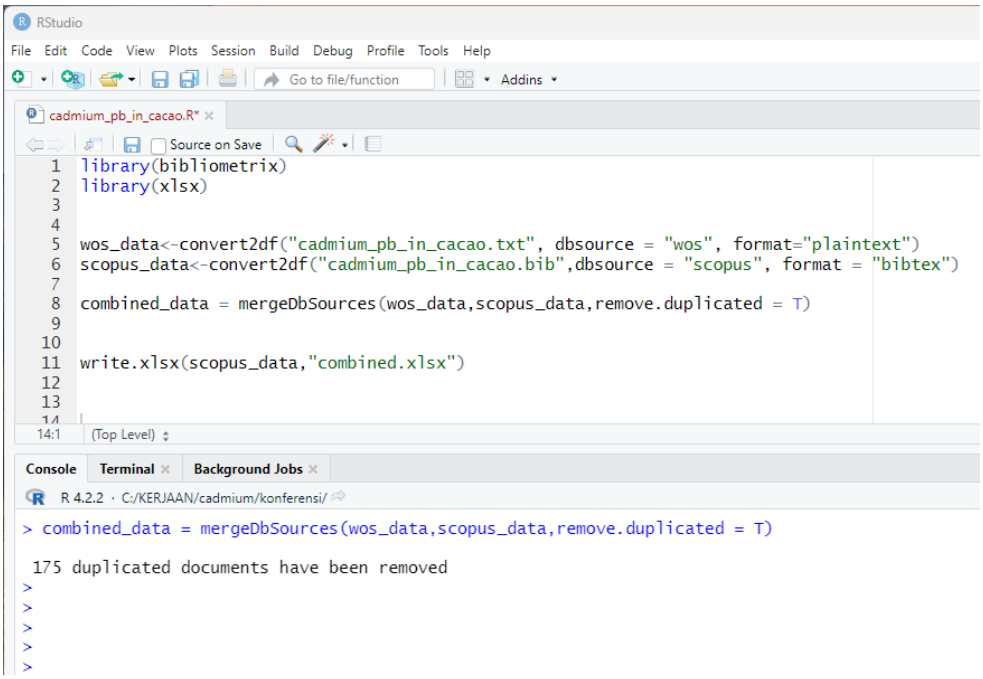

Fig. 2. Merging Scopus and WoS datasets using RStudio

The second phase employs RStudio to merge datasets obtained from WoS and Scopus while removing redundant data. The combined data is converted to Excel format so the

Bibliometrix may read it for further analysis, as seen in Figure 2. RStudio provides convenience and speed in merging datasets from different database sources, which previously required high effort.

Third, after choosing the articles that come up in the search results and combining the dataset, a bibliometrics study is carried out. In this bibliometrics study, the network and keyword density revealed by the articles were mapped using Bibliometrics. In the final phase, we conducted a content analysis of the articles containing the most pertinent subjects from the clustered thematic map to comprehend the topics under investigation better.

3 Results and Discussion

Search results from the literature database yielded 239 papers from Scopus and 384 papers from the Web of Science combined using RStudio to yield 446 papers after eliminating 175 duplicate papers. Subsequent investigations using bibliometrics obtained 1455 author keywords, 2118 authors, 58 correspondent author countries, 12.34 average citations per document, and other statistics listed in Table 1 comprise key information from this search 11 authors have published itself, showing the importance of author collaboration. The annual scientific publication percentage growth rate is only around 7.73%. The results of the current investigation are presented in the following sections.

Table 1. Primary record information.

Description	Scopus	WoS	Combined result
MAIN INFORMATION			
Period	2014:2023		
Journals	152	250	289
Papers	237	384	446
Annual Growth Rate %	8.97	6.68	7.73
Average citations per doc	13.48	13.19	12.34
KEYWORDS AND AUTHORS			
Keywords Plus (ID)	2635	1506	2404
Author's Keywords (DE)	782	1315	1455
Authors	1106	1920	2118
Single-authored docs	7	7	11
International co-authorship %	37.13	39.06	33.63
Corresponding Author's Countries	43	55	58

3.1 Publication and Impact

3.1.1 Annual Growth

The annual scientific publication on cadmium and lead in cacao grew by 7.73%. The growth rate in published research over time could be more noteworthy. Nevertheless, the graph continues to exhibit a rising trend, keeping with the Figure 3 bar chart's upward trend. In comparison, the average annual citation count is displayed on the line graph, showing the

impact of published papers. In 2019, there has been a rapid increase in published works, coinciding with the introduction of the Cd limiting regulations on cocoa set by the European Union and regulations from the Codex Alimentarius. According to EU regulations, the maximum level of Cd in cocoa products is 0.8 mg/kg for dark chocolate and 0.3 mg/kg for milk chocolate [13]. Therefore, it is necessary to alleviate the concentration of Cd and Pb, which contaminate cacao plants, cocoa beans, and their derivatives. The need to reduce cadmium levels, which is also to comply with regulations, has increased the number of publications and prompted a more comprehensive search for themes highlighting the significance of the cadmium problem in cocoa for scientific study.

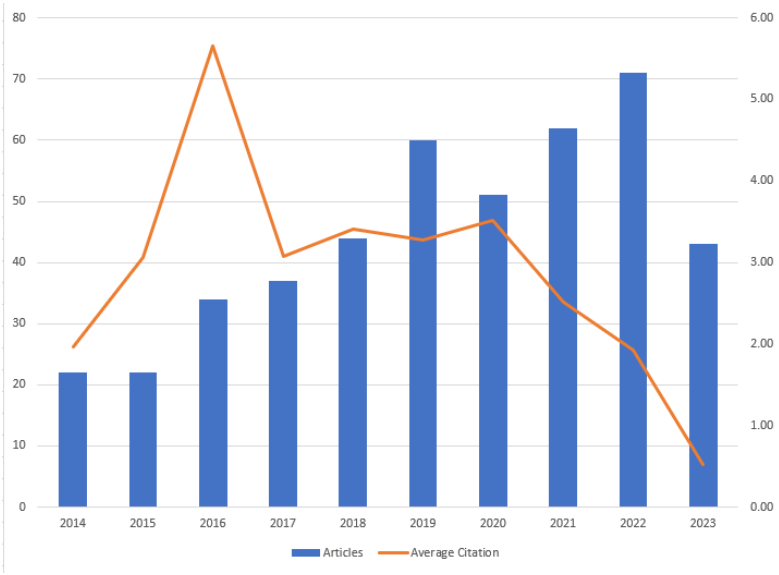

Fig. 3. Annual scientific publication and average citation per year

3.1.2 Most Relevant Journals

Publishing scientific articles in journals of international reputation is crucial because it increases the credibility and recognition of research results. Reputable journals have a rigorous peer-review procedure, which ensures that published articles meet rigid scientific criteria. In addition, reputable journals have a broad readership, allowing the research results to be read and cited by numerous individuals. It can increase the scientific relevance and influence of the research findings. Source analysis consists of identifying the most relevant journals and their impacts as measured by the h-index. The results reveal the top 10 relevant journals that have published cadmium and lead in cacao.

Science of the Total Environment and Food Chemistry are the most prominent sources publicizing 15 and 11 articles with h-indexs 10 and 8, successively. Food Research International (12) and Journal of Food Composition and Analysis (7) are next, along with the other sources indicated in Table 2.

Table 2. The most relevant sources.

Sources	Articles	Cited	Average per Art	h-index
Science of the Total Environment	15	542	36.13	10
Food Research International	12	153	12.75	8
Food Chemistry	11	300	27.27	8
Journal of Food Composition and Analysis	7	154	22.00	6
Plos One	7	105	15.00	5
Agronomy Basel	6	61	10.17	4
LWT-Food Science and Technology	6	117	19.50	4
Chemosphere	4	167	41.75	4
Microchemical Journal	4	117	29.25	4
Environmental Monitoring and Assessment	4	45	11.25	4

Publications in the listed journals continue to experience significant growth, as shown in Figure 6, confirming that Cd and Pb in cocoa still require further research. Science of the Total Environment (STE), Food Research International, and Food Chemistry (FC) are the journals with the highest growth rate. It can be an important reference in conducting heavy metal studies on cacao plants or their processed products. Until 2023, both of them have published 15, 12, and 11 papers, respectively, on the topics of cadmium and lead in cacao. The last article on STE, entitled "Revealing the Pathways of Cadmium …" discusses the new findings about Cd uptake and translocation pathways in cocoa plants, which can help develop mitigation strategies to reduce Cd content in cocoa beans [14]. Meanwhile, the last article from FC, entitled "Incubating Tests Mimicking Fermentation …" explained that the fermentation experiment reduced the concentration of Cd in cocoa beans [15]. Both provide additional important references regarding ways to reduce Cd contamination in cocoa.

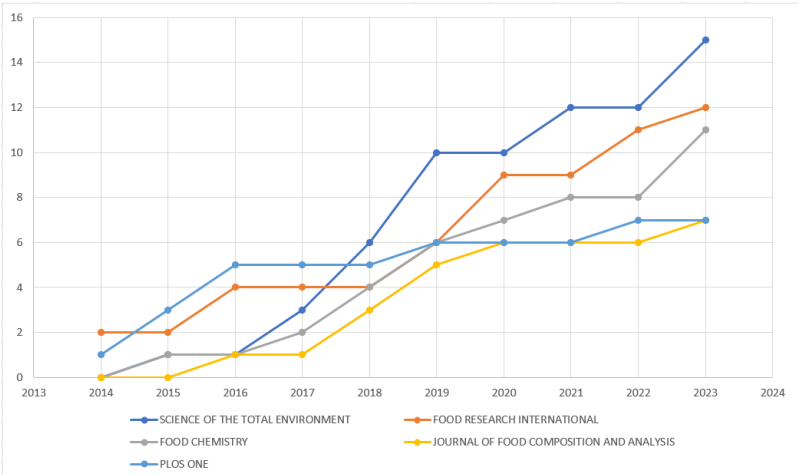

Fig. 4. Source growth

3.1.3 Impactful Papers

Impact papers are papers that have great influence or significance in the field being studied, which is the study of cadmium and lead in cacao. Impactful papers can be measured by various indicators, such as citations, the impact factor, or the h-index. These indicators reflect how often a paper becomes a reference or gets the attention of other researchers. Local cited (LC) documents are those that are specific to the documents offered in the analysis software, whereas global cited (GC) documents are those that are related to the main theme of the search. The top 10 cited documents are listed in Table 3. The papers "Chavez E, 2015, Sci Total Environ", "Arguello D, 2019, Sci Total Environ", and " Bertoldi D, 2016, Food Control", which discuss Cd content and trace element in cacao are papers with the highest citations, both LC and GC as well. Nevertheless, the papers with the highest LC/GC ratio are "Lewis C, 2018, Sci Total Environ", "Engbersen N, 2019, Sci Total Environ", and "Zug Klm, 2019, Water Air Soil Poll" each of which has LC/GC 71.43, 70.97 and 66.67. Of the 10 articles selected, generally have topics on cadmium or heavy metal content in soils and cacao and provide knowledge about genetic variation in Cd uptake and distribution in cocoa plants that can help develop mitigation strategies to reduce Cd content in cocoa beans.

Table 3. The most cited documents

Paper	LC	GC	LC/GC (%)	Research finding
Chavez E, 2015, Sci Total Environ	60	105	57.14	Cd concentration decreases with soil depth. The content of Cd in cacao exhibited a decrease in the following order of beans > shell > leaves. The concentration of Cd in cocoa has a high correlation with Cd in the soil [16].
Arguello D, 2019, Sci Total Environ	43	79	54.43	The spatial distribution of Cd within cocoa beans is subject to the influence of several soil and agronomic conditions [17].
Bertoldi D, 2016, Food Control	40	94	42.55	The content of certain elements in cocoa beans can distinguish between cocoa producing countries with high accuracy [18].
Yanus Rl, 2014, Talanta	39	62	62.90	The average heavy metal content in the soil of cocoa plantations in Peru is 0.44 mg kg-1. Other findings, the average cadmium within cocoa beans is 0.90 mg kg-1, exceeding the 0.60 mg kg-1 threshold set by the EU [19].
Arevalo-gardini E, 2017, Sci Total Environ	39	78	50.00	The process of making chocolate can affect the trace element content in it. In general, the trace element content increases with increasing cocoa solid content in the chocolate [20].
Barraza F, 2017, Environ Pollut	29	49	59.18	The mean cumulative concentration of cadmium in the soil is 0.51 mg kg-1, higher than the natural background value (0.35 mg kg-1) in the soil and cocoa plants in the areas affected by the activities oil in Ecuador [21]
Gramlich a, 2017, Sci Total Environ	29	46	63.04	Cacao plants grown in agroforestry had lower Cd content in their leaves than in monoculture. Cacao plants fed with organic fertilizers had lower Cd content in their

Paper	LC	GC	LC/GC (%)	Research finding
				leaves than those fed with inorganic fertilizers [22].
Villa Jel, 2014, J Agr Food Chem	28	50	56.00	The average Cd content in chocolate is 107.6 ng/g, and the average Pb content is 138.4 ng/g. The concentrations of Cd and Pb positively correlated with the proportion of solid cocoa in the chocolate. Cd and Pb content also varies between brands and countries of origin of chocolate [23].
Gramlich a, 2018, Sci Total Environ	28	49	57.14	Soil factors that influence the uptake of Cd by cocoa plants are pH, organic carbon (OC), nickel (Ni), manganese (Mn), copper (Cu), zinc (Zn), iron (Fe), cobalt (Co), and molybdenum (Mo). Agronomic factors that affect the uptake of Cd by cocoa plants are plantation age, genotype (CCN-51 vs. Trinitario), pruning, organic fertilizers, inorganic fertilizers, and lime [24].
Lewis C, 2018, Sci Total Environ	25	35	71.43	The application of organic fertilizers can reduce the Cd content in cocoa beans by 21% compared to inorganic fertilizers. Genetic variation affects the uptake and distribution of Cd in cocoa plants [25].

3.2 Topics and Thematic Analysis

Identifying and comprehending topics and themes, trends and advancements, and the current state of study on Cd and Pb in cacao plants provide valuable insights and directives that may be utilized to address the predicament of Cd and Pb contamination in cacao plants. In addition, these insights also extend their influence to inform the postharvest processing stages of cocoa, ultimately creating a comprehensive approach that addresses the challenges of Cd and Pb contamination throughout the cocoa cultivation and processing cycle.

3.2.1 Topics Trend

In a literature search on Cd and Pb contained in cocoa, the emerging topics experienced a trend from year to year. Between 2014 – 2023, some topics emerged and then faded, or topics that continued to grow, as shown in Figure 5. Pb is a topic that has been developing between 2017 – 2020. Meanwhile, cadmium, cacao, heavy metals, and soils are still being researched and discussed until 2023. The figure also shows that fermentation is an effort to reduce cadmium content, and the adsorption of cadmium is still a trend and getting interest today.

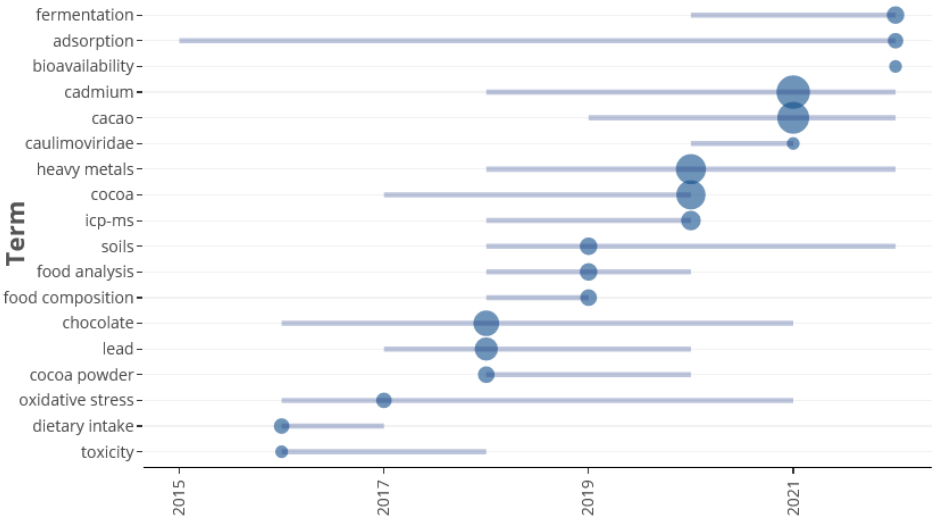

Fig. 5. Trend Topics over Years

3.2.2 Thematic Evolution

The development of the topic can also be seen in the theme evolution shown in Figure 6. Developing these themes shows the growth of research clusters between 2014 – 2023 by limiting the visualization to 100 keywords. Cadmium clusters, where Pb is included in this cluster, began to appear between 2014-2018. This theme continues into 2019-2021. The cadmium theme in 2019-2021 is an accumulation of cadmium, growth, metabolism, metals, and chocolate themes that appeared in the previous period. The cadmium theme remains a cluster until 2022-2023, continuing cadmium, cocoa, and chocolate themes developing in 2019-2021.

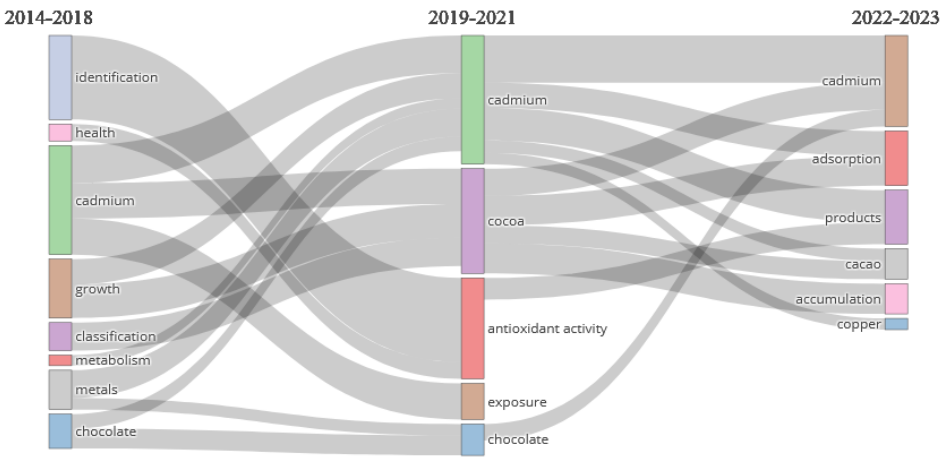

Fig. 6. Theme Evolution

3.2.3 Thematic Map

The findings of the theme mapping study demonstrated that the co-occurrence network clusters were visually depicted as circular shapes within a graph, with their placement determined by their centrality and density rankings. The magnitude of the bubble is ascertained by the frequency of word occurrences within the cluster. The graph's X-axis indicates the centrality measure for network clusters, which denotes the extent of connectivity and interaction with other clusters within the graph. This statement pertains to quantifying the significance attributed to a specific research topic. In this context, the vertical axis represents the density measure, a quantitative indicator of a cluster network's internal cohesiveness and extension. Using 125 words from Keywords Plus, the thematic analysis conducted by Bibliometrix categorized 446 research publications into five distinct thematic clusters. These clusters are then organized into four quadrants on the topic map, as illustrated in Figure 7.

Quadrant I, the motor theme in the upper right, is the most cited and influential theme in the research field. It represents the core topics and keywords with a high impact and centrality in the literature. This quadrant encompasses two clusters, such as cadmium and risk assessment.

In the top left, Quadrant II encompasses a distinct cluster biosorption topic. This quadrant pertains to topics characterized by high density and low centrality, signifying their significance but limited relevance.

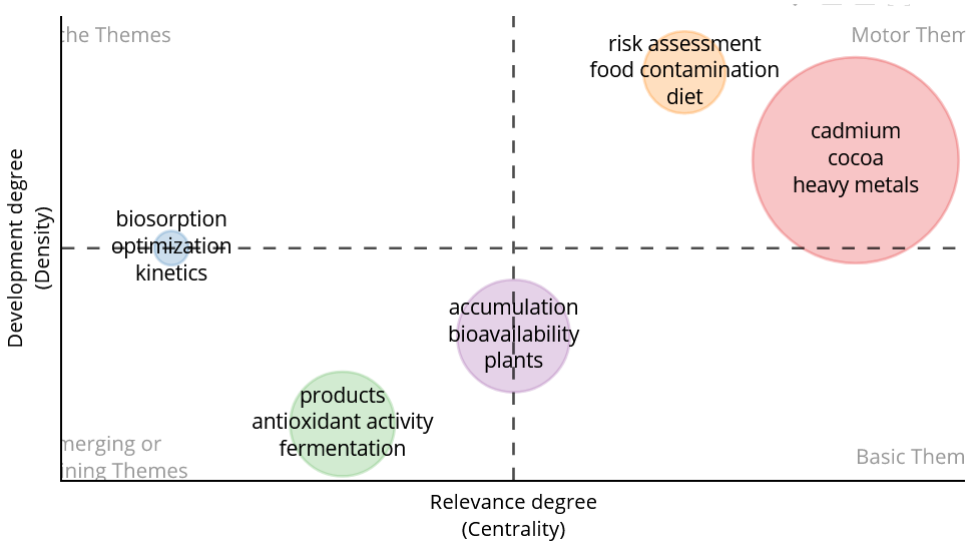

Fig. 7. Thematic map for cadmium and lead in cacao

Quadrant III encompasses developing or vanishing themes, characterized by clusters of product and accumulation. These topics have low centrality and low density, indicating that they are in a nascent stage of development and are widely dispersed.

In Quadrant IV, the primary theme in the bottom right quadrant exhibits a characteristic of high centrality and low density. Accumulation is the cluster in this theme, hold significant relevance within the context being studied, although there is a limited amount of discourse or discussion surrounding them.

3.2.4 Cadmium and lead contents

Cluster cadmium, pink circles, is a cluster that contains 155 papers and has keywords such as cadmium, cocoa, heavy metals, accumulation, soils, trace elements, bioavailability, adsorption, plants, bioaccumulation, growth, products, soil pollutant, extraction, metabolism, elements, contamination, fermentation, biosorption, chromium, mechanism, pH, photosynthesis, pollution, translocation, acid, digestion, flavor, iron, optimization, leaves, manganese, organic-matter, polyphenols, speciation, stress, temperature, and biochar.

The focus of this cluster pertains to the examination of the presence of cadmium, lead, and other heavy metals in chocolate and cocoa beans. This presence is subject to impact from a multitude of factors, including the cadmium concentration found in the soil, the agricultural systems and management practices employed, the chocolate manufacturing process, and the genetic variability of the cacao plant. Cd content in soil varies between regions and countries and can be affected by natural or anthropogenic activities. The Cd content in the soil usually decreases with increasing soil depth [16]. The Cd content that specific chemical methods can extract can reflect the availability of Cd for cacao plants.

The concentration of Cd in cocoa beans varies between samples and may exceed thresholds set by certain authorities [19]. The Cd content in cocoa positively correlates with the Cd content that can be extracted from the soil [17]. The Cd content in cocoa is also influenced by soil factors such as pH, organic carbon, manganese, iron, zinc, copper, nickel, cobalt, and molybdenum. Agronomic factors that affect the Cd content in cocoa beans are the age of the garden, genotype, pruning, organic fertilizers, inorganic fertilizers, and lime [24].

Applying organic fertilizers can reduce Cd contamination in cocoa beans compared to inorganic fertilizers [25]. The agroforestry system can reduce the Cd content in cacao leaves and beans compared to the monoculture system [22]. Genetic variation can affect the uptake and distribution of Cd in cacao plants. Several accessions or cacao varieties have lower or higher Cd content than others [25].

The content of some aspects of cocoa beans can distinguish between cocoa-producing countries with high accuracy [18]. This distinction can be used as an authentication method for cocoa and chocolate products.

3.3 Mitigation Strategies

A comprehensive examination was carried out on the articles in the cocoa cluster to gain insight into methods to reduce the Cd content in cocoa beans. Out of 155 articles from the cadmium cluster, 37 articles can be identified as articles that focus explicitly on efforts to alleviate the Cd content within cacao, cocoa, or chocolate. These articles can be categorized based on the mitigation strategies, i.e., land management, soil amendment, crop-based strategies, or postharvest processing.

3.3.1 Land management

Adequate land management can help reduce the effects of Cd-contaminated cacao land. The first stage before planting cacao is planning, which includes taking into account various anthropogenic and natural elements to assess the level of Cd in the soil used to grow cocoa and contribute to efficient and sustainable cocoa production [26].

3.3.2 Soil amendment strategy

Soil amendment is a mitigation strategy based on adding certain materials to the soil to reduce Cd uptake by cocoa plants. These materials can be organic, inorganic materials, or microorganisms. Amendments to the soil impact the factors that determine how much Cd cocoa trees absorb. In general, soil pH acidity, high organic matter, fine soil texture, and low nutrient elements increase Cd uptake by cocoa trees [22].

Liming and Inorganic Materials
The Ramtahal study examined the potential of soil amendments, especially the application of lime and biochar to reduce cadmium accumulation in cocoa plants [27, 28]. In a separate study conducted by Hussein, it was found that adding lime and micronutrients (Se and Si) may increase soil pH, be adsorbed by negative charges, and assist in alleviating Cd toxicities [6]. Argüello et al.'s findings show that applying liming in the subsurface demonstrates better efficacy in reducing Cd levels [5, 29]. Mayana et al., researching inorganic materials, discovered that zinc can reduce cadmium toxicity in juvenile cocoa plants [30]. Apraez Muoz et al. conducted research on Pb content by adding manganese to the soil and discovered that manganese decreased Pb absorption by the root system and prevented the accumulation of Pb at toxic levels in plant roots and foliage [31].

Organic Materials
As research conducted by Davila-Zamora et al., the use of two organic materials, compost, and poultry manure, showed a decrease in soil Cd and Pb levels of more than 75% and 98%, respectively [8]. While Chavez et al., in their experiment, found the effectiveness of vermicompost and zeolite in alleviating the availability of Cd in the three types of soil [32]. In a different study, Julian E. Lopez attempts to lessen the accumulation of cadmium in cocoa plants by using biochar [33]. In the meantime, Ruth revealed the possibility of using cadmium-tolerant bacteria (CdTB) to reduce cadmium contamination in cocoa plants in Antioquia, Colombia [34]. Similarly, Arce-Inga discussed bioremediation using cadmium-removing bacteria as a sustainable alternative to overcome cadmium toxicity in cocoa plants in Amazonas [35]. Meanwhile, Diez-Marulanda and Brandão isolated urease-producing bacteria Serratia and Acinetobacter, from cocoa farming soil in Santander, Colombia, for cadmium remediation and showed notable outcomes [36].

Fungi
In research on the use of fungi to remediate soil contaminated with Cd, Vallejos-Torres et al. discovered that inoculating arbuscular mycorrhizal function (AMF) and organic amendment could reduce Cd in cacao plant stems [37]. In a separate study, Guerra et al. discovered *Talaromyces santanderensis*, a new fungus with tolerance to Cd concentrations exceeding the allowable limit for contaminated soils, its use showing promise in a bioremediation strategy for removing Cd from highly contaminated agricultural soils [38].

3.3.3 Plant-based strategy

Plant-based strategy is a mitigation strategy based on selecting cocoa cultivars with a low resistance to Cd or low translocation to cocoa beans. Arevalo-Hernandez proposed cacao genotypes with low accumulation resistance to Cd planted in the soil to reduce Cd uptake [39]. These cultivars can be obtained through genetic selection or genetic engineering. This cultivar can mitigate the absorption or accumulation of Cd in cocoa beans by regulating the transport of Cd ions through roots, stems, leaves, and fruit. This cultivar can also increase

tolerance to oxidative stress caused by Cd by increasing the production of antioxidants or detoxification enzymes.

3.3.4 Post-harvest strategy

Post-harvest processing is a mitigation strategy based on treating cocoa beans after they are harvested to reduce the Cd content in the final product. This treatment can be in the form of fermentation or winnowing [7]. *Fermentation* is a biochemical process that involves microbial activity to change the chemical components of cocoa beans. Fermentation can reduce Cd levels in cocoa beans by increasing microbial activity, which can bind and remove Cd from the seeds, or lowering the beans' pH, making it more difficult for Cd to dissolve. According to Vanderschuere et al., too much acidity reduces the flavor characteristics of cacao, so a balance between flavor development and Cd elimination must be struck at a nib pH [40]. Winnowing is the process of separating the seed coat from the core. Winnowing affects the reduction of Cd, Pb, and Ni concentrations in the seed core by removing the seed coat, which has a higher heavy metal content than the core [41].

The four mitigation strategies must be combined to achieve a final product that complies with new EU regulations and the Codex Alimentarius. These mitigation practices must be adapted to the specific conditions of each cocoa production area, such as soil amendment, cultivar variety, or postharvest handling and processing methods [7]. These mitigation practices should also consider their impact on cocoa beans and chocolate's quality and taste characteristics.

4 Conclusions

We investigate the current research, development, and gaps and guide future research on cadmium or lead in cocoa. Our findings in this paper contribute to improving knowledge of cadmium and lead in cocoa research development through bibliometric analysis of papers published in scientific journals. By conducting the bibliometric analysis, we proposed and explored various strategies to reduce cadmium and lead content in cocoa by carefully analyzing selected papers. Several methods have been identified that utilize natural materials such as biochar and organic matter in the soil to mitigate the absorption of heavy metals by cocoa plants. This study further emphasizes the importance of choosing cocoa cultivars with a lower capacity to collect heavy metals. In addition, researchers highlight the critical role of cocoa harvesting and processing in reducing heavy metal content. Processing processes such as fermentation and drying cocoa beans reduce heavy metal levels. For future research, mitigation strategies to reduce Cd and Pb uptake by cocoa plants, such as using soil conditioners, cultivar varieties, or processing methods, must be adapted to the specific conditions of each cocoa production area to produce better quality and taste and safer cocoa products.

HME obtained the literature datasets from the Scopus and Web of Science databases. Subsequently, a bibliometric analysis was conducted, and a manuscript draft was written. BOB, NS, and PA authored the manuscript. The manuscript was evaluated by AA and SJM, who provided suggestions. The manuscript underwent revision with the collaborative input of MJD, AL, and YPR. The final manuscript was read and approved by all of the authors.

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