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RESEARCH TRENDS ON INFRARED SPECTROSCOPY FOR COCOA QUALITY: A BIBLIOMETRIC STUDY USING VOSVIEWER

Riana Listanti [1,2*], Rudiati Evi Masithoh [1], Arifin Dwi Saputro[1], Hanim Zuhrotul Amanah[1], and Andra Tersiana Wati [1]

[1] Department of Agricultural and Biosystems Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia.
[2] Department of Agricultural Engineering, Jenderal Soedirman University, Purwokerto, Indonesia

* Email: rianalistanti1983@mail.ugm.ac.id

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ABSTRACT

Infrared spectroscopy is a non-invasive analytical method that is particularly effective for evaluating the chemical makeup and physical quality of cocoa beans. It offers rapid results, minimal sample preparation, low operational costs, and is environmentally sustainable. However, only a limited number of studies have explored the use of infrared spectroscopy in cocoa. This study aims to investigate the research focus concerning the application of Infrared Spectroscopy Technology in cocoa commodities. The methodology employed includes a literature review with a bibliometric analysis approach and systematic literature review: identification, screening, eligibility, and inclusion. The data were collected from the Scopus database. The study results indicate an increase in publications related to the application of Infrared Spectroscopy Technology in cocoa commodities from 1988 to 2024, particularly from 2022 to 2023. Most research papers were published in Q1 journals, with Brazil leading in publications followed by other countries. New themes that emerge in research regarding related to infrared spectroscopy in cocoa include chemical structure, physicochemical properties, chemometrics, and thermogravimetric analysis. This research offers important insights into the present state and future prospects of infrared spectroscopy in cocoa analysis, emphasizing its importance in enhancing cocoa quality assessment and production efficiency in the chocolate industry. By exploring previous research, this study seeks to offer a deeper understanding of the role and potential of infrared spectroscopy technology.

Keywords**:** Bibliometric, Cocoa, Infrared Spectroscopy, Quality, Vosviewer

INTRODUCTION

Cocoa is a key ingredient in chocolate productions (Perez, 2021),(Barišić et al., 2019). Each stage of cocoa processing will affect the quality of the chocolate product produced (Giacometti, Jolić, & Josić, 2015), (Achaw & Danso-Boateng, 2021). The process of cocoa production involves several detailed post-harvest steps, including fermentation, drying, roasting, and grinding of cocoa beans, as well as blending ingredients, conching, and tempering (Hinneh, 2020), (Dorin, 2003). These processes are crucial in determining the overall quality of confectionery items. Therefore, quickly assessing the quality of cocoa beans is highly important for quality control during cocoa manufacturing.

The growing demands within an increasingly competitive and globalized environment require the agri-food sector to deliver higher quality products, necessitating continuous inspection throughout the entire production process process (Lezoche, Hernandez, Díaz, Panetto, &

Kacprzyk, 2020), (Ma et al., 2016). Consequently, there is a significant progress in the development of rapid, precise, and non-invasive technologies designed to evaluate individual products effectively (Abasi, Minaei, Jamshidi, & Fathi, 2018), (Gupta, Khan, Butola, & Singari, 2022). Among these, Infrared spectroscopy has gained recognition as a potential alternative approach (Freitag, Sulyok, Logan, Elliott, & Krska, 2022). This method allows for rapid, accurate, and economical evaluation of quality attributes in a non-invasive manner, eliminating the requirement for initial sample preparation, with the possibility of developing instruments for real-time in-line measurements (Cortés, Blasco, Aleixos, Cubero, & Talens, 2019),(Edwards, Manley, Hoffman, & Williams, 2021).

Research on infrared spectroscopy has advanced rapidly over the past decade (Beć, Grabska, & Huck, 2021). Infrared Spectroscopy research on agricultural commodities has indeed increased in recent years, including cocoa commodities, research on infrared spectroscopy has also seen significant growth (Quelal-Vásconez, Lerma-García, Pérez-Esteve, Talens, & Barat, 2020). Infrared spectroscopy technology application in agricultural commodities involves the utilization of infrared radiation to analyze and characterize various properties of agricultural products (Kharbach, Alaoui Mansouri, Taabouz, & Yu, 2023), (Lohumi, Lee, Lee, & Cho, 2015). This non-destructive analytical method determines whether the molecules in the sample absorb, reflect, or emit infrared light. This information is useful in determining the sample's chemical makeup, structural characteristics, and quality attributes (Odularu, 2020).

Numerous investigations have exhibited the efficacy of infrared spectroscopy in evaluating the quality of agricultural products, including cocoa. Infrared spectroscopy has been frequently employed in the assessment of cocoa quality, both in the near infrared (NIR) and mid-infrared (MI) bands (Castillejos-Mijangos, Acosta-Caudillo, Gallardo-Velázquez, Osorio-Revilla, & Jiménez-Martínez, 2022), (Sitorus & Lapcharoensuk, 2022). NIR is a quick and accurate substitute for conventional techniques when calculating the amount of lipids, protein, pH, titratable acidity, dry matter, and ash in cocoa beans (Forte et al., 2023). The fat content of cocoa beans can be quickly and non-destructively assessed using Near Infrared Spectroscopy (NIRS) in the wavelength range of 1000 to 2500 nm. It can also be used to predict and determine the fat contents of cocoa beans with substantial correlation coefficients and RPD indices, making it a valuable method for quality assessment (Munawar, Zulfahrizal, Hayati, & Syahrul, 2022). Adulteration in the cocoa industry, such as using carob flour as a substitute, can be rapidly detected with high accuracy using NIR spectroscopy and chemometrics (Teye, 2020). Analysis of the study's results using a statistical technique is necessary in order to comprehend the research focus and find new information. One useful method that is often employed to examine research in certain disciplines is bibliometric analysis. At present, there is no evidence that this topic has been investigated using bibliometric analysis. There has been no bibliometric study that explicitly examines the application of infrared spectroscopy in cocoa-related research. While previous publications have explored its role in quality evaluation and chemometric analysis, none have approached the topic through a bibliometric lens. This research introduces a novel contribution by systematically mapping the global scientific output in this field—highlighting key authors, keywords, publication venues, and patterns of international collaboration. In doing so, the study provides a fresh perspective on the evolution and direction of scholarly work concerning infrared spectroscopy in cocoa science.

A tool for mapping the state of the art in a field connected to a body of scientific information is bibliometrics (Mohadab, Bouikhalene, & Safi, 2020). Bibliometric analysis refers to the application of quantitative statistical techniques to evaluate scholarly publications, including books, journal articles, and other scientific literature (Martín-Martín, Thelwall, Orduna-Malea, & Delgado López-Cózar, 2021). To gather information from publications related to the application of infrared spectroscopy in cocoa, accessing a comprehensive database is crucial. The data for this investigation was obtained from the Scopus database. Scopus is a reputable multidisciplinary abstract and citation database, widely used by researchers and scholars worldwide (Montoya, Alcayde, Baños, & Manzano-Agugliaro, 2018), (Baas, Schotten, Plume, Côté, & Karimi, 2020). Researchers can browse a wide range of papers using the Scopus database,

extract pertinent data, and evaluate the effect of studies pertaining to the application of infrared spectroscopy in cocoa in order to study research trends (Aleixandre-Tudo, Castello-Cogollos, Aleixandre, & Aleixandre-Benavent, 2022).

This study aims to explore the main research directions and the novelty linked to the application of discovery learning in the field of infrared spectroscopy related to cocoa. The study aims to explore the following research questions:

1. What are the publication trends over time concerning infrared spectroscopy research in cocoa?
2. Which countries, authors, and journals have made the most significant contributions to this field?
3. What are the most frequently occurring keywords, and what do they indicate about research focuses?
4. How are international collaborations structured in the context of cocoa-related infrared spectroscopy research?

METHODE

This study utilized bibliometric methods to analyze the body of literature concerning the application of infrared spectroscopy in cocoa-related research, obtained from the Scopus bibliographic database, spanning the period from 1988 to 2024, as this range captures the earliest indexed publication on the topic and includes the most recent developments available at the time of data collection, thus allowing for a comprehensive assessment of long-term research trends and emerging themes. The data gathering procedure adhered to identification, screening, eligibility, and inclusion steps (Triansyah et al., 2023),(Yusoff, Ismail, & Nordin, 2024).

The publication trend on infrared spectroscopy in cocoa was analyzed descriptively using bibliometric data information obtained through the Scopus bibliographic database. A chart representing annual publication counts and their linear trend over the last ten years will be generated using Microsoft Excel. The trend in citations for research on infrared spectroscopy in cocoa is assessed through an analysis of the average citations received per publication.

Microsoft Excel is utilized by researchers to generate visual representations of journal rankings that show rankings based on quartile values. We shall group the data into four categories: (Q1), (Q2), (Q3), and (Q4). The data came from the Scopus database and covers 15 journals. This illustrates that the articles produced by researchers have been published in journals ranking above. An event analysis, coupled with keywords related to Infrared spectroscopy in cocoa, was conducted to ascertain the research's focus and novelty. The data for analysis is sourced from the Scopus database, which requires preprocessing. The research focus is identified through common keywords, which are visualized using VOSviewer software.

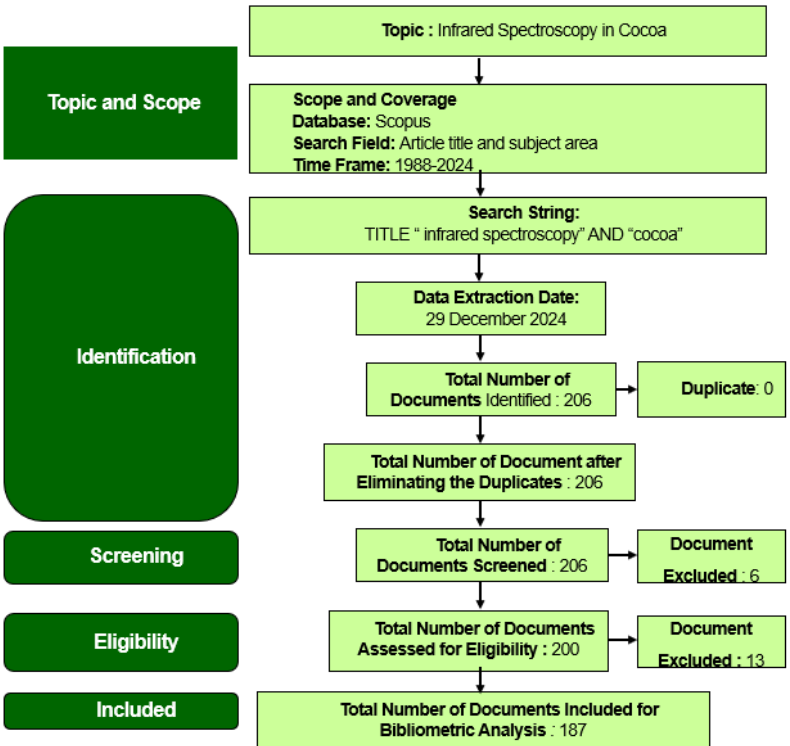

Figure 1. Data Collection Process

In the initial stage of identification, targeted keywords pertinent to the research theme, such as "infrared spectroscopy" and "cocoa," were entered into the Scopus database. This produced 206 publications that satisfied the predetermined standards. After that, duplicate data was checked, and since none was discovered, all 206 publications moved on to the next phase. Publications were carefully examined during the screening process to make sure they were written in English and took the form of articles. As a result of this process, a total of six publications were excluded due to non-compliance with the inclusion criteria. Therefore, 200 qualified publications were forwarded to the eligibility phase for in-depth examination.

Evaluating the viability of 189 documents from the prior step is part of the eligibility procedure. In this stage, these documents' titles and abstracts will be examined to see if the terms "infrared spectroscopy" and "cocoa" are used specifically. 187 publications that fit the requirements were found after the eligibility evaluation was completed, and they can move on to the inclusion phase.

RESULTS AND DISCUSSION

Patterns of Publications and Citations

The growth trend in scientific literature on infrared spectroscopy research in cocoa from 1988 to 2024 shows a steady annual increase, as demonstrated by the trend line shown in Figure 2 below.

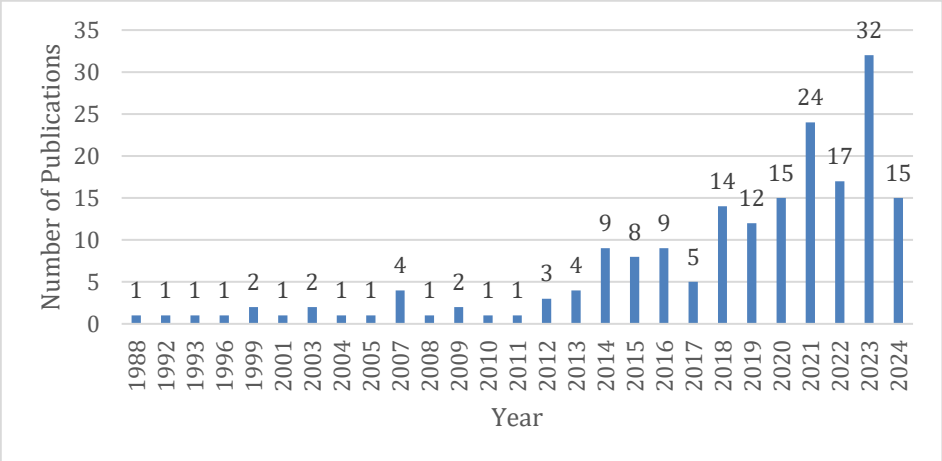

Figure 2. Publication Trends

Figure 2 highlights that the year 2023 marked the highest publication output in this research area, with a total of 32 articles, indicating a significant increase relative to preceding years. The period between 2022 and 2023 witnessed the most substantial increase, with the

publication count experiencing a twofold rise. These results are in agreement with those reported by (Johnson, Walsh, Naiker, & Ameer, 2023), that research on infrared spectroscopy, particularly in cocoa, is experiencing rapid growth. Publications in the field under consideration date back to 1988, with only a single document published that year. This reflects a growing interest and emphasis among researchers on investigating the prospects of utilizing infrared spectroscopy in cocoa. The high volume of publications in 2023 might also indicate a major advancement in our knowledge of and use of this technology in cocoa.

Figure 3. Visualization of the Most Frequently Cited Results

According to Figure 3, it can be concluded that Saucier, C., Mahato, D.K., Fazal,S., Cheman, and are the authors with the most citations recorded, as indicated by the larger circle. The article by (Saucier et al., 2015) is frequently cited by other researchers for its innovative focus on the preparation and characterization of microwave-assisted cocoa shell activated carbon. This study aims to eliminate sodium diclofenac and nimesulide from aqueous effluents. The use of microwave-induced pyrolysis for activated carbon production in a short time frame could offer advantages over traditional methods, potentially leading to more cost-effective and time-efficient wastewater treatment processes.

Table 1. Top 5 authors that published articles on infrared spectroscopy

Author	Title	Number of citations
Saucier et al., 2015	Microwave-assisted activated carbon from cocoa shell as adsorbent for removal of sodium diclofenac and nimesulide from aqueous effluents	293
Mahato et al., 2019	Aflatoxins in Food and Feed: An Overview on Prevalence, Detection and Control Strategies	220
Fazal et al., 2014	Green Synthesis of Anisotropic Gold Nanoparticles for Photothermal Therapy of Cancer	164
Che Man et al., 2005	Analysis of potential lard adulteration in chocolate and	148

	chocolate products using Fourier transform infrared spectroscopy	
Kutsanedzie et al., 2018	Near infrared system coupled chemometric algorithms for enumeration of total fungi count in cocoa beans neat solution	136

The article by (Mahato et al., 2019) provides information on the use of cutting-edge technologies and management techniques to regulate aflatoxins before and after harvest in order to increase agricultural output. The paper's contributions include a summary of aflatoxins in food and feed, their prevalence, methods of detection, and control measures. The 2014 article by Fazal, S. et al. highlighted the potential of nanoparticles to trigger cell death in cancer cells when exposed to laser irradiation, showing potential for use in photothermal ablation therapy.

The article by (Fazal et al., 2014) discusses green chemistry-based development of non-spherical gold nanoparticles for photothermal cancer applications.The synthesis of anisotropic gold nanoparticles via green chemistry for use in photothermal cancer therapy. The synthesis is achieved without using toxic capping agents, with cocoa extract serving as both the reducing and stabilizing agent, making it more biocompatible. The resulting gold nanoparticles show NIR (near-infrared) absorption in the range of 800-1000 nm, suitable for photothermal ablation of cancer cells. They are proven to be biocompatible and effective in photothermal therapy at low power levels, while also providing good contrast for CT scans.

The article by (Che Man, Syahariza, Mirghani, Jinap, & Bakar, 2005) highlighted the potential of nanoparticles to trigger cell death in cancer cells when exposed to laser irradiation, showing potential for use in photothermal ablation therapy. This research employed Fourier Transform Infrared (FTIR) spectroscopy integrated with Attenuated Total Reflectance (ATR) and Partial Least Squares Regression (PLSR) to detect the presence of lard in chocolate-based samples. The article by (Kutsanedzie et al., 2018) contributes by employing Fourier Transform Near-Infrared Spectroscopy (FT-NIRS), in conjunction with a range of chemometric models, was applied to estimate the total fungal load (TFC) in neat cocoa bean solutions. The study proposes an in-situ nondestructive method for enumerating TFC in cocoa beans, aimed at efficiently monitoring fungi and tackling quality and safety issues. The five articles offer important critical overview of the potential and implementation of infrared spectroscopy techniques, making them a valuable reference for researchers.

Distribution of Journal Rankings

Researchers commonly refer to quartile metrics from sources like Scopus and Scimago when analyzing journal quality rankings (Ayoub, Amin, & Wani, 2023), (Mason & Singh, 2022). After organizing journals by quartile, They calculate the distribution of publications across the different quartile categories (Q1 to Q4).

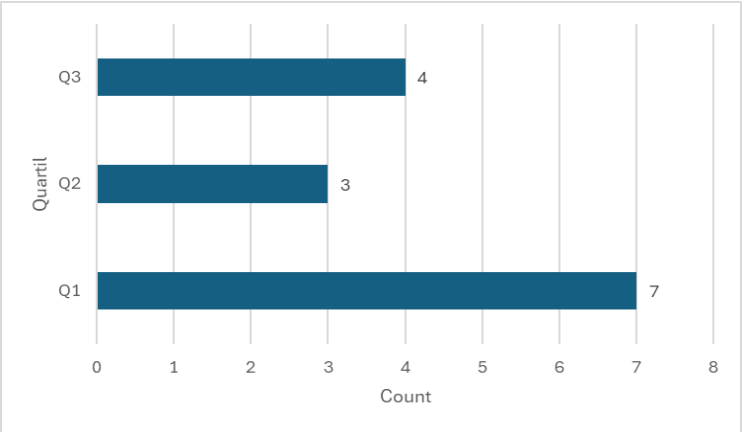

Figure 4. Distribution of Journal Rankings

Journal rankings are determined according to quartile rankings, covering 15 publications classified within the Q1 to Q3 quartile range. A notable portion of these publications focuses on infrared spectroscopy in cocoa. The image highlights that Q1 journals contain the highest concentration, with 7 publications, while Q3 journals follow with 4 publications. This table summarizes the journals and the volume of related publications they contain.

Table 2. The journal with the quantity of articles published

Journal	Number of Article	Quartile
LWT	2	Q1
Bioresource Technology	1	Q1
Case Studies in Chemical and Environmental Engineering	1	Q1
Food Chemistry	1	Q1
Food Science and Nutrition	1	Q1
International Journal of Biological Macromolecules	1	Q1
Surface and Coatings Technology	1	Q1

The table above shows journals that have published articles on infrared spectroscopy in cocoa from 1988 to 2024, with 15 documents published. These journals serve as potential publication venues for researchers focusing on infrared spectroscopy in cocoa.

Geographical Mapping of Publications and International Collaboration Networks

Publications related to infrared spectroscopy in cocoa, spanning the years 1988 to 2024 and originating from 55 countries, have been compiled by the researcher. This diversity is visualized th gure 5 shows that Brazil leads cation of infrared spectroscopy eleventh position with a total ve come from all continents.

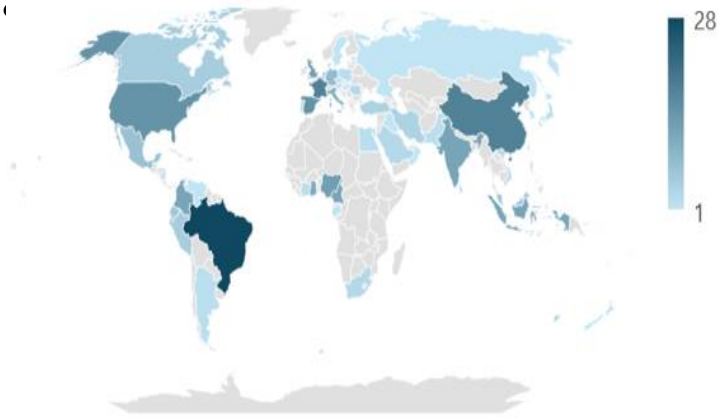

Figure 5. Geographic Distribution

Figure 6 illustrates the collaborations across nations in scientific collaboration on infrared spectroscopy in cocoa. It is clear that Brazil has numerous connections with other nations, indicating that Brazil not only leads in publication count but also shows a higher level of collaboration compared to other countries.

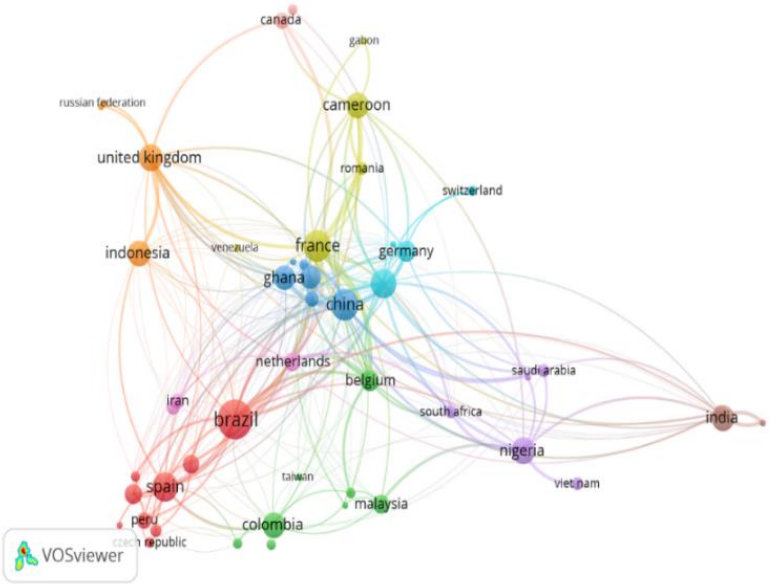

Figure 6. Visualization of keyword occurrence network

Innovative Aspects and Core Research Themes

Studies on infrared spectroscopy applied to cocoa between 1988 and 2024 have been categorized into five main clusters through the VOSviewer tool, highlighting the primary focus areas of rese

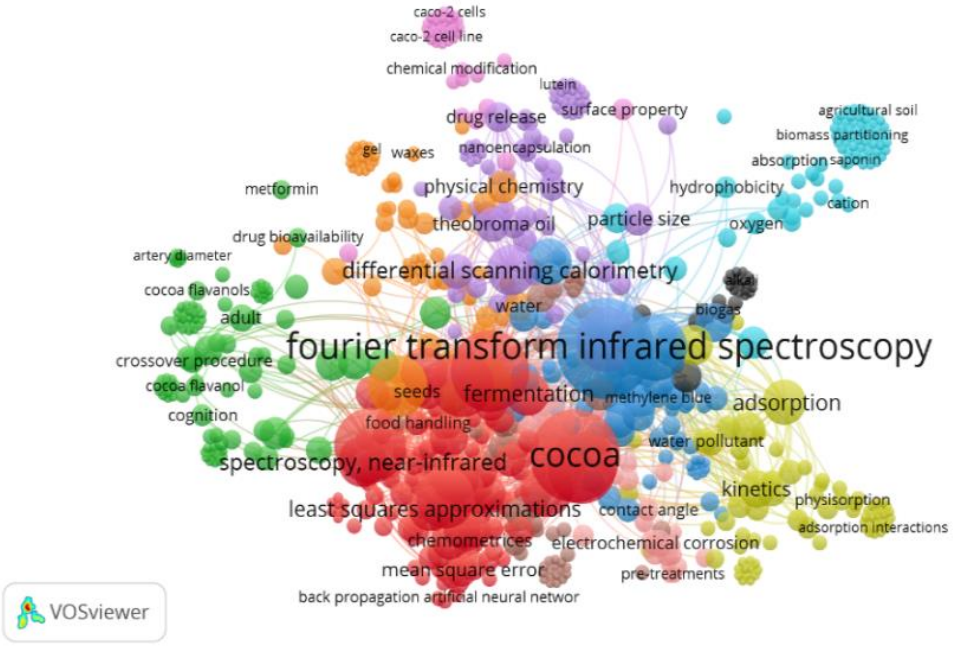

Figure 7. Visualization of Bibliometric Networks

Figure 7 shows a total of 122 items, divided into five different color-coded categories using the visualization tool VOSviewer. The color scheme illustrates distinct research clusters highlighting various emphases on infrared spectroscopy in cocoa within the period of 1988 to 2024.The first focus, represented by red circles with 34 items, highlights key topics such as cocoa, near-infrared spectroscopy, infrared devices, quality control, and least squares approximations. The second focus, marked by green circles comprising 33 items, emphasizes infrared spectroscopy based on Fourier transform, scanning electron microscopy, and infrared spectroscopy. The most recent research area, denoted by black circles with 30 items, features keywords like food analysis, mass spectroscopy, and food composition, indicating these topics as a primary theme in recent scholarly investigations within this domain.

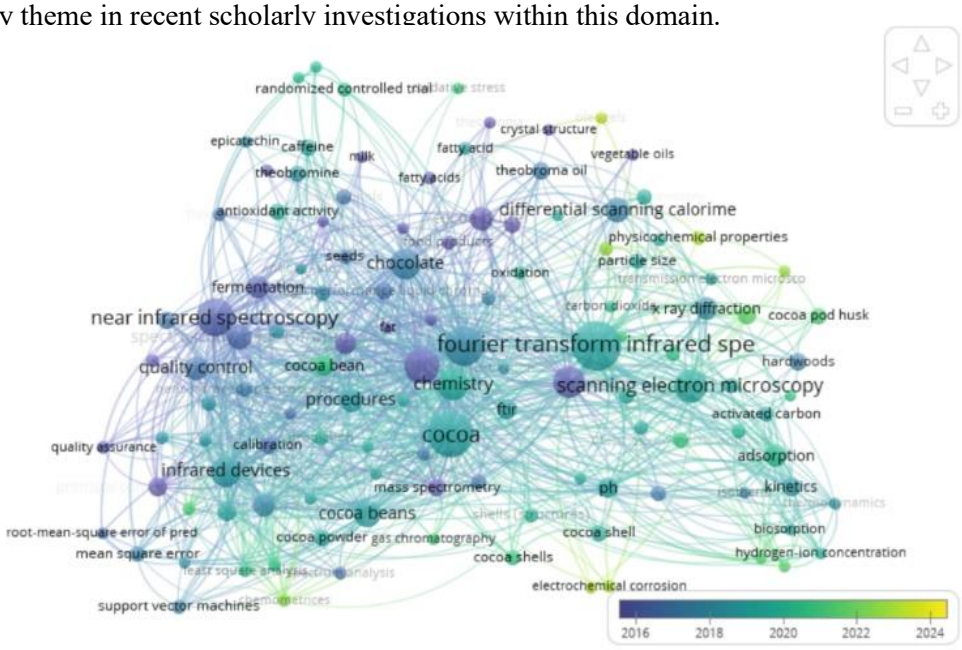

Figure 8. Visualization of Evolving Research Trends Over Time

Figure 8 presents 122 items, organized into five color-coded categories using the visualization tool VOSviewer. The color scheme illustrates different research focuses connected to infrared spectroscopy in cocoa from 1988 to 2024. The first cluster, shown in red with 34 items, highlights key topics such as cocoa, near-infrared spectroscopy, infrared devices, quality control, and least squares approximations. The second cluster, in green with 33 items, focuses on infrared spectroscopy based on Fourier transform, scanning electron microscopy, and infrared spectroscopy. The most recent research area, represented by black circles with 30 items, includes keywords like food analysis, mass spectroscopy, and food composition, indicating that these subjects are the primary theme in contemporary scientific inquiry in the field (Quelal-Vásconez et al., 2020). Analyzing with the infrared spectroscopy spectra, researchers can gain insights into the chemical makeup and structural features of cocoa compounds. Refers to the physicochemical properties of cocoa, such as solubility, melting point, and stability. Infrared spectroscopy can provide information of the influence of cocoa's chemical structure on its physicochemical properties.

Chemometrics applies multivariate analysis and other mathematical frameworks to gain insights from complex chemical measurements. In this context, it refers to the application of these techniques to interpret infrared spectroscopy data. Using chemometric models, researchers can extract meaningful information from complex infrared spectra, such as identifying patterns, quantifying components, and predicting the quality of cocoa samples (Farghal, Mansour, Khattab,

Zhao, & Farag, 2022). Thermogravimetric analysis (TGA) calculates a sample's weight change as it heats up (Saadatkhah et al., 2020). This technique helps in understanding the thermal stability and composition of cocoa. When combined with IR spectroscopy, TGA can provide complementary information about the decomposition products and the thermal behavior of different cocoa constituents.

The application of infrared spectroscopy technology can make a significant contribution to addressing the business sustainability and climate change challenges facing the cocoa industry conducting bibliometric analysis provides a systematic approach to understanding the existing state and potential future directions of infrared spectroscopy technology in the cocoa industry. It supports informed decision-making, promotes collaboration, identifies research gaps, and ensures that technological advancements are aligned with industry needs and sustainability imperatives. Through the application of bibliometric insights, stakeholders may optimize the capability of infrared spectroscopy to improve the resilience, sustainability, and quality of the cocoa supply chain in the face of changing environmental and economic constraints.

CONCLUSION

The findings of this study reveal a growing trend in the number of publications on the application of infrared spectroscopy in cocoa research, particularly between 2017 and 2020. Notably, more than 293 citations were recorded in 2015 alone, marking a significant rise compared to previous years. Among the 28 identified publications, most appeared in Q2-ranked journals, indicating growing academic interest and recognition of the field. Through bibliometric analysis, this study has illuminated various dimensions of infrared spectroscopy research in cocoa, including publication patterns, citation metrics, and research hotspots. The results highlight that researchers are increasingly focused on exploring the technological potentials of infrared spectroscopy for cocoa quality assessment. The distribution of publications across different journal ranks underscores the academic relevance of this domain, while geographically, Brazil has emerged as the most active contributor, followed by other countries engaged in collaborative international research. Cluster analysis indicates that over the years, research themes have evolved from quality control and polyphenol analysis to applications in food processing and antioxidant activity. These findings demonstrate the dynamic and expanding nature of cocoa-related infrared spectroscopy research. However, this study has some limitations. The data were sourced exclusively from the Scopus database and retrieved in December 2024; therefore, studies indexed in other databases or published after that date were not included in the analysis. Future studies should consider integrating multiple data sources and more recent datasets to provide a broader and updated bibliometric perspective. situation and potential paths of infrared spectroscopy research in cocoa. The technology's significance in improving the evaluation of cocoa quality and manufacturing efficiency is emphasized, which will ultimately help the chocolate industry's producers and consumers.

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