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Bibliometric Analysis and Literature Review of Ultrasound-Assisted Extraction

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Abstract

The challenges of the chemical industry to achieve green chemical products motivate strategies to increase strength, and safety, and reduce energy consumption, and cost. Ultrasound as a technique that is clean, efficient, inexpensive, and highly safe has become a research trend in extraction methods. Therefore, it is important to review research developments and trends in these emerging techniques. This article analyzes bibliometric ultrasound-assisted extraction data from the VOSviewer application. Bibliometric data was collected from 2021 to 2023 in a total of 1,312 articles. Research hotspots and future research directions are predicted through co-occurrence and co-authorship analysis. The featured category is Chemistry with 500 articles. The journal with the most dominant productivity is Ultrasonic Sonochemistry. China is ranked first in the article publication. The top author is Parag Gogatei. Collaboration is carried out between researchers, research groups, and countries. Ultrasound-assisted extraction has high efficiency so it can reduce process costs and achieve green chemistry. In addition, ultrasound is widely used to maintain essential oil content and has been tested for safety with low cytotoxicity. The use of solvents is used in the ultrasound-assisted extraction process to increase process efficiency. In the last stage, ultrasound-assisted extraction became a research hotspot.

Keywords: ultrasound-assisted extraction; bibliometric analysis; VOSviewer

1. Introduction

In the last decade, the extraction of bioactive compounds has progressed in the bioenergy, food, cosmetic, and pharmaceutical industries [1]. The challenges of the chemical industry are to determine strategies to increase product yield and safety and reduce energy consumption, and cost [2]. The Soxhlet method is used to extract *Moringa oleifera* leaves, but this method results in low-quality oil, high-energy consumption, toxic effects, and high safety risks [3].

Green chemistry is a chemical process that proceeds without causing environmental pollution [4–7]. Optimization of extraction with minimum use of energy and raw materials to achieve green chemistry has been an area attracting a lot of attention in recent times [8–10]. Recent findings identify extraction by ultrasound method as providing superior quality extract while reducing energy and raw material use [1,11].

Ultrasound-assisted extraction improves process efficiency and is used in various industries, such as the pharmaceutical industry [12]. Ultrasound is used in mixing various matrices such as liquid-solid or liquid-liquid [13]. In this process, ultrasound releases high-frequency waves into the environment [14]. Ultrasound waves are divided into high frequencies (2-10 MHz), medium (300-1000 kHz), and low (20-100 kHz) [15]. Ultrasound represents a high-efficiency, simple-to-use, low-trace, as well as a simple-to-facilitation extraction

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method through the sonication phenomenon. Ultrasound produces sound waves which cause cavitation phenomena. The growth or collapse of ultrasound waves is acoustic cavitation [16]. Microbubbles are caused by pressure differences caused by ultrasound waves [17]. The growth and collapse of micro-bubbles occur briefly [18]. The high pressure and temperature caused microwave collapse [19]. High pressure and temperature conditions destroy plant polysaccharides by the chemical, mechanical, or thermal effects of ultrasound waves [20]. This can help to increase the diffusion and penetration of solvents into the cell. Therefore, under short time conditions, it can produce the mass transfer of cell materials with solvents [21]. Various studies on ultrasound-assisted extraction have increased extraction efficiency for carob kernels where pressure, type of solvent, extraction time, and temperature were the key factors in extraction efficiency [22].

Bibliometrics measures and evaluates journal content, trends, and publication visibility through statistical and mathematical modeling [23]. In the bibliometric analysis, keywords and publication trends are classified and analyzed to evaluate articles [24]. The quantity of publications from countries and universities is also analyzed in the bibliometric [25,26].

Scientific mapping as well as performance analysis is evaluated in bibliometric analysis. Scientific mapping represents the dynamic features and structure of scientific research. Meanwhile, performance analysis is reviewed from quotations and publications from scientific authors [27–29].

Research groups and researchers can be assessed based on bibliometric indicators. This can represent the research conditions and can be used as a reference for expert judgment [30,31]. Appropriate methods and standards of use are applied and supported by sufficient knowledge to produce reliable bibliometric analysis [32]. The bibliometric analysis becomes a reference for making decisions in analyzing certain research topics [33–35]. The research dataset on ultrasound-assisted extraction produced to date has been analyzed in low-cost research. Thus, bibliometric studies increase cost and time efficiency which is a challenge faced by researchers and companies in developing extraction processes.

This article represents published bibliometric studies published from 2021 to 2023 regarding ultrasound-assisted extraction. Provided are the most influential publications, bibliographical references, and publication quantities by authors, organizations, and countries of ultrasound-assisted extraction. Bibliographic and keyword matches were analyzed through a bibliometric graphical representation obtained from the VOSviewer application (Figure 1).

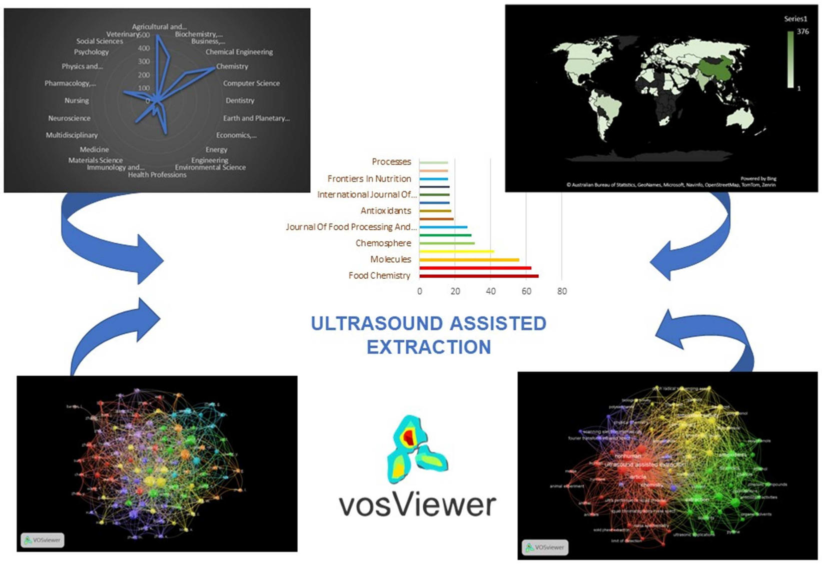

Figure 1: Schematic representation of the bibliometric analysis and literature review of ultrasound-assisted extraction

2. Methodology

The bibliometric data in this study were obtained from a collection of Scopus publications. Searches on the Scopus database were performed using the query: (TITLE-ABS-KEY("Ultrasound-Assisted Extraction") AND PUBYEAR > 2021 AND PUBYEAR > 2021). At the 2000-2006 stage, only a few articles were published each year. The 2007-2021 period shows a slow increase in article publications. The years 2021-2023 experienced rapid development and received a lot of public attention. This shows that ultrasound-assisted extraction is a hot topic. Therefore, in 2021–2023 in disbursing bibliometric data on Scopus with the keyword ultrasound-assisted extraction, 1,312 articles were obtained. The data was retrieved on 12 February 2023.

Bibliometric studies analyze and provide descriptions of research publications through a quantitative approach. Bibliometric analysis was used to evaluate trends in ultrasound-assisted extraction. Sources of information and quantity of publications are analyzed through this methodology.

VOSviewer is used for bibliometric mapping and visualization in ultrasound-assisted extraction publications. Graphical visualizations from VOSviewer were used to analyze investigator relationships, study groups, bibliographies, and articles that predominate in ultrasound-assisted extraction publications. Analysis of trends in emerging research subjects, related knowledge, research groups, and authors who contributed to research publications.

3. Results and Discussion

3.1. Research Category Analysis

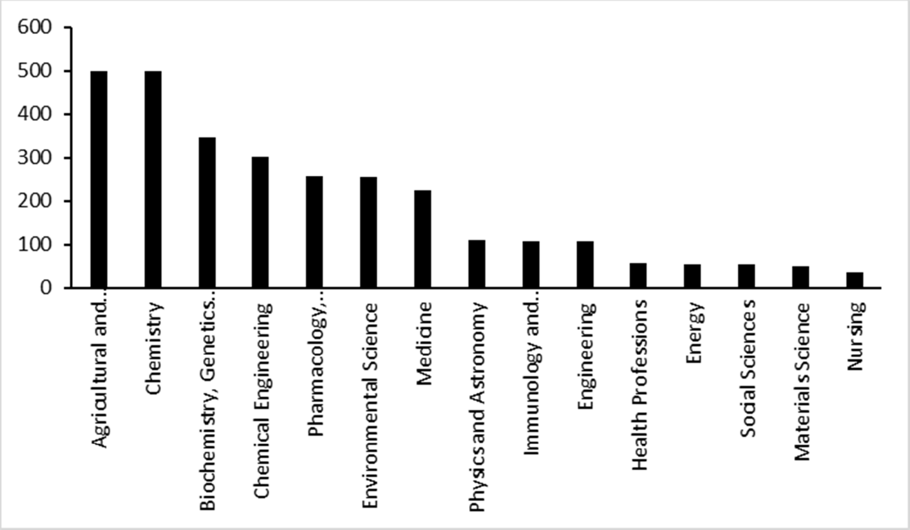

Figure 2: Ultrasound-assisted extraction research article category

The publication numbers of articles on ultrasound-assisted extraction were collected from 2021 to 2023 (Figure 2). The categories provide references to the topics selected for evaluation. Agricultural and Biological Sciences and the Chemistry category were the most productive categories with 500 articles (38.11% of 1,312 articles), Biochemistry, Genetics, and Molecular Biology with 346 articles (26.37%), Chemical Engineering with 302 articles (23.02%), Pharmacology, Toxicology and Pharmaceutics with 257 articles (19.59%), Environmental Science with 253 articles (19.28%), Medicine with 223 articles (17.00%), Physics and Astronomy with 111 articles (8.46%), Immunology and Microbiology with 107 articles (8.16%), Engineering with 106 articles (8.08%), Health Professions with 57 articles (4.34%), Energy with 55 articles (4.19%), Social Sciences with 55 articles (4.19%), and Materials Science with 48 articles (3.66%). The percentage of the total category was more than 100%. This is because different categories can be followed by one journal [36]. Chemistry Category; Chemical Engineering; Engineering; Energy; Physics and Astronomy; Material Science; and Social Science relating to the ultrasound-assisted extraction process which considers energy use efficiency, social science, and environmental sustainability to achieve a sustainable process (green process). The Agricultural and Biological Sciences category implies a large number of studies related to agriculture to identify various ingredients in the ultrasound-assisted extraction process. Pharmacology, Toxicology, and Pharmaceutics Category; medicine; and Health Professions imply many studies related to the content of essential oils resulting from ultrasound-assisted extraction by identifying health and safety aspects in their use. Categories of Biochemistry, Genetics, and Molecular Biology; as well as Immunology and Microbiology identifying molecular and micro-scale ultrasound-assisted extraction research with a bioprocess (green process).

3.2. Journal Analysis

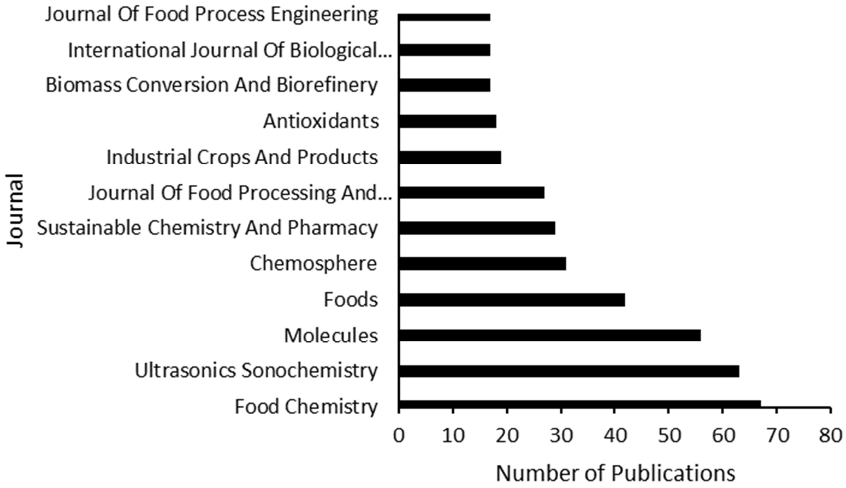

Figure 3: The most productive journal of ultrasound-assisted extraction

The publication of ultrasound-assisted extraction identified 1,312 articles in 160 journals. The top 15 journals (Figure 3) include Food Chemistry with 67 articles 5.11 % of 1,312 articles, Ultrasonics Sonochemistry with 63 articles (4.80 %), Molecules with 56 articles (4.27 %), Foods with 42 articles (3.20 %), Chemosphere with 31 articles (2.36%), Sustainable Chemistry and Pharmacy with 29 articles (2.21%), Journal of Food Processing and Preservation with 27 articles (2.05%), Industrial Crops and Products with 19 articles (1.44 %), Antioxidants 18 articles (1.37%), and Biomass Conversion and Biorefinery 17 articles (1.29%). The Journal of Ultrasonics Sonochemistry identifies the extraction process using ultrasound with sonochemistry phenomena. Additionally, the Chemosphere Journal is linked to the chemical process category, indicating that the topic is receiving significant research interest from a chemical process perspective. This is related to the extraction process itself which is a chemical process. Journal of Food Processing and Preservation; Foods; Industrial Crops and Products; Sustainable Chemistry and Pharmacy; Biomass Conversion and Biorefinery; and Antioxidants representing the use of extraction products using ultrasound in the food, pharmaceutical, and biomass industries. The journal Molecules identifies the ingredients of the ultrasound-assisted extraction product.

3.3. Analysis of Countries and Authors

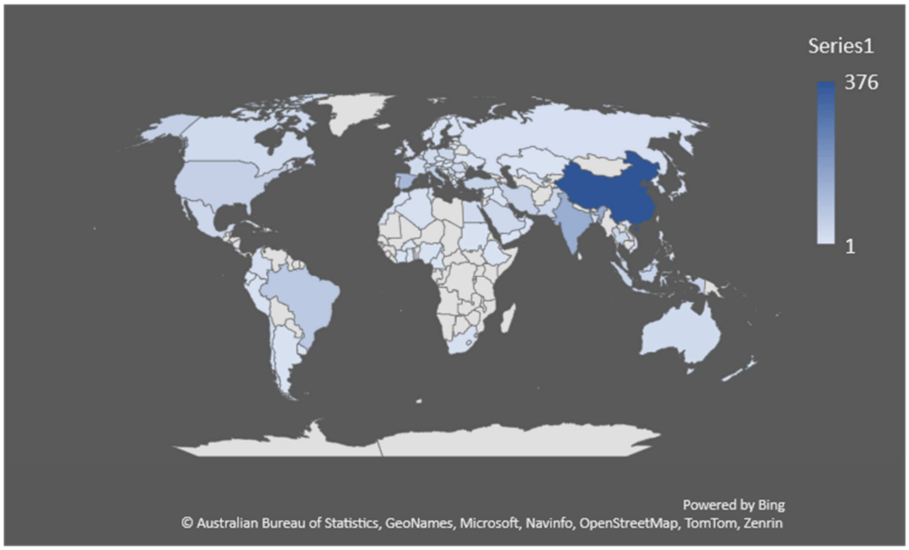

Figure 4: Countries with the most published article with the keyword 'ultrasound-assisted extraction' in interval 2021-2023

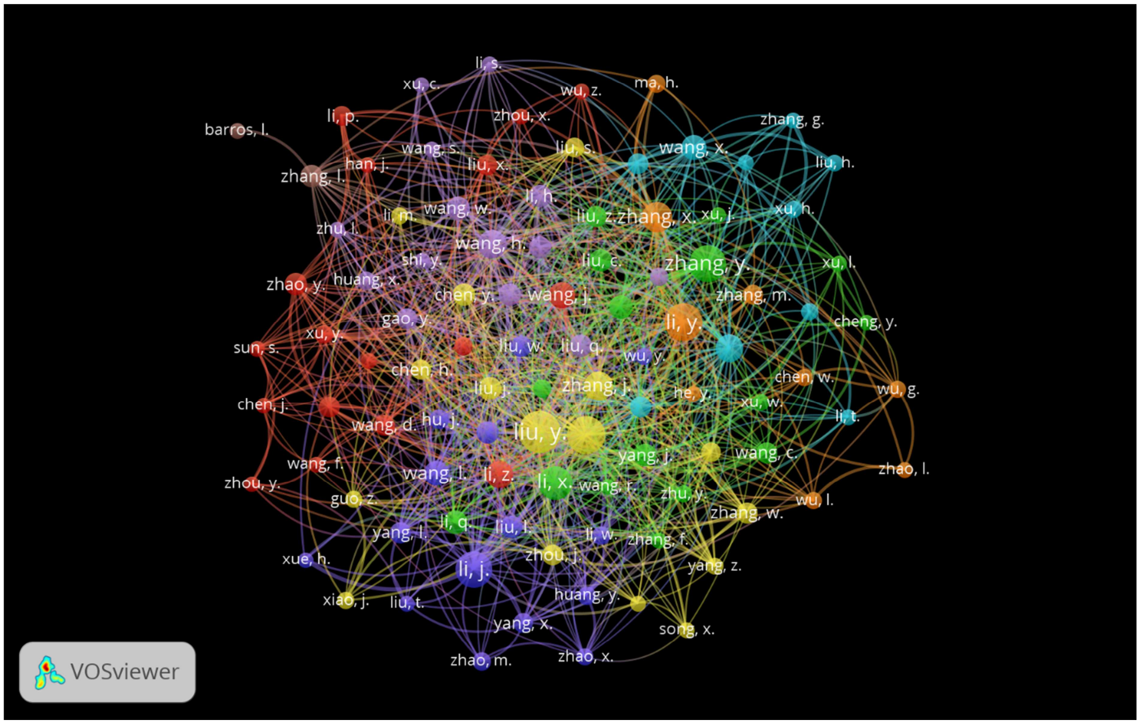

Figure 5: Visualization of author collaboration network using VOSviewer

Figure 4 represents the countries with the most publications. The 10 most productive countries consist of 2 American countries, 3 European countries, and 5 Asian countries. China leads with 376 articles (28.66% of 1,312 articles), followed by India with 144 articles (10.97%), Spain with 112 articles (8.54%), Brazil with 72 articles (5.49%), and Italy with 60 articles (4.57%). The total percentage obtained is more than 100% because each article can be published from various collaboration countries [37]. The publication of ultrasound-assisted extraction has a trend in developed countries. This is motivated by the ongoing green process of development in developed countries. Green processes are techniques that reduce or eliminate the formation of some substances harmful to human health and the environment. Ultrasound-assisted extraction can improve extract quality as well as solvent efficiency to achieve a green process method of extraction. The growth and collapse of ultrasound waves is a cavitation phenomenon [38]. Pressure variations in liquids caused by ultrasound waves induce the formation of large numbers of micro-bubbles [39]. Very high temperatures are generated from the ultrasound waves [40]. The ultrasound-assisted extraction mechanism requires advanced technology in its development [41]. However, developing countries can develop ultrasound-assisted extraction. Bangladesh with 8 articles, Ethiopia with 3 articles, and Sudan with 3 articles have developed ultrasound-assisted extraction.

The VOSviewer application maps and visualizes co-authorship as shown in Figure 5. There are 160 authors contributing to research on ultrasound-assisted extraction. The large nodes shown by researchers such as Liu Y., Li X., Wang Y., and Zhang J. represent their active publications. Tiwari B.K. is collaborating with Zhao M. Meanwhile, researchers are also actively collaborating in research groups. For example, Lorenzo J.M. collaborated with Bangar S.P., Anita. T., Dey A., Pandiselvam R., Dhumar S., Radha, Senaphaty M., Kennedy J.F., Sanpathrajan V., Abdel Wahab B.A., and Kumar M.

3.4. Keyword Analysis

Figure 6 represents the visualization and mapping of the ultrasound-assisted extraction keywords evaluated with VOSviewer. Keywords are represented by balls, while keyword relationships are represented by lines. The colors in the images mark related studies with the same goal. Ultrasound-assisted extraction is classified into 4 parts which are shown in different colors.

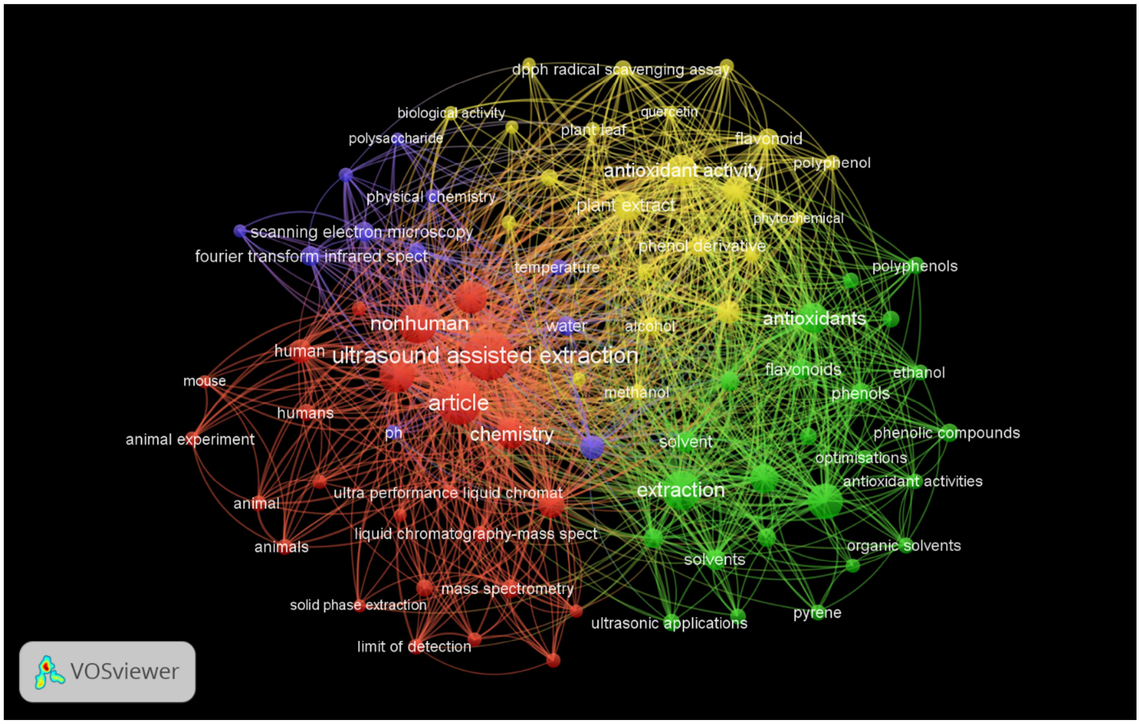

Figure 6: Visualization of the network of events with keywords using VOSviewer

Cluster 1. The first cluster colored "yellow" focuses more on factors regarding ultrasound-assisted extraction. "Ultrasound-assisted extraction", "extraction", "ultrasonic", "antioxidants", "solvent", and "phenol" were the most dominant keywords. Thus, it can be explained in these results that innovation at optimum conditions will result in great results. Ultrasound-assisted extraction has a higher efficiency with the use of 70-99% solvent [42–44]. The ability of the solvent to diffuse the extract greatly affects the extraction efficiency [45–48]. Solvent polarity and process efficiency are important factors in the use of solvents in extraction processes such as n-hexane. Other solvents that have been studied include dichloromethane [49], methanol [48], and ethanol [50–53]. Meanwhile, the incorporation of solvents in binary compositions such as n-hexane with methanol, and propane with ethanol has been developed to increase extraction efficiency [54–56]. Xie et al. [57] analyzed rosemary extraction using ultrasound-assisted extraction using a solvent mixture and showed that the ChCl solvent mixture with a ratio of 1/2/1 showed a very significant efficiency compared to traditional solvents. Elahi et al. [58] identified the effect of the addition of DES on ultrasound-assisted extraction showing the use of DES increased the extraction results and economic benefits. The study of Naseem et al. [59] also revealed that DES solvent was better than ethanol solvent in ultrasound-assisted extraction.

Cluster 2. This cluster is colored "blue" and the top keywords are "scanning electron microscopy", "Fourier transform infrared spect", "ultrasound", "water", and "physical chemistry" which are enhanced by the frequency of occurrence together. The keywords in this cluster represent the method of identifying extracted ingredients from ultrasound-assisted extraction. In ultrasound-assisted extraction methods are used to identify essential oil content as a parameter of essential oil quality. Physicochemical factors such as viscosity, surface tension, solubility, pH, and temperature affect the results of ultrasound-assisted extraction [60,61]. Increasing the temperature at the initial conditions can increase solubility and desorption and decrease the viscosity of the solvent so that the extraction efficiency increases. Meanwhile, the productivity of ultrasound-assisted extraction decreased due to product damage caused by cavitation phenomena [62,63]. Many factors influence the temperature of bioactive components [64,65]. Microbubbles caused by cavitation of ultrasound waves increase the pressure thereby reducing the pressure difference between the outside and inside of the bubble. This causes a decrease in the micro-bubble explosion, resulting in decreased process efficiency. Meanwhile, the quality of the ultrasound-assisted extraction results was damaged due to the increased shear stress [66]. Increasing temperature and pressure also accelerate oxidation due to hydrolysis. This causes a decrease in the results of ultrasound-assisted extraction [67]. pH affects the quality of ultrasound-assisted extraction results. Hydrophobic interactions between molecules cause the lowest ultrasound-assisted extraction efficiency to occur at pH 8. Meanwhile, efficiency increases occur with increased solubility in acidic and basic conditions. Therefore, the condition with a pH of 8 is the isoelectric point of ultrasound-assisted extraction. Collagen precipitation and aggregation increase due to hydrophobic interactions at pH 8 which causes a decrease in solubility. Meanwhile, the repulsion between polypeptides causes an increase in the diffusion process at high pH (alkaline) [68,69]. The effect of ultrasound treatment on solubility can be seen in the research conducted by Pezeshk et al. [70]. The research by Song et al. [71] revealed that the extraction of polysaccharides from lilies with ultrasound-assisted extraction showed optimum conditions in an acidic condition. Determination of optimum conditions by analyzing the results of ultrasound-assisted extraction using scanning electron microscopy and Fourier-transform infrared spectroscopy. SEM is a microscopic technique used to determine the shape, surface properties, and diameter of nanoparticles [72–74]. Quantitative analysis with FTIR has a safe and fast operation and does not cause damage to the sample [47,75]. Absorption of infrared radiation causes vibrations that indicate the atoms involved in the bond and the strength of their bond or molecular interactions [76–78].

Cluster 3. This cluster is colored "green". The third cluster contains essential oils from ultrasound-assisted extraction. Top keywords include "plant extract", "antioxidant activity", "antioxidant", "flavonoids", and "phenol derivatives". Cui et al. [79] analyzed the extraction of *Astragalus membranaceous* waste using ultrasound-assisted extraction producing extraction results that have high-efficiency biological activity and flavonoid content. Similarly, Jamshaid & Ahmed [80] studied the ultrasound-assisted extraction of *Melia azedarach* at optimum conditions with a power of 130 W with a solvent concentration of 50% DES yielded 9.154 mg of phenol and 21.880 mg of flavonoid with 51.166% anti-radical. Yusoff et al. [81] revealed that ultrasound-assisted extraction was very effective in retaining the content of bioactive compounds such as thymol, protein, phenolics, saponins, and flavonoids. Meanwhile, Vo et al. [82] studied ultrasound-assisted extraction of watermelon using DPPH and ABTS analysis resulting in optimal flavonoid and phenolic content. Zhu et al. [83] explored the ultrasound-assisted extraction of jujube peels revealing the destruction of the cell walls and accelerating the release of flavonoids. Apart from that, Zhu et al. [83] also proposed ultrasound-assisted extraction as a green process. Hazmi et al. [84] studied ultrasound-assisted extraction from kenaf using ethanol and water solvents by carrying out phytochemical screening tests resulting in optimizing the content of flavonoids and phenolic compounds in the ultrasound-assisted extraction results. Meanwhile, Kaewbangkerd et al. [85] compared the tracheal biochemical activity of boiler chickens in conventional extraction and ultrasound-assisted extraction resulted in scanning using SEM and FTIR identifying ultrasound did not affect the tracheal microstructure of boiler chickens, while conventional methods damaged the microstructure of the tracheal biochemistry of chickens. Ultrasound-assisted extraction increased 53% of xanthones (*mangiferin*) extracted from the manganese by-product '*criollo*' compared to conventional methods [86].

Cluster 4. This cluster is colored "red". The last cluster contains safety concerns and the effects of ultrasound-assisted extraction results. Based on the closer tissue visualization in VOSviewer, ultrasound-assisted extraction is related to four keywords: "Ultrasound-assisted extraction", "nonhuman", "controlled study", "unclassified drug", and "chemistry". In ultrasound-assisted extraction research, it should be noted that safety in use is also a central factor in the process [87–89]. In ultrasound-assisted extraction techniques, acoustic cavitation is associated with micro-bubbles in the target tissue that form high, tissue-dependent acoustic intensities that cause the wave blast phenomenon. micro shock, which damages the target and surrounding tissues [90–92]. Experiments using animals such as rats and pigs were carried out to avoid invasive human biopsies [93]. Mice have in vitro similarities to humans [94]. Analyzed Li et al. [95] ultrasound-assisted extraction of polysaccharides from Pericarpium Citri Reticulatae "Chachiensis" as an anti-obesity drug with experiments using rats showed very low toxicity and weight loss in rats. In addition, supplementation of the extracted ultrasound regulates the key metabolic pathways of the rats. Gao et al. [96] revealed that ultrasound-assisted extraction is an enzymatic hydrolyzate with high bioavailability in experiments using rapeseed meal protein injected into rats. Akram et al. [97] identified in vitro anti-inflammatory activity of essential oils showing significant anti-inflammatory effects. Meanwhile, gas chromatography and mass spectrometry tests identified a 25% higher extraction yield. Türker & Doğan [98] revealed in the research of ultrasound-assisted extraction with natural eutectic solvents that it has low cytotoxicity in humans and is environmentally friendly. This is an opportunity and can become a research trend to develop ultrasound-assisted extraction in extracting food ingredients and developing unclassified drugs in the pharmaceutical field.

4. Conclusion

Ultrasound-assisted extraction has experienced rapid development observed from 2021. The chemistry category is the leading category. Research on ultrasound-assisted extraction has been published in 160 journals. Ultrasound-assisted extraction has become a research trend in developed countries. This article analyzes bibliometric ultrasound-assisted extraction data from the VOSviewer application. Bibliometric data was collected from 2021 to 2023 in a total of 1321 articles. Research hotspots and future research directions are predicted through co-occurrence and co-authorship analysis. The featured category is Chemistry with 500 articles. The journal with the most dominant productivity is Ultrasonic Sonochemistry. China is ranked first in the article publication. The top author is Parag Gogatei. Collaboration is carried out between researchers, research groups, and countries. Ultrasound-assisted extraction has high efficiency so it can reduce process costs and achieve green chemicals. In addition, ultrasound is widely used to maintain essential oil content and has been tested for safety with low cytotoxicity. The use of solvents is used in the ultrasound-assisted extraction process to increase process efficiency. There is also focus on ultrasound-assisted extraction, emphasizing safety concerns and efficiency. The research highlights its relevance in extracting food ingredients and developing pharmaceuticals, showcasing low toxicity and promising bioavailability, suggesting a burgeoning research trend. In the last stage, ultrasound-assisted extraction became a research hotspot.

5. Future Directions

The importance of ultrasound-assisted extraction as a topic of extraction method publications. Ultrasound-assisted extraction can increase the quantity, high security, energy consumption, and cost savings. Green chemical is a chemical process without causing environmental pollution. Optimization of extraction with minimum use of energy and raw materials to achieve green chemistry. Recent findings identify extraction by ultrasound providing superior extract quality while reducing energy and raw material use. Therefore, ultrasound-assisted extraction must be a future extraction method to achieve green chemical and environmentally friendly.

6. Conflict of Interests

The authors declare that there is no conflict of interest.

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