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Biosensors and Green Synthesized Silver Nanoparticles: A Bibliometric Analysis

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ABSTRACT

To improve biosensors performance, the working electrodes used in biosensor design are modified by using different materials such as carbon dots, silver nanoparticles, conductive polymers etc. Environmentally friendly production of these materials is important for a sustainable environment. In this study, the use of environmentally friendly silver nanoparticles in electrode modification was determined. For this purpose, research and review articles indexed by the Science Citation Expanded Index (SCI-EXP) and Emerging Sources Citation Index (ESCI) in the Web of Science (WOS) database were searched using the keywords "green synthesis*" and "biosensor*" and "silver nanoparticle*". A total of 276 articles containing these three keywords in title, abstract, and author keywords were identified. The data of the articles were saved as Bibtex files and analyzed using R-programmer, Bibliometric R-package (Biblioshiny tool). India (n=387) was determined as the country with the highest number of studies on this subject. Keywords related to silver nanoparticles (n=175), green synthesis (n=191), nanoparticles (n=81), and biosensors (n=72) were prominent in the word cloud. Although the studies have increased since 2010, it was seen that the use of environmentally friendly silver nanoparticles in biosensor design was limited. It was clear that it is important to increase these studies for a sustainable environment.

KEYWORDS
Biosensors, green synthesis, silver, nanoparticles, Bibliometric analyses

1. INTRODUCTION

Biosensors are devices that combine a biological material and a physical transducer to obtain a measurable signal proportional to the concentration of analytes. The biological material interacts with the analyte and transducers with electrochemical, optical, and calorimetric properties are used to generate meaningful signals and quantify the analyte [1]. In 1962, after Clark and Lyons developed enzyme electrodes, biosensors have been used in a wide range of fields from medicine to the environment [2, 3]. Various biological materials such as enzymes, antigen-antibodies, microorganisms, organelles, tissues, and cells are used in the design of biosensors [4, 5]. Among these biological materials, enzymes are the most widely used biomaterial due to their high sensitivity and specificity [6].

During the operation of biosensors, the analyte is first transported from the

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solution to the biosensor's electrode surface in various ways such as diffusion, mixing, etc. [3]. The biological component could be absorbed by a polymeric porous membrane (such as cellulosic dialysis membrane) or sandwiched between the sensor and the polymeric membrane (cellophane, cellulose, acetate/nitrate, polyvinyl alcohol, polyurethane, etc.) or retained in a polymeric gel. As a result of the interaction of between analyte and biocomponent, gas molecules could be released or utilized, selective ions could be formed, heat could be generated or reduced, optical density could change and electrons could be released or utilized [7]. The above-mentioned changes on the sensor surface are detected and converted into a magnitude that could be measured by electrical circuits [7].

The parameters such as selectivity, reproducibility, accuracy, stability, responsiveness, and linearity are the major factors that affects the biosensors' performance [8]. Modification of the electrodes used in biosensors using different materials to improve the sensitivity, selectivity and overall analytical performance of the sensor is very popular [9]. Modification of electrodes with nanomaterials (gold nanoparticles, carbon nanotubes, graphene, etc.) or functional polymers increases the electrode surface area, allowing more bioreceptors to bind and facilitating electron transfer kinetics, leading to the design of higher performance biosensors [10]. Furthermore, modifying the surface with different functional materials significantly increases the selectivity toward target analytes [11]. Therefore, electrode modification is a widely common used application in terms of the accuracy and efficiency of biosensors.

Nanoparticles are used in biosensor applications due to their high surface area/volume ratio, tunable surface properties and electrical, optical and magnetic properties [12]. In particular, gold (AuNP), silver (AgNP), silica, magnetic and carbon-based nanoparticles are used for many purposes such as immobilization of recognition elements, signal amplification and detection of specific interactions with target analytes by electrochemical, optical or piezoelectric transduction [13].

Nanoparticles could be synthesized by various techniques such as physical, chemical and biological. The chemical techniques could be carried out using chemical reduction, sol-gel, microemulsion, thermal decomposition and hydrothermal methods [14]. However, toxic chemicals and hard synthesis conditions such as high temperature and pressure are harmful to the environment [15]. For this reason, there is a need for an alternative method to obtain eco-friendly nanoparticles [16].

Green synthesis is a technique that enables the synthesis of nanoparticles using natural reducing agents such as plant extracts and microorganisms and widely used today as an alternative to chemical methods. Green synthesis provides to obtain metallic nanoparticles with low energy, not using toxic chemicals. This provides to obtain eco- friendly and bio-compatible nanoparticles [17]. Since the plant extracts contain many biomolecules such as phenolic, proteins, carbohydrates, tannins, etc. the reduction and stabilization process takes place in one step [14]. Many metallic nanoparticles such as gold (Au), silver (Ag), platinum (Pt), palladium (Pd), zinc oxide (ZnO) and copper (Cu) could be synthesized by green synthesis technique [17].

The green synthesized silver nanoparticles (AgNPs) are preferred in medical applications due to their high antimicrobial effects [18]. However, AgNPs have the potential to use biosensors with their high surface area, conductivity, and chemical stability [6]. When the literature was examined it was seen that there were less study about the using green synthesized silver nanoparticles in biosensor application. Therefore, in this study, to guide the researchers and to identify the studies in the literature about the green synthesized silver nanoparticles in biosensor applications that indexed in Web of Science (WOS) database were summarized by using bibliometric analysis.

2. MATERIALS AND METHODS

In this study, a bibliometric analysis was carried out to obtain in depth knowledge on biosensors and green synthesized silver nanoparticles. For this purpose, the articles indexed in Web of Science (WOS) were searched with "silver nanoparticle*" and "biosensor*" and "green synthesis" keywords. In the data collection process, all research and review articles in English indexed in Science Citation Expanded Index (SCI-EXP) and Emerging Sources Citation Index (ESCI) were refined and Early-Access articles were excluded. Among the research data, information such as the year of publication of the articles, the journal in which they were published, the authors, the countries where the publications were made, as well as common words and keywords, including their impact and productivity, were included in the data. There was no year limit in the research. A Bibtex file was exported according to the full record of researched articles. The obtained data was transferred to the RStudio (2024.04.2+764) program for the statistical analyses. The Biblioshiny tool was used to obtain graphs in the Bibliometrix programme [19]. All data was filtered and performed preprocessing by authors before the analyses to remove duplicate entries and correct inconsistencies in author names.

3. RESULTS and DISCUSSION

In this study, it was aimed to obtain a general screening of green synthesized silver nanoparticles and biosensors. 276 articles were determined as a result of a WOS search with keywords “silver nanoparticle*” and “biosensor*” and “green synthesis”. When the data analyzed by the RStudio program, it was seen that the articles related to these three keywords were published in 2010. The growth rate was found as 20.79% until 2025s’ first stage. In total 1542 authors were studied but only one of them was seen as a single author. A rate of 34.06 % was found as international co-authorship. In addition, it was determined that the articles were written by using 22452 references in total. The number of articles published between 2010 and 2025 was presented as a line graph in Fig. 1.

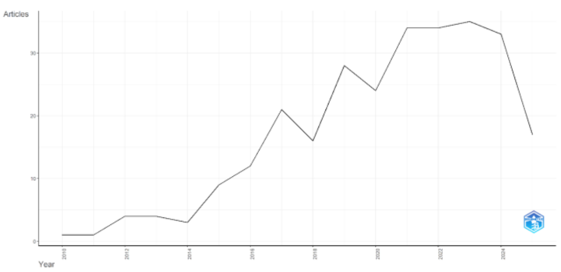

Figure 1: The changes of article numbers by the year

When the Fig. 1 was examined, it was seen that the number of article has been increased by the year. It was though that as a result of the importance of sustainability, the number of studies were increased specially after 2016.

The distribution of the countries where the articles in the data set analyzed within the scope of the research were made was presented in the world map (Fig. 2).

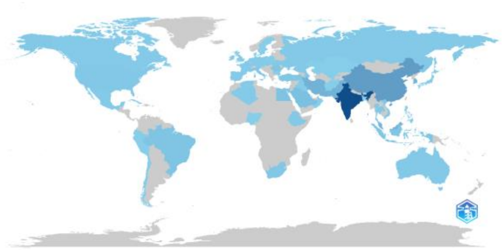

Figure 2: The world map of the scientific production

The colors of the countries showed the intensity of the published articles. The dark blue (India, n=387) had the maximum number of published articles. It was determined that China (n=141), Iran (n=78), Pakistan (n=74), Malaysia (n=73), Saudi Arabia (n=38), Brazil (n=27) and Türkiye (n=20) published articles related to the search keywords. The number of production articles by countries was also presented in line graph (Fig. 3).

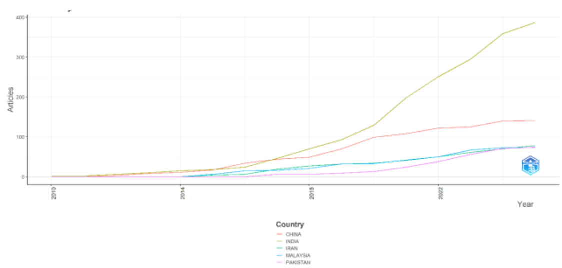

Figure 3: The line graph of country productions by the year

When the Fig. 4 was examined, it was seen that the articles were mostly published in RSC Advances (n=10), Biosensors & Bioelectronics (n= 8) and the Arabian Journal of Chemistry (n= 6).

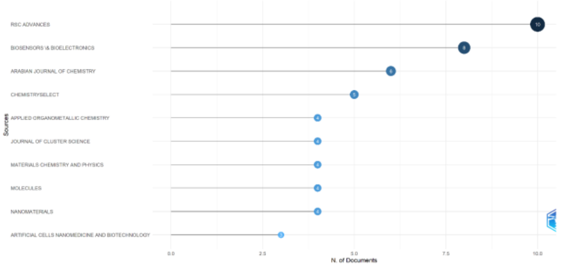

Figure 4: The most published Journals

The most cited countries were also presented in Fig. 5.

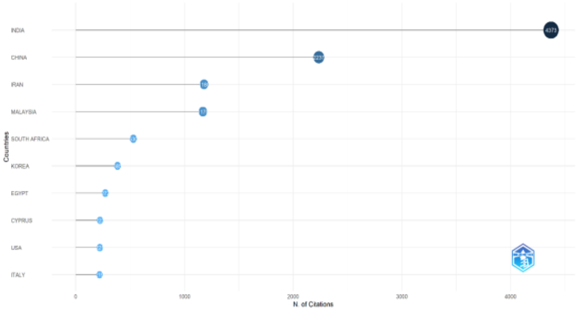

Figure 5: Distribution of countries on the subject

When the Fig. 5 was examined, it was determined that India (n=4373) had the maximum citation about the topic. China (n=2237), Iran (n=1180), and Malaysia (n=1170) followed the India.

The cloud of keywords was presented in Fig. 6. It was seen that silver nanoparticles (n=175), green synthesis (n=191), gold nanoparticles (n=91), nanoparticles (n=81) and biosensors (n=72) were the most relevant keywords.

Figure 6: The cloud of keywords

The thematic graph showing the co-use of the keywords in groups by authors was given in Fig. 7.

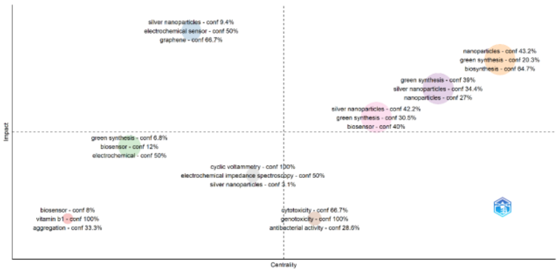

Figure 7: Thematic graph of keywords cluster

When the thematic graph in Fig. 7 was examined, it was seen that nanoparticles, green synthesis and biosynthesis keywords were mostly preferred keywords clusters. On the other hand, silver nanoparticles, electrochemical sensor, and graphene keywords cluster is in Niche Themes which means the keywords has importance in main topic but limited with other disciplines.

When the studies were examined, it was seen that the using of silver nanoparticles obtained by green synthesis technique in biosensor design has increased over time and the use of these green synthesis, biosensor and silver nanoparticle keywords in the WOS database was also in motor themes. For example, in a study conducted by Bodur et al. [20], the green synthesized silver nanoparticles were used to modify electrode to determine H_2O_2. In another study, it was determined that synthesized silver nanoparticles had potential to determine human serum albumin [21]. In a study conducted by Munir et al. [22] silver nanoparticles were used to determine glucose levels. In another study, it was reported that silver nanoparticles were improved the sensitivity of glutathione biosensor [23]. In a study, it was reported that green synthesized silver nanoparticles could use to modify carbon paste electrode to determine glucose levels [6]. Ureña-Castillo et al. [24] was reported that organic waste could use as a reducing and capping agent and they could be used in many applications. It was clear that green synthesized silver nanoparticles could be used in biosensor applications to detect many analyte in different areas [25-29].

4. CONCLUSION

When the obtained data were examined in general, it was seen that the issue was become increasingly important over the years, it was addressed by many countries with different researches, although the issues addressed in the researches differ from year to year, they were carried out in similar contexts, and researches were carried out with international cooperation. It was clear from the data that modifications of the electrodes used in the designing of biosensors that allow the determination of analytes even at low concentrations increase the performance of the designed biosensors. However, toxic chemicals formed both during and after the production of silver nanoparticles synthesized using chemical techniques are very harmful to the environment. Within the scope of sustainability studies carried out worldwide, it is important to use environmentally friendly materials for a sustainable environment. The silver nanoparticles should be obtained using green synthesis technique and their use in the designing of electrochemical biosensors should be expanded due to their unique properties. However, it was seen that the number of studies was limited about the containing “green synthesis” and “biosensors” and “silver nanoparticles” keywords. For a sustainable environment and future, it is important to further expand the use of silver nanoparticles obtained using green synthesis technique in biosensor design and the multidisciplinary studies should be performed.

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