A Bibliometric Analysis of Antibacterial Textiles

Habiba Halepoto 1,2, Tao Gong 2,*, and Hafeezullah Memon 3

1 Engineering Research Center of Digitized Textile and Fashion Technology, Ministry of Education, Donghua University, Shanghai 201620, China
2 College of Information Science and Technology, Donghua University, Shanghai 201620, China
3 International Institute of Silk, College of Textile Science and Engineering, Zhejiang Sci-Tech University, Hangzhou 310018, China

* Correspondence: taogong@dhu.edu.cn

Abstract: Scientists worldwide are always interested in making new discoveries; thus, the scientific literature has been growing exponentially. Keeping abreast of the body of literature at a rapidly advancing pace poses significant challenges to active researchers and society. Although numerous data resources have been made openly available, effectively navigating the vast amount of information with heightened levels of uncertainty remains a significant bottleneck. Here, we searched and analyzed the literature regarding antibacterial treatments in the textile industry. The Web of Science, the most extensive database for scientific literature, was targeted to extract the data. We extracted the raw data from the Web of Science Core Collection. The documents were published from 1998 to 2022, from a total of 878 sources. A total of 3625 documents were found, 2898 of which were articles. A total of 11,192 authors contributed to the topic during this period. We used the Bibliometrix sub-tool Biblioshiny and extracted the basic information about the documents. With an annual growth rate of 26.27%, there was a boost in the literature during the period under study.

Keywords: antibacterial; textiles; bibliometric analysis; database; web of science

1. Introduction

Textiles can be considered a suitable source for the growth of microbes such as fungi, bacteria, and even some protozoans [1]. These microbes affect not only textile materials but also the end user. Besides other effects, microbe growth may generate unwanted odor, discoloration, and contamination and reduce the fabric’s mechanical strength [2,3]. The use of antimicrobial textiles that eradicate microorganisms can stop the spread of pathogens via textiles [4]. Antimicrobial agents are applied to textile substrates to create antibacterial textiles, or textile fibers with intrinsic antimicrobial efficiency can be used instead. Depending on the chemistry of the antimicrobial agent and the textile, there are multiple ways to attach antimicrobial chemicals to textiles [5]. Consumers’ demand for comfort and well-being and their views toward hygiene have generated a quickly expanding market for antibacterial materials.

Consequently, there has been substantial research in this field in recent years [6]. Because they are hydrophobic, synthetic fibers have been shown to be more resistant to microbial attack, while natural fibers are more susceptible. Thus, some researchers have combined the effect of hydrophobicity and the antibacterial activity of textile materials in their research [7]. Additionally, microbes can obtain nutrients from dust, sweat, and soil [8]. About 85% of the total manufacturing of antimicrobial textiles is made up of lingerie, activewear, socks, and shoe linings. A significant market for antimicrobial fibers has also recently emerged in air filters, outdoor textiles, furniture, and medical textiles [9].

In addition to having antimicrobial properties, an antimicrobial agent must meet a few prerequisites to be successfully applied to textiles and allow for their commercial usage. The fundamental needs of an effective antimicrobial agent for textile substrates...
can be summarized as follows: they should have a preference for a particular fabric and kind of fiber, be suitable to apply to textile substrates, be capable of eliminating unwanted microorganisms yet keeping favorable microorganisms unaffected, inert to any chemicals that may be used to treat the textile, and so on [5,10]. Furthermore, an infestation of fibers by pathogenic bacteria can cause health problems such as asthma, allergic sensitization, or eczema [11]. Therefore, textiles should be protected to resist bacterial attachment.

Textiles have significant potential to be used for biological and chemical applications, particularly as antibacterial material [12,13]. There are several methods to protect textile materials from microbes. The most general approach to protecting fabrics from bacteria is based on antimicrobial agents in textile finishing, such as silver nanoparticles [14,15]. A wide variety of antibacterial products and chemicals are currently available. The majority of antimicrobial substances used in textile sanitizers have long been found in food preservatives, antiseptics, bandages, and pool cleaners [16]. The attachment of these chemicals to textile surfaces or their interaction with the fiber can significantly diminish their activity and limit the availability of antibacterial agents.

Furthermore, the antibacterial ingredient may be gradually removed by washing and using the textile. Metal salts (for example, silver), quaternary ammonium compounds, halogenated phenols (for example, triclosan), polybiguanide (for example, polyaminopropyl biguanide), chitosan, and N-halamines are the most often used antimicrobial agents for textile applications [17]. In addition, siloxane sulfopropylbetaine has also been proposed for antibacterial cotton fabrics and is claimed to be an eco-friendly product [18].

Bibliometric analysis has recently gained immense fame in research in multiple fields [19–33]. This research method can reveal the distribution patterns of articles published in databases within a given topic, field, institution, and country. The Science Citation Index Expanded from the Web of Science Core Collection of Clarivate Analytics, previously known as Thomson Reuters, is the most valuable and widely used data repository for analyzing scientific achievements across all research fields. Several factors play roles in the popularity of bibliometric studies, such as the advancement, availability, and accessibility of bibliometric software such as Gephi [34], Leximancer [35,36], and VOS viewer [37], and the easy accessibility to scientific databases such as Scopus and Web of Science. More importantly, bibliometric analysis plays a role in handling large volumes of scientific data and, as a result, generates a high research impact. Bibliometric analysis can be used for various reasons, such as to uncover emerging trends in article and journal performance, partnership patterns, and research constituents, and to explore the intellectual structure of a specific domain in the extant literature [38,39]. Bibliometric analysis helps to decipher and map the cumulative scientific knowledge and evolutionary nuances of well-established fields by making sense of large volumes of unstructured data in rigorous ways [29]. Therefore, bibliometric studies foster innovation and help to build a strong basis for advancing a research area in meaningful ways. Bibliometric analysis enables and empowers researchers to (1) have a one-stop overview, (2) investigate knowledge gaps, (3) design innovative ideas for investigation, and (4) position their intended contributions to the field.

Notwithstanding its merits, the deployment of bibliometric analysis does not fully realize its potential. This occurs when bibliometric studies rely on a limited set of data and techniques and provide only a piecemeal understanding of the field under study (e.g., performance analysis without science mapping; [40]). Although some studies are available regarding the bibliometric analysis of bacterial products in the textile industry [19,21,41], these studies lack some details on the most relevant issues to the field, such as (i) the most frequently explored research topics, (ii) publications with the most citations, and (iii) researchers with the most contributions to the body of knowledge in the field, among others. Given that there has not been such discipline-specific bibliometric research, we sought to analyze the literature on antibacterial treatments in the textile industry between 1998 and 2022 since, according to the search on the Web of Science, the first article appeared in 1998. Thus, we studied from the first article to the date of export of the data and conducted a bibliometric analysis of the literature in the mentioned timeframe to answer the following questions:
1. What are the major types of publications?
2. What are the most often explored topics?
3. What are the most highly cited publications and authors?
4. What are the most highly cited journals?
5. Which country/region has the most cited publications?

This bibliometric analysis demonstrates the importance of antibacterial textiles and highlights leading papers, authors, institutes, countries, and so on. We believe that this research can be helpful for researchers to understand and realize the importance of the domain, also providing a basic understanding of the level of work related to antibacterial textiles. Moreover, it will be helpful for industrials and professionals to endorse technology development and aid funding agencies in deciding on the novelty and innovations of antibacterial textiles.

2. Data Collection and Research Methodology

2.1. Data Collection

Web of Science (WoS), as one of the most comprehensive databases, contains articles from high-quality scientific journals. For bibliometric analysis, selecting appropriate keywords is crucial because they impact the research findings directly [42,43]; thus, we did not use the Baidu index [44,45], which is considered a reliable source in China. We extracted the raw data from the Web of Science Core Collection. Since the Web of Science does not allow the export of all the data at once, we chose 500 files at a time. A total of eight files were extracted; seven of them consisted of 500 documents, while the eighth consisted of 125 documents. These files were merged into a single file by using the Python program. The single file of all the documents was then saved to the Python directory with the txt extension. This single file was used for further data analysis.

2.2. Bibliometrix: An R-Tool

The number of academic publications is increasing rapidly, and it is becoming increasingly unfeasible to remain up to date with everything being published. Moreover, the emphasis on empirical contributions has resulted in voluminous and fragmented research streams. This hampers the ability to accumulate knowledge and actively collect evidence through earlier research papers. Therefore, literature reviews are increasingly assuming a crucial role in synthesizing past research findings to effectively use the existing knowledge base, advance a line of research, and provide evidence-based insight into the practice of exercising and sustaining professional judgment and expertise [46]. We examined the scientific productivity of articles, productive authors, citable documents, the most relevant institutions, cited countries, co-occurrence of keywords, thematic mapping, co-citations, and collaboration of authors and countries. We used Biblioshiny to conduct the performance and science mapping analyses [46].

2.3. Literature Search and Analysis

A comprehensive search of the primary scientific literature was conducted on 10 June 2022 on the Web of Science. The Web of Science is considered the most reliable and authentic database among the research community. The search was further modified to include other terms, such as “antibacterial textiles”, “antimicrobial textiles”, “antibacterial textile”, “antimicrobial textile”, “anti-bacterial textiles”, “anti-microbial textiles”, “anti-bacterial textiles”, and “anti-microbial textile”, to extract specific scientific literature. The following filters were manually activated for the search: (i) relevance, (ii) title and abstract, (iii) year of publication, which ranged between 1998 and 2022, (vi) researchers, (v) research categories, (vi) research type, (vii) source titles, and (viii) journal list. The source data’s statistical details were downloaded as plain text files and processed with the bibliometric analysis tool Bibliometrix [47,48].
3. Results

3.1. Data Analysis

The documents are from 1998 to 2022 from a total of 878 sources. A brief description is provided in Table 1. A total of 3625 documents were found, of which 2898 were articles. A total of 11,192 authors contributed to the topic during the period under study. The document’s average age was 5.14 years, and the average number of citations per document was 22.8, totaling 110,295 references. The author’s keywords amounted to 7390, while the KeyWords Plus reached 4808. There were only 149 documents attributed to a single author. We found that one book chapter was published on the topic, along with three corrections and twenty meeting abstracts. There were 308 review papers, 2 book review chapters, and 240 proceeding papers. We found three corrections, one news item, and one letter (refer to Table 1).

Table 1. Main information about the data.

| Description                              | Results          |
|------------------------------------------|------------------|
| **Main Information About Data**          |                  |
| Timespan                                 | 1998–2022        |
| Sources (journals, books, etc.)          | 877              |
| Documents                                | 3625             |
| Annual growth rate %                     | 26.27            |
| Document average age                     | 5.14             |
| Average citations per doc                | 22.8             |
| References                               | 110,295          |
| **Document Contents**                    |                  |
| KeyWords Plus (ID)                       | 4808             |
| Author’s keywords (DE)                   | 7390             |
| **AUTHORS**                              |                  |
| Authors                                  | 11,192           |
| Authors of single-author docs            | 118              |
| **Authors Collaboration**                |                  |
| Single-author docs                       | 149              |
| Co-authors per doc                       | 4.87             |
| International co-authorships %           | 23.17            |
| **Document Types**                       |                  |
| Article                                  | 2898             |
| Article; early access                    | 1                |
| Article; book chapter                    | 1                |
| Article; early access                    | 89               |
| Article; proceedings paper               | 43               |
| Correction                               | 3                |
| Editorial material                       | 1                |
| Letter                                   | 1                |
Table 1. Cont.

| Description                    | Results |
|--------------------------------|---------|
| Meeting abstract               | 20      |
| News item                      | 1       |
| Proceedings paper              | 240     |
| Review                         | 308     |
| Review; book chapter           | 2       |
| Review; early access           | 17      |

3.2. Annual Publications

We used the Bibliometrix sub-tool Biblioshiny and extracted the basic information on the publications. We can see a substantial increase in the number of publications each year, with an annual growth rate of 26.27%. Only one document was published in 1998. The article describes the synthesis, stability, surface activity, and antimicrobial properties of a new family of cationic surfactants (the long chain arginylalkylamide dihydrochloride salts) derived from the condensation of the amino acid arginine, and a long-chain alkylamine was described. Based on Google Scholar metrics, this article has been cited by 40 researchers as of the end of August 2022. The addition of documents to the literature was sparse until 2007. From 1999 to 2002, no single document was published. In 2003, one more document was added to the literature. In this publication, the antibacterial activities of a newly formed compound were measured with *Escherichia coli* 8099 as a Gram-negative strain and *Staphylococcus aureus* ATCC 6538 as a Gram-positive strain. According to the journal’s official metrics, this article has been cited by 39 researchers as of August 2022. No document was added for the next three years, i.e., 2004–2006.

There was a considerable boost in publications in 2007. A total of 53 documents were added to the literature in 2007 and 79 documents in 2008. There has been a continuous increase in the number of documents published each year. In 2021, a total of 534 documents were published, and by mid-2022, a total of 228 documents had been added to the literature, as shown in Figure 1.

![Figure 1. Annual scientific production during each year. (Bar chart created by Origin Pro 2022b, Northampton, MA, USA).](image-url)
3.3. Annual Citations

As more and more research has been conducted over time, the citations of the articles has increased. In the beginning, there were few articles, and there was a decline in the literature. In 1998, there was only one citation, and no citations were available from 1999 to 2002. In 2003, a total of 1.8 citations per year were available. For the next three years, there was not a single citation available; however, in 2007, we can see exponential growth in the number of citations, as shown in Figure 2. Until 2021, we can see that there has been a diverse range of citations each year, increasing in some years and decreasing in others. However, we can see a considerable rise in citations during the calendar year 2022.

![Average Article Citations per Year](image)

**Figure 2.** Average citations per year. The $x$-axis indicates years; the $y$-axis shows the average citations. In 1998, there was a single citation, and there was an exponential rise in citations in 2007.

3.4. Most Relevant Sources and Corresponding Authors’ Countries

We performed an analysis to identify the most relevant sources. We found that the National Research Center, Egypt (NATL RES CTR), is at the top, with a total of 260 documents. The Islamic Azad University, Iran (ISLAMIC AZAD UNIV), is second, with a total of 177 documents; the third was Donghua University, China (DONGHUA UNIV), with a total of 131 documents (Figure 3).

![Most Relevant Affiliations](image)

**Figure 3.** The most relevant affiliated institutes. The $x$-axis indicates the number of documents; the $y$-axis shows the institute name.
Similarly, the corresponding authors’ countries were evaluated. As shown in Figure 4, China is the leading country regarding the corresponding authors, with a total of 144 multiple-country publication (MCP) documents and 578 single-country publication (SCP) documents, followed by India, with an MCP of 78 documents and an SCP of 409 documents.

![Corresponding Author's Country](image)

**Figure 4.** Corresponding authors’ countries. The x-axis indicates the number of published documents; the y-axis shows the country names. China leads with a total of 144 MCP documents and 578 SCP documents.

### 3.5. Most Relevant Author and Author’s Local Impact

The data were evaluated to identify the most relevant authors. Montazer M., with 71 documents, is the leading author, followed by Ibrahim N. A. and Simoncic B., with 34 documents (Figure 5). We also analyzed the data to determine the authors’ production over time. The leading author, Montazer M., published two articles in 2007, one article in 2009, two articles during the calendar year 2010, five articles in 2011, four articles in 2012, seven articles in 2013, five articles each in 2014 and 2015, seven articles in 2016, eight articles in 2018, six articles in 2019, two articles in 2020, six articles in 2021, and only one article in 2022. The highest number of articles he published in a calendar year is nine. Similarly, the authors’ impact was evaluated. Montazer M., with a total of 3294 citations, is the leading author, followed by Mohammad F., with 1663 citations (Figure 6).

![Most Relevant Authors](image)

**Figure 5.** The most relevant authors. The x-axis indicates the number of documents; the y-axis indicates the authors’ names. Montazer M. leads with a total of 71 documents.
3.6. Most Frequent Words

The most frequent words used in the literature from 1998 to date were “textiles”, which led with a total count of 597, followed by “nanoparticles”, with a total count of 457, and “antibacterial”, with a total count of 445 (Figure 7).

3.7. Word Cloud of KeyWords Plus

The co-occurrence network was generated using the KeyWords Plus. The most relevant words were “textiles” with a frequency of 597, “cotton” with a frequency of 286, and “fibers” and “fabrics” with a frequency of 282 each, as shown in Figure 8.
3.8. Most Cited Countries

We analyzed the data to identify the leading countries that have produced the most publications. We found that China was at the top, with a total of 12,985 citations having 1678 scientific productions, followed by India, with a total of 10,038 citations and 1080 scientific productions. Iran stands in the third position with a total of 8883 citations and 544 documents, as shown in Figure 9 and Table 2.

![Figure 8. Word cloud of KeyWords Plus. Textiles, with a frequency of 597, is the leading term, followed by cotton.](image1)

![Figure 9. Most cited countries. The x-axis indicates the total number of citations; the y-axis shows the names of the countries. Only the top 10 countries were selected.](image2)

**Table 2. Country frequency in terms of scientific production.**

| Country  | Frequency |
|----------|-----------|
| China    | 1678      |
| India    | 1080      |
| Egypt    | 610       |
| Iran     | 544       |
| USA      | 531       |
| Turkey   | 362       |
| Pakistan | 310       |
| Italy    | 263       |
| Romania  | 253       |
| France   | 245       |
3.9. Most Globally Cited Documents

We found that "Antibacterial properties of nanoparticles", a review article by Hajipour M. J. et al., 2012, is the most cited document in this field, published in the journal *Trends in Biotechnology* [49]. This article is a review of the literature about antimicrobial activity in multiple fields. The authors also mention the importance of nanoparticles in antimicrobial activities. So far, this article has been cited in 1511 documents (Table 3).

| Title                                           | Authors         | Journal                  | Total Citations | TC (Year) | Reference |
|-------------------------------------------------|-----------------|--------------------------|-----------------|-----------|-----------|
| Antibacterial properties of nanoparticles        | Hajipour MJ et al. | *Trends Biotechnol.*, 2012 | 1511            | 137.36    | [49]      |
| Nanosilver: A nanoproduct in medical application | Chen X et al.   | *Toxicol. Lett.*, 2008   | 1357            | 90.47     | [50]      |
| The Chemistry and Applications of Antimicrobial Polymers: A State-of-the-Art Review | Kenawy ER et al. | *Biomacromolecules*, 2007 | 1165            | 72.81     | [51]      |
| Curcumin: the Indian solid gold                  | Dastjerdi R et al. | *Colloid Surface B*, 2010 | 934             | 71.85     | [52]      |

3.10. Most Relevant Authors and Authors’ Production over Time

We found that Montazer M. is the most relevant author, with a total of 71 documents, followed by Simoncic B. and Ibrahim N. A., with a total of 34 documents for each author (Figure 10). Similarly, we analyzed the data to identify the authors’ production over time. We found that Montazer M. published two articles in 2007 and received 10.94 citations. A significant boost was seen in his production in 2017, when he published nine articles in a calendar year (Figure 11).

![Figure 10. Most relevant authors. The x-axis indicates the number of documents; the y-axis indicates the authors’ names.](image-url)
3.11. Most Relevant Sources

The most relevant sources were *Fibers and Polymers*, with a total of 156 documents, followed by *Cellulose* with a total of 137 documents and *The Journal of The Textile Institute* with a total of 104 documents, as shown in Figure 12. Similarly, the source of local impact was found. *Carbohydrate Polymers*, with an H-index of 43, is the most impactful source, followed by *Applied Surface Science*, as provided in Figure 13.

![Figure 11. Authors’ production over time. The x-axis indicates the year; the y-axis indicates the authors’ names. The circle size shows the number of articles.](image1)

![Figure 12. Most relevant sources. The x-axis shows the number of documents; the y-axis indicates the source name.](image2)

![Figure 13. Source local impact based on H-index. The x-axis indicates the H-index measurement; the y-axis shows the source name.](image3)
3.12. Authors and Keywords

We identified the links between the authors, keywords, and sources. The most impactful author was Montazer M., and the most impactful source was Cellulose. The most frequent keyword was “cotton”, followed by “antimicrobial”, as shown in Figure 14.

![Figure 14. Links between authors, keywords, and sources.](image)

3.13. Trending Topics

We analyzed the data to extract the trending topics from titles and abstracts. From the titles, “antibacterial” was the most trending topic, with a total frequency of 908. The second most trending topic was “antimicrobial”, which appeared 690 times in the literature, as shown in Figure 15. The trending topics extracted from the abstracts were “antibacterial”, with a frequency of 4299, followed by “fabrics”, with a frequency of 3718, as shown in Figure 16. The other trending topics extracted from the abstracts were “properties”, “antimicrobial”, “activity”, “surface”, and so on.

![Figure 15. Trending topics extracted from titles. “Antibacterial”, with a total frequency of 908, was the most trending topic, followed by “antimicrobial”, with a total frequency of 690. The x-axis shows the years; the y-axis shows the topic. The circle size indicates the frequency.](image)
4. Discussion

Bibliometric analysis has been gaining immense recognition in research in multiple fields [19,21–23,31,53,54]. This research method can reveal the distribution patterns of articles published in databases within a given topic, field, institution, and country. Several databases can be used to retrieve the raw data for bibliometric analysis, such as Scopus, Web of Science, etc. The Science Citation Index Expanded from the Web of Science Core Collection of Clarivate Analytics (previously known as Thomson Reuters) is the most valuable and widely used data repository for analyzing scientific achievements across all research fields. Bibliometric analysis helps in deciphering and mapping the cumulative scientific knowledge and evolutionary nuances of well-established areas by making sense of large volumes of unstructured data in rigorous ways. In this study, we extracted the raw data from the Web of Science Core Collection. The documents, from a total of 878 sources, were published from 1998 to 2022.

A total of 3625 documents were found, and 2898 were articles. A total of 11,192 authors have contributed to this research field. We used the Bibliometrix sub-tool Biblioshiny and extracted the documents’ basic information. We found a sizeable increase in the number of publications each year, with an annual growth rate of 26.27%. Almost every scientific field has significantly increased [55,56]. Our data date back to 1998, and only one document was published that year. From 1999 to 2002, not a single document was published. In 2003, one document was added to the literature. Not a single document was published for the next three years. However, there was a boost in 2007, when a total of 53 documents were added to the literature, followed by 79 documents in 2008. There has been a continuous increase in the documents published each year. In 2021, a total of 534 documents were published, and by mid-2022, a total of 228 documents had been added to the literature. As more and more research has been performed with time, the citations of the articles are boosted. In the beginning of the period under study, there were few articles, and there was a decline in the literature. In 1998, there was only one citation; no citation was available from 1999 to 2002. In 2007, we observed exponential growth in the number of citations, as presented in Figure 3. There was a steep rise in citations during the calendar year 2022. The National Research Center, Egypt (NATL RES CTR), has published 260 documents, the leading institute among all. China is the top country in terms of the corresponding authors, with a total number of 278 multiple-country publication (MCP) documents and 1118 single-country publication (SCP) documents, followed by India with an MCP of 150 documents and an SCP of 780 documents. Montazer M. was the most impactful author, with a total of 6588 citations, followed by Mohammad M., with a total of 3326 citations. The most frequently used word in the literature from 1998 to date is “textiles”, leading with a total.
count of 1160, followed by “nanoparticles” with a total count of 888 and antibacterial with a total count of 848. Overall, nanotechnology, including nanofibers, has been useful for anti-bacterial textiles [57,58]. The high number of publications shows that the policies and funding agencies in certain countries are interested in exploring this particular research area. Thus, reporting a country’s frequency of scientific production is significant. We found that China was at the top, with a total of 25,970 citations having 3356 scientific productions, followed by India, with a total of 20,076 citations and 2160 scientific productions. The most relevant sources were Fibers and Polymers, with a total of 312 documents, followed by Cellulose with 274 and The Journal of The Textile Institute with 208.

5. Summary

5.1. Conclusions

This study summarizes the importance of antibacterial textiles and suggests that antibacterial textiles have been an important research topic over the past two decades. Our thematic analysis showed that introducing nanoparticles to textile materials is the most common approach for making antibacterial textiles. Bibliometric research is helpful for deciphering and mapping the cumulative scientific knowledge and evolutionary nuances of well-established fields by making sense of large volumes of unstructured data in rigorous ways. With an annual growth rate of 26.27%, we have seen a considerable boost in the literature. We suggest that a future study use multiple databases to extract data for analysis. As for every study, this research has certain limitations, as we focused only on data from WoS; thus, there might be some variation in the results if the data are taken from other sources. This study does not contain any information about reviewers or top editors in this field—since open publishing is being appreciated worldwide, we intend to analyze the information on reviewers and editors in the future.

5.2. Implications

With the rapid growth of publications worldwide in every field of science and technology, it has become difficult for researchers to read all papers and predict research trends. Bibliometric analysis is an effective way to precisely cover a wide field to predict research trends. For instance, in this study, we learned that silver nanoparticles have been widely explored for antimicrobial applications and used mostly on cotton fiber. Moreover, chitosan treatments are also widely used after the nanocoating finishing of textile materials. Thus, this study would be useful for new researchers looking to choose an appropriate approach. Moreover, it will help industrialists endorse the technology being studied the most. In addition, this work can be useful for funding agencies to gauge the influence and research gaps at a short glance, as this study summarizes numerous research works in one place.

5.3. Limitations and Future Research Directions

As with every scientific work, this study also has some limitations; for example, this study only covers the articles published on the Web of Science and thus overlooks many valuable works in other databases. Moreover, this study does not review the works of various authors, as often presented in review papers—it only analyzes research trends in the given field. Additionally, we did not analyze who reviewed the papers, such as who was the most influential reviewer in the given field. Furthermore, this study does not discuss whether the citations were self-citations and citations pushed by friends and workmates. Moreover, we did not discuss the usage count of the articles. A detailed study covering all these areas might be worth conducting to analyze the research direction more effectively. In addition, different tools or software might yield different results, and a comparison could be made. Finally, a similar field could be investigated by changing some keywords related to this research direction.

Author Contributions: Conceptualization, H.H. and H.M.; methodology, H.H.; software, H.H.; validation, H.H.; formal analysis, H.H.; investigation, H.H.; resources, H.H.; data curation, H.H.;
writing—original draft preparation, H.H.; writing—review and editing, H.M. and T.G.; visualization, H.H. and T.G.; supervision, T.G.; project administration, T.G. and H.M.; funding acquisition, H.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was supported by the Research Fund for International Scientists (RFIS-52150410416) and National Natural Science Foundation of China (no. 61673007).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data can be provided by corresponding author on request.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**

1. Wang, W.-Y.; Chiou, J.-C.; Yip, J.; Yung, K.-F.; Kan, C.-W. Development of Durable Antibacterial Textile Fabrics for Potential Application in Healthcare Environment. *Coatings* **2020**, *10*, 520. [CrossRef]

2. Kumar, M.N.R. A review of chitin and chitosan applications. *React. Funct. Polym.* **2000**, *46*, 1–27. [CrossRef]

3. Gupta, D.; Haile, A. Multifunctional properties of cotton fabric treated with chitosan and carboxymethyl chitosan. *Carbohydr. Polym.* **2007**, *69*, 164–171. [CrossRef]

4. Lan, S.; Zhang, J.; Li, J.; Guo, Y.; Sheng, X.; Dong, A. An N-Halamine/Graphene Oxide-Functionalized Electrospun Polymer Membrane That Inactivates Bacteria on Contact and by Releasing Active Chlorine. *Polymers* **2021**, *13*, 2784. [CrossRef]

5. Yuan, G.; Cranston, R. Recent Advances in Antimicrobial Treatments of Textiles. *Text. Res. J.* **2008**, *78*, 60–72. [CrossRef]

6. Granados, A.; Pleixats, R.; Vallribera, A. Recent Advances on Antimicrobial and Anti-Inflammatory Cotton Fabrics Containing Nanostructures. *Molecules* **2021**, *26*, 3008. [CrossRef]

7. Xue, C.-H.; Chen, J.; Yin, W.; Jia, S.-T.; Ma, J.-Z. Superhydrophobic conductive textiles with antibacterial property by coating fibers with silver nanoparticles. *Appl. Surf. Sci.* **2012**, *258*, 2468–2472. [CrossRef]

8. Broadhead, R.; Craeye, L.; Callweaert, C. The Future of Functional Clothing for an Improved Skin and Textile Microbiome Relationship. *Microorganisms* **2021**, *9*, 1192. [CrossRef]

9. Correia, J.; Rainert, K.T.; Oliveira, F.R.; de Cássia Siqueira Curto Valle, R.; Valle, J.A.B. Cationization of cotton fiber: An integrated view of cationic agents, processes variables, properties, market and future prospects. *Cellulose* **2020**, *27*, 8527–8550. [CrossRef]

10. Kramer, A.; Guggenbichler, P.; Heldt, P.; Jünger, M.; Ladwig, A.; Thierbach, H.; Weber, U.; Daeschlein, G. Hygienic relevance and risk assessment of antimicrobial-impregnated textiles. *Biofunct. Text. Ski.* **2006**, *33*, 78–109.

11. Bajpai, V.; Bajpai, S.; Jha, M.K.; Dey, A.; Ghosh, S. Microbial adherence on textile materials: A review. *J. Environ. Res. Dev.* **2011**, *5*, 666–672.

12. Lugoloobi, I.; Shahriari Khalaji, M.; Memon, H. Advanced Biological Applications of Modified Cotton. In *Cotton Science and Processing Technology: Gene, Ginning, Garment and Green Recycling*; Wang, H., Memon, H., Eds.; Springer: Singapore, 2020; pp. 473–500.

13. Lugoloobi, I.; Tebyetekerwa, M.; Memon, H.; Sun, C. Advanced Chemical Applications of Modified Cotton. In *Cotton Science and Processing Technology: Gene, Ginning, Garment and Green Recycling*; Wang, H., Memon, H., Eds.; Springer: Singapore, 2020; pp. 501–527.

14. Memon, H.; Wang, H.; Yasin, S.; Halepoto, A. Influence of Incorporating Silver Nanoparticles in Protease Treatment on Fiber Friction, Antistatic, and Antibacterial Properties of Wool Fibers. *J. Chem.* **2018**, *2018*, 4845687. [CrossRef]

15. Liu, Y.; Hussain, M.; Memon, H.; Yasin, S. Solar irradiation and Nageia nagi extract assisted rapid synthesis of silver nanoparticles and their antibacterial activity. *Dig. J. Nanomater. Biostuct.* **2015**, *10*, 1019–1024.

16. Salazar-Alemán, D.A.; Turner, R.J. Metal Based Antimicrobials: Uses and Challenges. In *Microbial Metabolism of Metals and Metalloids*; Hurst, C.J., Ed.; Springer International Publishing: Cham, Switzerland, 2022; pp. 77–106.

17. Simoncic, B.; Tomsic, B. Structures of novel antimicrobial agents for textiles—A review. *Text. Res. J.* **2010**, *80*, 1721–1737. [CrossRef]

18. Chen, S.; Chen, S.; Jiang, S.; Xiong, M.; Luo, J.; Tang, J.; Ge, Z. Environmentally Friendly Antibacterial Cotton Textiles Finished with Siloxane Sulfopropylbetaine. *ACS Appl. Mater. Interfaces* **2011**, *3*, 1154–1162. [CrossRef]

19. Yafetto, L. Application of solid-state fermentation by microbial biotechnology for bioprocessing of agro-industrial wastes from 1970 to 2020: A review and bibliometric analysis. *Heliyon* **2022**, *8*, e09173. [CrossRef]

20. Ho, Y.-S.; Fahad Halim, A.F.M.; Islam, M.T. The Trend of Bacterial Nanocellulose Research Published in the Science Citation Index Expanded From 2005 to 2020: A Bibliometric Analysis. *Front. Bioeng. Biotechnol.* **2022**, *9*, 795341. [CrossRef]

21. Han, M.-C.; Cai, S.-Z.; Wang, J.; He, H.-W. Single-Side Superhydrophobicity in Si3N4-Doped and SiO2-Treated Polypropylene Nonwoven Webs with Antibacterial Activity. *Polymers* **2022**, *14*, 2952. [CrossRef]

22. Borregan-Alvarado, J.; Alvarez-Meaza, I.; Cilleruelo-Carrasco, E.; Garechana-Anacabe, G. A Bibliometric Analysis in Industry 4.0 and Advanced Manufacturing: What about the Sustainable Supply Chain? *Sustainability* **2020**, *12*, 7840. [CrossRef]

23. Provin, A.P.; dos Reis, V.O.; Hillesheim, S.E.; Bianchet, R.T.; de Aguiar Dutra, A.R.; Cubas, A.L.V. Use of bacterial cellulose in the textile industry and the wettabiliy challenge—A review. *Cellulose* **2021**, *28*, 8255–8274. [CrossRef]
24. Kuilang, Y.; Qian, X. Research on the innovation frontier of global intelligent textile technology based on patentometrics. *J. Silk* 2021, 58, 48–55. [CrossRef]

25. Noor, S.; Guo, Y.; Shah, S.H.H.; Halepoto, H. Bibliometric Analysis of Twitter Knowledge Management Publications Related to Health Promotion. In Proceedings of the 13th International Conference, Hangzhou, China, 28–30 August 2020, pp. 341–354.

26. Syed Hamd Hassan, S.; Saleha, N.; Atif Saleem, B.; Habiba, H. Twitter Research Synthesis for Health Promotion: A Bibliometric Analysis. *Iran. J. Public Health* 2021, 50, 2283–2291. [CrossRef]

27. Xiang, F.; Xiaopeng, W.; Xiaoxiao, Q.; Laili, W. Bibliometric analysis of literatures on textile and clothing footprint based on CiteSpace. *Adv. Text. Technol.* 2022, 30, 9–17. [CrossRef]

28. Mei, P.; Lizhu, G.; Zili, K.; Lan, Z. Research review and prospects of VOSviewer-based textile plant dyeing. *J. Silk* 2021, 58, 53–59. [CrossRef]

29. Halepoto, H.; Gong, T.; Noor, S.; Memon, H. Bibliometric Analysis of Artificial Intelligence in Textiles. *Materials* 2022, 15, 2910. [CrossRef]

30. Xizhen, L.; Zhiqin, S. Research on the knowledge map and visualization of fashion design field in China based on CiteSpace. *J. Silk* 2020, 57, 25–34. [CrossRef]

31. Abuhasna, H.; Awae, F.; Bayouni, K.; Alzitawi, D.U.; Alsharif, A.H.; Yahaya, N. Understanding Online Learning Readiness among University Students: A Bibliometric Analysis. *Int. J. Interact. Mob. Technol.* 2022, 16, 81–94. [CrossRef]

32. Alsharif, A.H.; Md Salleh, N.Z.; Baharun, R.; Rami Hashem, E.A. Neumorrospection research in the last five years: A bibliometric analysis. *Cognet Bus. Manag.* 2021, 8, 197620. [CrossRef]

33. Ali, J.; Jusoh, A.; Idris, N.; Abbas, A.F.; Alsharif, A.H. Nine Years of Mobile Healthcare Research: A Bibliometric Analysis. *Int. J. Online Biomed. Eng.* 2021, 17, 144–159. [CrossRef]

34. Omotayo, T.; Moghayayed, A.; Avuzie, B.; Ajayi, S. Infrastructure elements for smart campuses: A bibliometric analysis. *Sustainability* 2021, 13, 7960. [CrossRef]

35. Wilk, V.; Cripps, H.; Capatina, A.; Micu, A.; Micu, A.-E. The status of the digitalentrepreneurship: A big data Leximancer analysis of social media activity. *Int. Entrep. Manag. J.* 2021, 17, 1899–1916.

36. Khan, S.; Rana, S.; Goel, A. Presence of digital sources in the international market: A review of literature using Leximancer. *Int. J. Technol. Mark.* 2022, 16, 246–274. [CrossRef]

37. Van Eck, N.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* 2010, 84, 523–538. [CrossRef]

38. Donthu, N.; Kumar, S.; Pandey, N.; Lim, W.M. Research constituents, intellectual structure, and collaboration patterns in Journal of International Marketing: An analytical retrospective. *J. Int. Mark.* 2021, 29, 1–25. [CrossRef]

39. Verma, S.; Gustafsson, A. Investigating the emerging COVID-19 research trends in the field of business and management: A bibliometric analysis approach. *J. Bus. Res.* 2020, 118, 253–261. [CrossRef]

40. Brown, T.; Park, A.; Pitt, L. A 60-Year Bibliographic Review Of the Journal of Advertising Research Perspectives on Trends in Authorship, Influences, and Research Impact. *J. Advert. Res.* 2020, 60, 353–360. [CrossRef]

41. Fernandes, M.; Souto, A.P.; Dourado, F.; Gama, M. Application of Bacterial Cellulose in the Textile and Shoe Industry: Development of Biocomposites. *Polysaccharides* 2021, 2, 566–581. [CrossRef]

42. AlRyalat, S.A.S.; Malkawi, L.W.; Momani, S.M. Comparing bibliometric analysis using PubMed, Scopus, and Web of Science databases. *JoVE J. Vis. Exp.* 2019, 152, e58494. [CrossRef]

43. Khudhair, H.Y.; Jusoh, D.; Bin, A.; Abbas, A.F.; Mardani, A.; Nor, K.M. A review and bibliometric analysis of service quality and customer satisfaction by using Scopus database. *Int. J. Manag.* 2020, 11, 459–470.

44. Chen, X.; Yunhe, H. Analysis of public concern on traditional dyeing and printing techniques based on Baidu index. *J. Silk* 2020, 57, 41108.

45. Hansen, W.; Jianfang, L. The impact of COVID-19 on the attention to sustainable clothing consumption: Analysis of Baidu indexes on old clothes recycling, old clothes renovation and old clothes donation. *J. Silk* 2021, 58, 40–46. [CrossRef]

46. Aria, M.; Misuraca, M.; Spano, M. Mapping the Evolution of Social Research and Data Science on 30 Years of Social Indicators Research. *Soc. Indic. Res.* 2020, 149, 803–831. [CrossRef]

47. Aria, M.; Cucurullo, C. Bibliometrics: An R-tool for comprehensive science mapping analysis. *J. Informetr.* 2017, 11, 959–975. [CrossRef]

48. Koo, M. Systemic Lupus Erythematosus Research: A Bibliometric Analysis over a 50-Year Period. *Int. J. Environ. Res. Public Health* 2021, 18, 7095. [CrossRef]

49. Haipour, M.J.; Fromm, K.M.; Ashkarran, A.A.; Jimenez de Aberasturi, D.; de Larramendi, I.R.; Rojo, T.; Serpooshan, V.; Parak, W.J.; Mahmoudi, M. Antibacterial properties of nanoparticles. *Trends Biotechnol.* 2012, 30, 499–511. [CrossRef]

50. Chen, X.; Schlesener, H.J. Nanosilver: A nanoproduct in medical application. *Toxicol. Lett.* 2008, 176, 1–12. [CrossRef]

51. Kenawy, E.-R.; Worley, S.D.; Broughton, R. The Chemistry and Applications of Antimicrobial Polymers: A State-of-the-Art Review. *Biomacromolecules* 2007, 8, 1359–1384. [CrossRef]

52. Dastjerdi, R.; Montazer, M. A review on the application of inorganic nano-structured materials in the modification of textiles: Focus on anti-microbial properties. *Colloids Surf. B Biointerfaces* 2010, 79, 5–18. [CrossRef]

53. Khan, M.A.; Pattnaik, D.; Ashraf, R.; Ali, I.; Kumar, S.; Donthu, N. Value of special issues in the journal of business research: A bibliometric analysis. *J. Bus. Res.* 2021, 125, 295–313. [CrossRef]
54. Alsharif, A.H.; Salleh, N.Z.M.; Baharun, R.; Abuhassna, H.; Hashem, E.A.R. Tendencias globales de investigación en neuromarketing: 2015–2020. Rev. Comun. 2022, 21, 15–32.

55. Yu, Y.; Li, Y.; Zhang, Z.; Gu, Z.; Zhong, H.; Zha, Q.; Yang, L.; Zhu, C.; Chen, E. A bibliometric analysis using VOSviewer of publications on COVID-19. Ann. Transl. Med. 2020, 8, 816. [CrossRef] [PubMed]

56. Cascella, M.; Monaco, F.; Nocerino, D.; Chinè, E.; Carpenedo, R.; Picerno, P.; Migliaccio, L.; Armignacco, A.; Franceschini, G.; Coluccia, S.; et al. Bibliometric Network Analysis on Rapid-Onset Opioids for Breakthrough Cancer Pain Treatment. J. Pain Symptom Manag. 2022, 63, 1041–1050. [CrossRef] [PubMed]

57. Fouda, M.M.G.; Abdel-Halim, E.S.; Al-Deyab, S.S. Antibacterial modification of cotton using nanotechnology. Carbohydr. Polym. 2013, 92, 943–954. [CrossRef]

58. Qiu, Q.; Chen, S.; Li, Y.; Yang, Y.; Zhang, H.; Quan, Z.; Qin, X.; Wang, R.; Yu, J. Functional nanofibers embedded into textiles for durable antibacterial properties. Chem. Eng. J. 2020, 384, 123241. [CrossRef]