coatings

MDPI

Review

Bibliometric Evidence on the Trend and Future Direction of the Research on Textile Coloration with Natural Sources

Md. Abdullah Al Mamun [1], Aminoddin Haji [2], Md. Himel Mahmud [3], Md. Reazuddin Repon [4,5] and Mohammad Tajul Islam [3,*]

[1] Department of Marketing and Management, Szechenyi Istvan University, 9026 Gyor, Hungary
[2] Department of Textile Engineering, Yazd University, Yazd 8915818411, Iran
[3] Department of Textile Engineering, Ahsanullah University of Science and Technology, Dhaka 1208, Bangladesh
[4] Department of Production Engineering, Faculty of Mechanical Engineering and Design, Kaunas University of Technology, Studentų 56, LT-51424 Kaunas, Lithuania
[5] ZR Research Institute for Advanced Materials, Sherpur 2100, Bangladesh
* Correspondence: tajul.dtt@aust.edu

Abstract: Synthetic dyes used for the coloration of textile goods are not readily biodegradable and are a major concern for water pollution. Nature has abundant sources of potential colorants for textile applications. There are many challenges in textile coloration using natural dyes and pigments, and significant research efforts are currently put into replacing synthetic textile dyes successfully. In order to gain insight into the future trajectory of dyeing research utilizing natural colorants, a bibliometric analysis from 1990 to 2021 using the Science Citation Index Expanded database was conducted. The analysis focused on how well the publication performed in terms of outputs and citations annually, mainstream journals, Web of Science categories, top universities, top nations, research trends, and hotspots. An overview of the most frequently used keywords derived from terms in the article title analysis, authors' keyword analysis, and KeyWords Plus analysis served as the foundation for determining current research goals and future trends. The findings indicated that no noteworthy research on this topic was conducted in the final decade of the previous century but that it did begin to get the attention of scholars in the first decade of this century. The use of natural dyes in industry has significantly expanded during the past ten years. "Fastness" is the interest point that has received the most attention. Mordants, or environmentally friendly extraction techniques such as ultrasonic, gamma irradiation, etc., represent the future of this research area. On the other hand, ultraviolet protection and antibacterial or antimicrobial properties are becoming more and more popular in the field of textile dyeing research using natural colorants.

Keywords: natural dye; sustainable dyeing; green coloration; extraction

Citation: Mamun, M.A.A.; Haji, A.; Mahmud, M.H.; Repon, M.R.; Islam, M.T. Bibliometric Evidence on the Trend and Future Direction of the Research on Textile Coloration with Natural Sources. *Coatings* **2023**, *13*, 413. https://doi.org/10.3390/coatings13020413

Academic Editor: Chi-wai Kan

Received: 28 December 2022
Revised: 4 February 2023
Accepted: 10 February 2023
Published: 12 February 2023

1. Introduction

Coloration is an essential step of the textile value chain where textile goods are dyed or printed to increase their fashion value. The textile coloration process involves specific steps including pretreatment, dyeing or printing, and finishing. All these steps require a large volume of water, resulting in wastewater containing a wide range of unused chemicals such as surface-active agents, dyes, pigments, thickeners, and softeners. Synthetic dyes and pigments of textile wastewater are toxic in nature and are not biodegradable. The acknowledgment of the persisting environmental issues and consequences of various industrial processes and practices has generated awareness of the need to search for sustainable and eco-friendly options or redesign existing methods [1]. Strict environmental regulations have promoted research in sustainable chemicals for textile coloration [2] and the substitution of harmful substances in the pretreatment [3], dyeing [4,5], printing [6], and finishing [7] of textile materials. Synthetic dyes and pigments are generally not biodegradable and are harmful to the environment. Given their continued use, researchers are trying to find suitable natural alternatives for the dyeing of nylon, wool, silk, cotton, leather, and other textile materials that traditionally use harmful and toxic synthetic colorants [8]. A wide range of colorants is available in nature that can be extracted for textile coloration purposes [9]. Natural dyes and pigments have received significant attention from researchers for textile coloration due to their environmentally benign nature. Although natural dyes and pigments are a more environmentally friendly option, there are some challenges in using natural colorants in textile coloration. Natural dyes and pigments are often time-consuming and labor-intensive to extract. The extraction yield (%) is generally low, making it economically unappealing for large-scale textile coloration [10]. Furthermore, the fastness properties of naturally dyed material are unsatisfactory. As a result, continuous research is being conducted worldwide to replace synthetic textile dyes and pigments with natural colorants.

An effective tool for mapping the body of research on a particular subject is bibliometrics. It has lately been used to follow the development of research in particular fields of inquiry, including coloring research [11], bacterial nanocellulose [12], and research on wound dressing [13]. Bibliometrics is a common research methodology in the library and information sciences and focuses on quantitative analysis and statistics. This research technique can show the distribution patterns of articles published in the database within a certain subject, industry, setting, and nation. The most valuable and frequently used data source for examining scientific accomplishments across all disciplines of study is the Science Citation Index Expanded (SCI-EXPANDED) from the Web of Science Core Collection of Clarivate Analytics (formerly known as Thomson Reuters).

To the best of our knowledge, the published literature does not provide a bibliometric study of natural-source textile coloring research. To better grasp the state of global research in this area, the last three decades of study on textile colors from natural sources were evaluated. The results of this bibliometric analysis can also be used to establish medium- and long-term plans for the study of natural colorants for textile coloring. The study synthesized quantitative descriptions of publications across major journals, Web of Science categories, annual outputs, top countries, and premier institutions. It also included hotspots for research that were discovered through assessments of paper titles, author keywords, and KeyWords Plus.

2. Data and Bibliometric Methods

SCI-EXPANDED Web of Science in Clarivate Analytics served as the source of the study's data (updated on 8 October 2022). On 28 June 2022, Journal Citation Reports published a report with the journal impact factors for 2021. In accordance with the definition of the journal impact factor, it is preferable to gather the articles published in 2021 from SCI-EXPANDED after 30 June 2022. SCI-EXPANDED was developed primarily to help scholars locate and explore the literature, but it does not provide data in a format that is easily accessible for bibliometric analyses [14]. Hence, bibliometric investigations require data mining, gathering, and preparation directly from SCI-EXPANDED. Recently, in utilizing the paper's title, abstract, and author keywords as a filter in commonly used bibliometric research, a significant difference was discovered [15]. By sifting through the titles of publications that writers in the ISI (now Clarivate Analytics) database cite in their bibliographies and footnotes to extract additional search terms, KeyWords Plus can supplement and improve title-word and author-keyword indexing [16]. The fact that papers could only be searched using KeyWords Plus was considered, and these documents had nothing to do with the topic searched [17]. The terms of the topic in the SCI-EXPANDED were searched using the keywords "dyeing," "dying," "printing," "printed," "fabric," "yarn," "fabrics," and "yarns," as well as "natural" and "naturally." From 2002 to 2021, 1183 documents were produced, of which 42 documents or 3.5% lacked search terms on their "first page." The term "textile coloring with natural sources publications" was only used to describe 1141 documents. In order to analyze these records, a spreadsheet was imported and further manual coding was carried out using Microsoft Excel 2016 [18]. Additionally, the 2022 Journal Citation Reports were used to obtain each journal's impact factor (IF2021).

In SCI-EXPANDED, the author of the communication is identified as a reprint author. In this study, however, we used the phrase "corresponding author." Whenever there were numerous corresponding authors for an article, just the first corresponding author's name, institution, and nation were listed as the corresponding author information. The single author was regarded as both the first and corresponding author in a single-author paper when the corresponding authorship was not declared. Similar to this, the institution of the first and corresponding author was identified in articles with only one institution. The citations that the publications obtained were examined using the following four citation metrics:

C_0: the total count of Web of Science Core Collection citations in the publishing year [19].

C_{year}: the total number of citations (in a particular year) from the Web of Science Core Collection. C_{2021} means the number of citations in 2021 [20].

TC_{year}: the total number of citations from the Web of Science Core Collection since publication year to the end of the most recent year [21]. In this study, the most recent year is 2021 (TC_{2021}).

CPP_{year}: citations per publication ($CPP_{2021} = TC_{2021}/TP$) [20], where TP is total number of articles.

3. Results and Discussion

3.1. Document Type and Language of Publication

The relationship between document type and citations per publication has allegedly been established [22]. By using the CPP_{year} citation indicator, which provides more precise statistics, the citations per article were increased in 2015 [23]. Recently, the term "number of authors per publication" (*APP*) has been employed in relation to several document types. The characteristics of six different document kinds are shown in Table 1, including 966 articles (84% of the total 1141 documents), which have an *APP* of 4.1. Eighteen authors made up Rizwanullah et al.'s [24] publication on textile color from natural sources, which had the most contributors overall. Due to three highly cited documents, the document type of the review scored the highest CPP_{2021}, which was 53.3. These are the articles with a TC_{2021} of 100 or more by Shahid et al. [25], Shahid ul et al. [26], and Yusuf et al. [9] with a TC_{2020} of 427, 161, and 136, respectively.

Table 1. Citations and authors according to document type.

Document Type	*TP*	*TP* *	%	*AU*	*APP*	TC_{2021}	CPP_{2021}
Article	966	966	84.7	3941	4.1	13688	14.2
Book Review	1	1	0.1	1	1	0	0
Data Paper	1	1	0.1	3	3	5	5
News Item	1	1	0.1	1	1	0	0
Proceedings Paper	152	152	13.3	526	3.5	194	1.3
Review	20	20	1.8	71	3.6	1066	53.3

TP: number of publications; *TP* *: number of publications with author information in SCI-EXPANDED; *AU*: number of authors; *APP*: number of authors per publication; TC_{2021}: the total number of citations from Web of Science Core Collection since publication year to the end of 2021; CPP_{2021}: number of citations (TC_{2021}) per publication (*TP*).

The CPP_{2021} of the reviews was almost four times the CPP_{2021} of the articles. A total of 20 reviews were published widely in 15 journals, mainly in the *Journal of Cleaner Production* (5 reviews; 25% of 20 reviews). The articles as a document type had the second highest CPP_{2021} of 14.2. Three classic articles with a TC_{2021} of 150 or more [27] were published by Han et al. [28], Kamel et al. [29], and Cristea et al. [30] with a TC_{2021} of 256, 194, and 187, respectively. Moreover, studies on textile coloration with natural sources made up seven of the top ten most frequently cited publications. Notably, there are two groups of documents that can be found in the Web of Science Core Collection. For instance, 145 documents were categorized in the proceedings, papers, and articles document categories. As a result, the total of the percentages exceeds 100% [31].

Only 1141 papers in total of all document types were chosen for additional analysis because they comprised the complete body of research, including the introduction, methods, findings, discussions, and conclusions. The language of publication is one of the most crucial factors in bibliometric study as a huge data analysis [21]. These 1141 articles were written in a total of nine different languages. The majority of articles (98.6%) were written in English, with the next most prevalent languages being Japanese (5 articles; 0.44% of the 1141 articles), Chinese (2; 0.18%), Turkish (2; 0.18%), and Portuguese (2; 0.18%). Other languages included the following: Slovene (1), Serbo-Croatian (1), Spanish (1), and Slovenian (1). Those published in English had a much higher CPP_{2021} of 13 than all non-English articles with a CPP_{2021} of 6.8. Articles published in English had a higher *APP* of 4 than non-English articles with an *APP* of 3.1.

3.2. Characteristics of Publication Output

Members of the research team discussed the relationship between the total annual number of articles (*TP*) and their citations per publication ($CPP_{year} = TC_{year}/TP$) by years [32] to examine publications and their influence patterns in a research field. The distribution of *TP* and their citations per publication (CPP_{2021}), shown as TC_{2021}/TP in Figure 1, are shown year by year; 2005 had a *CPP* of 58.6 and 14 articles, which was the highest. The total number of widely referenced publications with a TC_{2021} of 150 or above that were published in 2005 was two, including one classic piece by [28] with a TC_{2021} of more than 250. With the exception of a few sporadic increases, CPP_{2021} has been on a downward trend since 2005, but *TP* has been rising at a quicker rate, reaching 165 in 2021. This suggests that researchers have given textile coloring using natural sources a lot of attention overall. Given how many more articles are published each year, it is reasonable to assume that the CPP_{year} will rise in the near future.

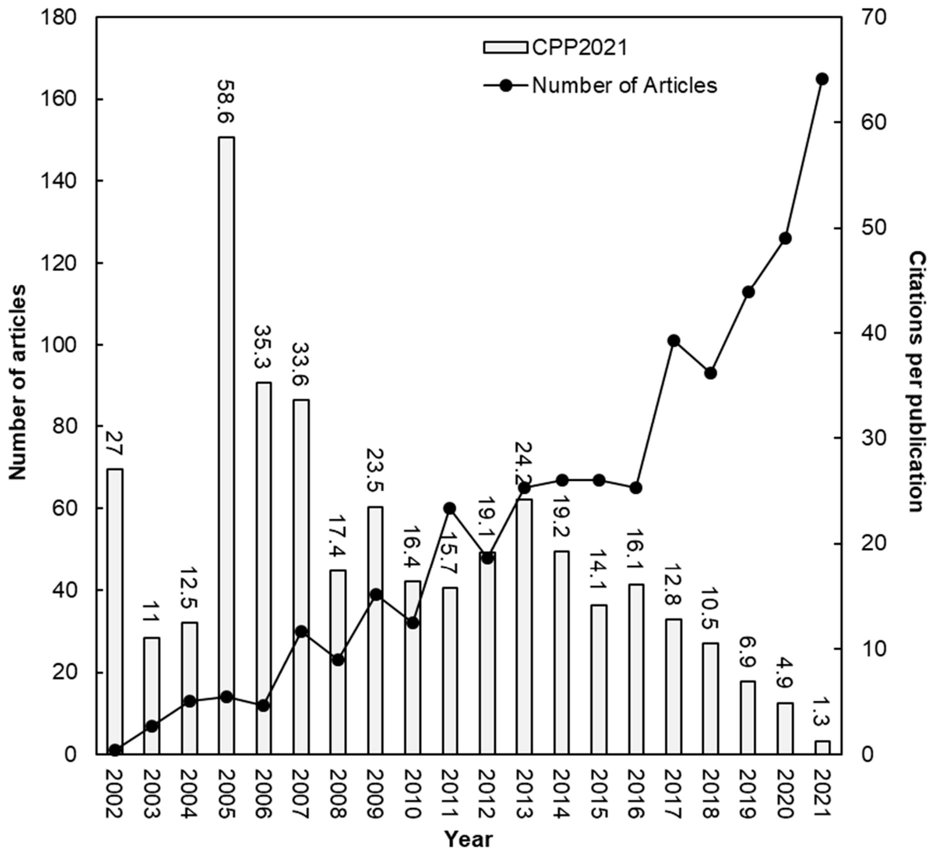

Figure 1. Number of articles and citations per publication by year.

3.3. Web of Science Categories and Journals

The 254 Web of Science categories in SCI-EXPANDED contained 21,494 journals that were indexed by Journal Citation Reports in 2021. To detect development trends between study disciplines and their interactions, a correlation between the number of articles in the categories and publication years was proposed [33]. The 1141 papers that were taken into consideration for this bibliometric analysis on textile coloring with natural sources were published in 312 journals under 167 different Web of Science categories in SCI-EXPANDED. In 2021, 64 journals published 163 papers; however, none of those publications had an impact factor. In 2020, these journals were not categorized in SCI-EXPANDED.

Table 2 shows the top 10 Web of Science categories. Textiles, which made up 338 of the 1141 articles in the Materials Science category on Web of Science, came in first, followed by Polymer Science (97, which made up 12.1%), and then Materials Science as a whole. Green and Sustainable Science and Technology publications on textile coloring with natural sources had the highest CPP_{2021} (CPP_{2021} = 42) when compared to the top 10 categories. The Applied Chemistry category had a high CPP_{2021} of 37 and produced 73 papers, placing third overall and accounting for 9.1% of the 1141 total articles. While the *APP* for Multidisciplinary Sciences was 3.6, it was 6 for Environmental Sciences. Journals listed in Web of Science can be divided into two or more categories. For instance, "Dyes and Pigments" is labeled under "Applied Chemistry," "Materials Science", "Engineering, Chemical", and "Textiles". The three categories stated above are also indexed for the Coloration Technology magazine. The growth of the top eight categories with 20 or more articles is shown in Figure 2. Environmental Sciences published the majority of articles before 2013. In the past ten years, studies on textile coloring from natural sources have primarily appeared in the category of Materials Science, Textiles. Heterogeneous areas including Materials Science, Textiles; Polymer Science, Chemistry, Applied; Engineering, Chemical; and Green and Sustainable Science and Technology have gained popularity recently and are placed second, third, and fourth in 2021, respectively. The Materials Science, Textiles category saw a total of 338 papers published (ranked first), with 70 articles appearing in 2021 (ranked 1st in 2021).

Table 2. The top 10 productive Web of Science categories.

Web of Science Category	*TP* (%)	TC_{2021}	CPP_{2021}	*AU*	*APP*
Materials Science, Textiles	338 (42.1)	2557	7.6	1290	3.8
Materials Science, Textiles; Polymer Science	97 (12.1)	1081	11.1	346	3.6
Chemistry, Applied; Engineering, Chemical; Materials Science, Textiles	73 (9.1)	2750	37.7	309	4.2
Green and Sustainable Science and Technology; Engineering, Environmental; Environmental Sciences	50 (6.2)	2116	42.3	218	4.4
Chemistry, Multidisciplinary	44 (5.4)	390	8.9	188	4.3
Agricultural Engineering; Agronomy	30 (3.7)	941	31.4	141	4.7
Multidisciplinary Sciences	24 (3)	123	5.1	87	3.6
Environmental Sciences	22 (2.7)	218	9.9	133	6
Polymer Science	22 (2.7)	362	16.5	87	4
Materials Science, Multidisciplinary	20 (2.5)	30	1.5	75	3.8

TP: number of publications; %: percentage of 1141 articles; TC_{2021}: the total number of citations from Web of Science Core Collection since publication year to the end of 2021; CPP_{2021}: number of citations (TC_{2021}) per publication (*TP*); *AU*: the total number of authors; *APP*: number of authors per publication.

The top five most productive journals were: *Journal of Natural Fibers* (IF2021 = 3.507) with 96 articles (8.4% of 1141 articles), *Fibers and Polymers* (IF2021 = 2.347) with 91 articles (7.9%), *Journal of Cleaner Production* (IF2021 = 11.072) with 46 articles (4.0%), *Coloration Technology* (IF2021 = 2.049) with 41 articles (3.6%), and *Journal of The Textile Institute* (IF2021 = 1.77) with 39 articles (3.4%).

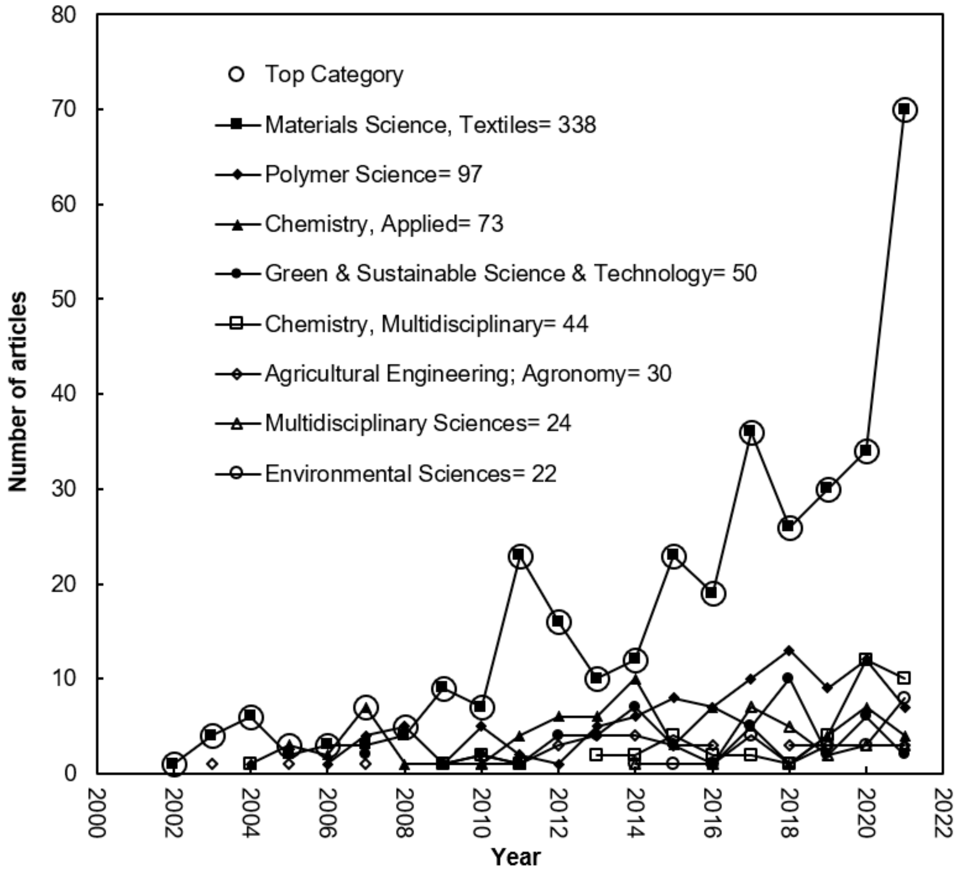

Figure 2. Developments of the top nine Web of Science categories.

3.4. Publication Performance: Countries and Institutions

Because 5 publications (0.42% of 1183 articles) lacked the authors' affiliation information in SCI-EXPANDED, they were not included in the analysis. Of the 1141 textile coloring with natural sources publications from 58 different nations, 178 (16%) were international collaborations, whereas 963 (84%) were single-country articles spanning 49 different countries. Table 3 lists the top 10 industrialized nations. The top ten list of publications included six Asian nations, two African nations, one transcontinental nation, and one American nation. Italy, with 34 articles, was ranked 12th; the top productive country in Europe.

Table 3. Top 10 productive countries.

Country	*TP*	*TPR* (%)	*TP* CPP_{2021}	*IPR* (%)	*CPR* (%)	*FPR* (%)	*FP* CPP_{2021}	*RPR* (%)	*RP* CPP_{2021}	*SPR* (%)
India	229	1 (20.1)	18.8	1 (21.2)	2 (14.7)	1 (19)	18.7	1 (19)	21.9	3 (9.2)
China	204	2 (17.9)	8.2	2 (15.9)	1 (30)	2 (16.7)	8	2 (16)	10.1	4 (7.7)
Turkey	93	3 (8.2)	7.9	3 (9.3)	10 (1.8)	3 (8.1)	8	3 (8.1)	3	1 (15.4)
Iran	83	4 (7.2)	16.3	4 (7.1)	6 (8.2)	4 (6.9)	16.6	4 (6.8)	12.4	2 (13.8)
Pakistan	77	5 (6.7)	15.6	5 (5.6)	4 (13.5)	5 (5.8)	17.4	5 (5.8)	7.7	N/A
Thailand	59	6 (5.2)	8.9	6 (5.2)	9 (5.3)	6 (5)	8.3	6 (5.1)	21.1	10 (4.6)
South Korea	58	7 (5.1)	14	8 (4.8)	7 (7.1)	8 (4.6)	14.9	7 (4.7)	8.8	5 (7.7)
Egypt	58	8 (5.1)	16.9	7 (4.9)	8 (5.9)	7 (4.8)	17.5	8 (4.4)	4.2	6 (6.2)
USA	45	9 (3.9)	22.5	11 (2.2)	3 (14.1)	10 (2)	28.8	11 (2.4)	16.9	7 (6.2)
Tunisia	43	10 (3.8)	15.3	10 (2.3)	5 (12.4)	9 (3.6)	16	9 (3.2)	15.1	18 (1.5)

TP: total number of articles; *TPR* (%): rank of total number of articles and percentage; *IPR* (%): rank of single-country articles and percentage in all single-country articles; *CPR* (%): rank of internationally collaborative articles and percentage in all internationally collaborative articles; *FPR* (%): rank of first-author articles and percentage in all first-author articles; *RPR* (%): rank of corresponding-author articles and percentage in all corresponding-author articles; *SPR* (%): rank of single-author articles and percentage in all single-author articles; CPP_{2021}: number of citations (TC_{2021}) per publication (*TP*).

Six metrics were utilized to compare publication performance: total number of papers (*TP*), articles published in a single nation (*IP*), articles written by several authors globally (*CP*), first-author articles (FP), corresponding-author articles (*RP*), and single-author articles (*SP*) [34] as well as their CPP_{2021}. India topped the four publication indicators, accounting for 229 articles (or 20% of 1141 papers), 204 articles (or 21% of 963 articles from a single nation), 217 articles (or 19% of 1141 first-author articles), and 217 articles (or 19% of 1132 publications with correlative authors). China came out on top in one publication indication with a *CP* of 51 articles (30% of 170 international collaborative publications), and Turkey came out on top in another with an *SP* of 10 articles (15% of 63 single-author articles). Thailand had the highest CPP_{2021} of RP, while the USA had the highest CPP_{2021} of TP and FP for textile coloring with natural sources articles compared to the top three countries. One of the top nations in the world for producing textiles and apparel is India, which has a large number of textile dyeing mills. Joshi et al. [35], Vankar et al. [36], Yusuf et al. [9], Shahid ul et al. [26], and Shahid et al. [25] are all Indian researchers who published 5 of the top 10 textile coloration with natural sources research articles.

A comparison of the development trends among the top six publishing-heavy nations is shown in Figure 3. Before 2009, less than 10 articles were published annually for each nation, with India publishing the majority of them. India dominated the study of textile color from natural sources, with the number of articles published each year dramatically rising to 30 in 2021. The first article was released in Thailand in 2007. Thailand ranked sixth in 2021 with 59 articles, thanks to a considerable increase in Thai publications in recent years.

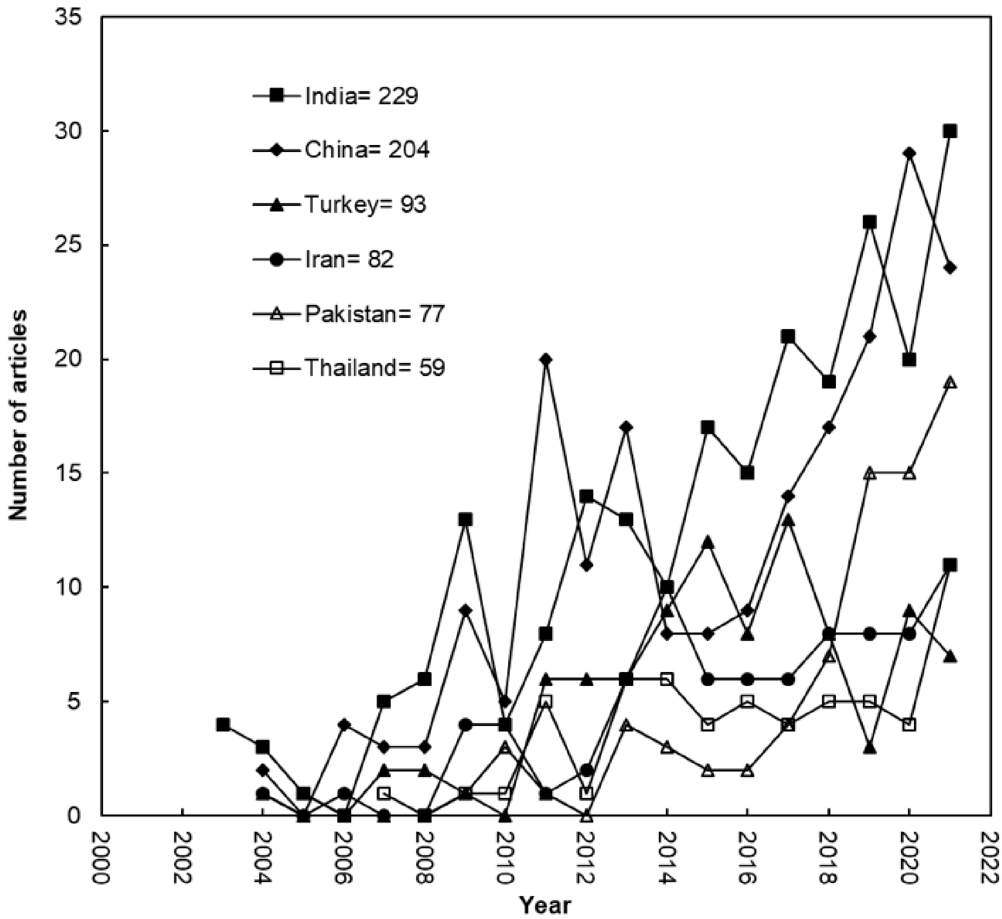

Figure 3. Comparison of development trends among the top six productive countries.

Regarding institutional performance, 415 of the 1141 papers (36% of the total) were contributed by a single institution, while 726 (64%) were the result of institutional collaboration. Table 4 displays the characteristics of the top 10 productive institutions as determined by the six publication indicators. The Indian Institute of Technology has earned the top spot in all three publication metrics, with *TP* at 45 publications (3.9% of 1141 articles), *IP* at 23 articles (4.2% of 407 single-institution articles), and RP at 38 articles (3.3% of 1141 corresponding-author articles). With a *CP* of 40 articles (6.6% of the 716 inter-institutionally collaborative papers) and *FP* of 39 articles (3.4% of the 1141 first-author articles), Pakistan's Govt College University took first place in both publication metrics.

Table 4. Top 10 productive institutions.

Institute	*TP*	*TPR* (%)	*IPR* (%)	*CPR* (%)	*FPR* (%)	*RPR* (%)	*SPR* (%)	CPP_{2021}
Indian Institute of Technology, India	45	1 (3.9)	1 (4.2)	4 (3.7)	3 (3.1)	1 (3.3)	N/A	24.7
National Research Center, Egypt	43	2 (3.8)	2 (3.8)	5 (3.7)	2 (3.3)	2 (3.1)	6 (2.9)	21.1
Jamia Millia Islamia, India	42	3 (3.6)	9 (1.6)	2 (5.5)	6 (2.6)	3 (2.7)	N/A	42.9
Govt College University, Pakistan	41	4 (3.6)	7 (2.2)	1 (6.6)	1 (3.4)	5 (2.2)	N/A	20.5
University of Monastir, Tunisia	37	5 (3.2)	14 (1.3)	3 (5.3)	4 (3.1)	6 (1.9)	N/A	17.6
Islamic Azad University, Iran	36	6 (3.2)	3 (3.6)	10 (2.7)	5 (2.7)	4 (2.7)	1 (7.2)	22.5
Donghua University, China	27	7 (2.4)	8 (1.6)	7 (3.1)	7 (1.9)	7 (1.9)	N/A	11.1
Wuhan Textile University, China	24	8 (2.1)	16 (1.1)	6 (3.4)	10 (1.1)	11 (1.3)	17 (1.4)	4.8
Erciyes University, Turkey	22	9 (1.9)	6 (2.2)	17 (1.7)	8 (1.6)	8 (1.6)	22 (1.4)	9.1
Soochow University, China	21	10 (1.8)	11 (1.5)	13 (2.6)	9 (1.4)	9 (1.4)	N/A	14.7

TP: total number of articles; *TPR* (%): rank of total number of articles and percentage; *IPR* (%): rank of single-institute articles and percentage in all single-institute articles; *CPR* (%): rank of inter-institutionally collaborative articles and percentage in all inter-institutionally collaborative articles; *FPR* (%): rank of first-author articles and percentage in all first-author articles; *RPR* (%): rank of corresponding-author articles and percentage in all corresponding-author articles; *SPR* (%): rank of single-author articles and percentage in all single-author articles; CPP_{2021}: number of citations (TC_{2021}) per publication (*TP*); N/A: not available.

The top 10 institutions that published single-author articles were solely created by the National Research Center of Egypt, Islamic Azad University in Iran, Wuhan Textile University in China, and Erciyes University in Turkey. The highest CPP_{2021} of 318 was found in publications about textile coloring with natural sources that were published by Jamia Millia Islamia in India, which was closely followed by Govt College University in Pakistan. In comparison, the CPP_{2021}/institute values were lower in Egypt and India. Due to the Indian Institute of Technology's numerous branches in numerous places, a bias developed [37]. Because the institute's publications were grouped under one institution for the sake of this study rather than as separate branches, the rankings would have varied.

3.5. The Most Frequently Cited Articles and the Most Impact Articles in 2021

Highly referenced works may or may not have significant impact or visibility after being published [38]. Readers may find more information about the impact of a heavily cited study today by looking at the amount of citations the study received in the most recent year of 2021 (C_{2021}) [20]. A different ranking was produced than the ranking that was produced by the C_{2021} sorting when 1141 textile color with natural sources articles were sorted by TC_{2021}. Of the 1141 publications, 422 (or 37%) had no citations in the most recent year (C_{2021} = 0), and 253 (or 22.1%) had none from the start of their publication year to the end of 2021 (TC_{2021} = 0). Furthermore, among the top 100 TC_{2021} articles were 33% of the top 50 C_{2021} publications. The title, abstract, and author keywords of the 1141 textile coloration with natural sources papers were searched. The title of an article serves as a heading that adequately describes its subjects. In order to improve indexing and searching, the writers provide author keywords to provide more details about the articles' core research. Search terms may not immediately relate to the search topic in articles whose abstracts include them.

Two popular publications titled "Ultrasonic assisted dyeing-III. Dyeing of wool with lac as a natural" [29] and "Anti-microbial activity of wool fabric treated with curcumin" [28] were among the top three most frequently cited articles. One other highly cited article regarding "Recent advancements in natural dye applications: a review" [25] only contained the search terms in its abstract. These articles have nothing to do with the study of textile coloring using natural sources.

Search terms appeared in the title, abstract, author keywords, and KeyWords Plus of 7 of the top 20 articles on TC_{2021}. Examples of this type include writings by Shahid et al. [25] ranked first with a TC_{2021} of 427. Han et al. [28] was ranked 256th with TC_{2021}. Kamel et al. had a TC_{2021} of 194 [29] and was ranked third. Shahid-ul-Islam et al. [26] had a TC_{2021} of 161, which placed seventh. With search terms in the title or author keywords, Figure 4 displays the citation records of the top seven most frequently cited articles. While Yusuf et al. [9] placed ninth on TC_{2021} with 136 but second on C_{2021} with 52, Han et al. [28] placed second on TC_{2021} with 256 but third on C_{2021} with 25. Similar to this, a paper by Kamel et al. [29] placed third on TC_{2021} with 194 but 114th on C_{2021} with 7. The study by Shahid et al. [25] from Jamia Millia Islamia in India, titled "Recent advancements in natural dye applications: a review," has had a high increase in citations over the past 10 years, indicating the growing interest of researchers in this paper. The top ten publications with the greatest number of citations that include search terms in the author keywords or title are shown in Table 5. India produced five of the top ten articles with the highest number of citations, trailed by Egypt (three articles) and France, Singapore, and Pakistan, each with one article. India's Jamia Millia Islamia produced four of the top ten pieces that were most widely cited.

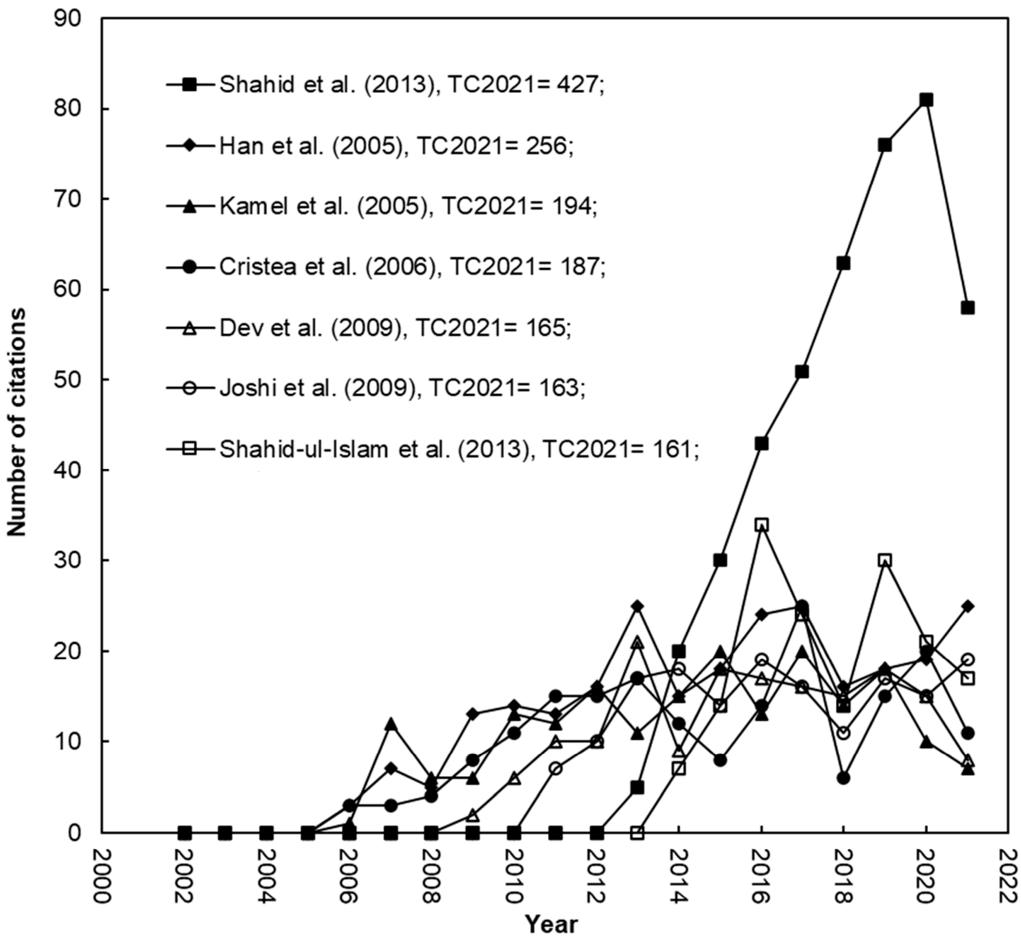

Figure 4. The citation life of the top seven most frequently cited articles with search keywords in their title or author keywords [25,26,28–30,35,39].

Table 5. The top 10 most frequently cited articles with search keywords in their title or author keywords.

R (TC_{2021})	R (C_{2021})	Title	Country	Reference
1 (427)	1 (58)	Recent advancements in natural dye applications: a review	India	[25]
3 (194)	114 (7)	Ultrasonic assisted dyeing-III. Dyeing of wool with lac as a natural dye	Egypt	[29]
4 (187)	46 (11)	Improving light fastness of natural dyes on cotton yarn	France	[30]
5 (165)	104 (8)	Dyeing and antimicrobial characteristics of chitosan treated wool fabrics with henna dye	Singapore, India	[39]
8 (142)	136 (7)	Dyeing of wool with natural anthraquinone dyes from Fusarium oxysporum	Egypt	[40]
9 (136)	2 (52)	Natural Colorants: Historical, Processing and Sustainable Prospects	India	[9]
11 (114)	22 (14)	Assessment of colorimetric, antibacterial and antifungal properties of woollen yarn dyed with the extract of the leaves of henna (Lawsonia inermis)	India	[41]
12 (104)	431 (2)	Ultrasonic assisted dyeing. IV. Dyeing of cationised cotton with lac natural dye	Egypt	[42]
13 (103)	74 (9)	Extraction of natural dye from red calico leaves: Gamma ray assisted improvements in color strength and fastness properties	Pakistan	[43]
14 (102)	61 (10)	Dyeing, fastness and antimicrobial properties of woolen yarns dyed with gallnut (Quercus infectoria Oliv.) extract	India	[44]

TC_{2021}: the total number of citations from Web of Science Core Collection since publication year to the end of 2021; C_{2021}: the number of citations of an article in 2021 only; *R*: ranking in 1141 textile coloration with natural colorants articles.

3.6. Research Focuses and Their Trends

According to a number of bibliometric studies, the distribution of words in article titles, abstracts, author keywords, and KeyWords Plus over time can be used to evaluate key research goals and then reveal how they change over time in study subjects [45]. For the period of the study, KeyWords Plus, author keywords, and article titles were all assessed and ranked in accordance with their frequency. More dyeing was used in subsequent research on the natural coloration of textile materials than other coloration methods such as printing (Figure 5). Table 6 lists the 20 most popular words in the titles and author keywords along with the KeyWords Plus rankings for each. The most popular search terms, such as dyeing, cloth, or natural, did not provide any information about the research hotspots. Cotton, a cellulosic textile fiber, wool, and silk, both protein fibers [46] appeared as the 5th, 8th, and 12th top most frequently searched words respectively and not indicate a research hotspot. The outcomes of a word analysis produced a number of supporting terms for each word cluster. “Mordant”, “antibacterial”, “ultraviolet”, “fastness”, “antimicrobials”, and “ultrasonic” were the six potential areas of study for textile coloring using natural sources. Fastness and mordanting are discussed together since they are typically used to enhance the fastness qualities of colored substrates. Two of the six research clusters are significantly connected to the functionalization of textile materials. This is not unexpected given how frequently textile materials are functionalized in current textile research [47]. The following sections provide summaries of influential and highly referenced articles that are relevant to certain research spots.

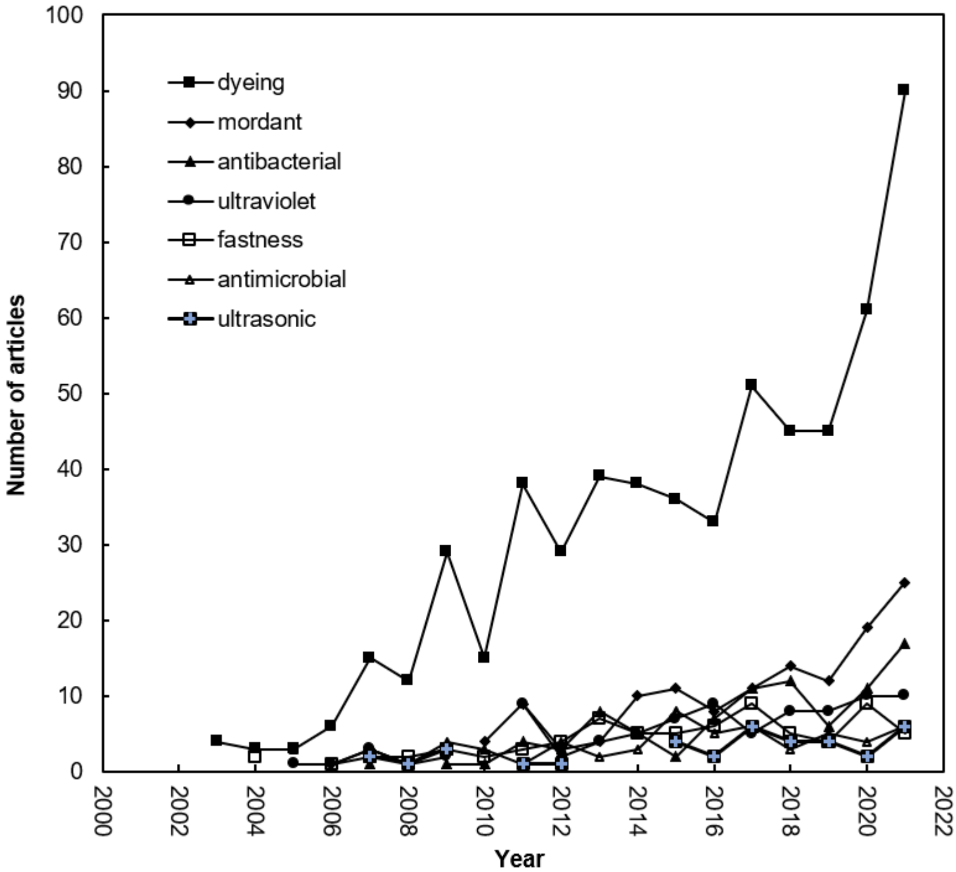

Figure 5. Development trends of the seven topics in textile coloration research with natural sources.

Table 6. Top 20 words in titles, author keywords, and *KeyWords Plus* in publications related to textile coloration with natural sources.

Title	*TP*	R (%)	Author Keywords	*TP*	R (%)	Keywords Plus	*TP*	R (%)
Dyeing	626	1 (54.86)	Natural	653	1 (57.23)	Cotton	294	1 (25.77)
Natural	599	2 (52.50)	Dyeing	473	2 (41.45)	Dyes	263	2 (23.05)
Fabric	342	4 (29.97)	Cotton	216	5 (18.93)	Natural	252	3 (22.09)
Cotton	307	5 (26.91)	Wool	191	6 (16.74)	Wool	186	4 (16.30)
Wool	229	8 (20.07)	Fastness	180	7 (15.78)	Fabrics	155	6 (13.58)
Silk	183	12 (16.04)	Fabric	162	8 (14.20)	Fastness	124	9 (10.87)
Extract	147	16 (12.88)	Mordant	160	9 (14.02)	Silk	103	11 (9.03)
Textile	98	18 (8.59)	Silk	141	10 (12.36)	Antimicrobial	100	13 (8.76)
Antibacterial	81	21 (7.10)	Antibacterial	113	11 (9.90)	Antibacterial	94	14 (8.24)
Eco	78	24 (6.84)	Textile	74	18 (6.49)	Leaves	82	17 (7.19)
Fastness	75	26 (6.57)	Antimicrobial	68	20 (5.96)	Antioxidant	74	18 (6.49)
UV	72	28 (6.31)	Chitosan	50	23 (4.38)	Adsorption	72	20 (6.31)
Leaves	62	30 (5.43)	Printing	37	28 (3.24)	Yarn	61	22 (5.35)
Antimicrobial	55	33 (4.82)	Strength	35	30 (3.07)	Acid	56	24 (4.91)
Bark	54	35 (4.73)	Acid	35	31 (3.07)	Textiles	53	25 (4.65)
Plant	50	37 (4.38)	Pigment	34	32 (2.98)	UV	49	27 (4.29)
Finishing	49	38 (4.29)	Antioxidant	32	34 (2.80)	Plasma	42	29 (3.68)
Mordant	48	39 (4.21)	Microwave	32	35 (2.80)	Chitosan	36	31 (3.16)
Sustainable	48	40 (4.21)	Ultraviolet	31	36 (2.72)	Ultrasound	14	79 (1.23)
Ultrasonic	27	79 (2.37)	Ultrasonic	23	55 (2.02)	Mordants	8	129 (0.70)

TP: total number of articles; R (%): rank of total number of articles and percentage.

3.6.1. Fastness and Mordants

All articles containing mordant, mordanting, and fastness on their front page are displayed in Figure 5, which shows that studies on improving fastness properties via mordanting rose rapidly and have taken the lead since 2007. Colorfastness is the primary requirement of any dyed textile goods. Due to the lower substantivity and durability [48] and also the non-substantive nature of most of the natural dyes [49], fatness improvement is required to obtain better and improved end products [48]. Otherwise, textile coloration with natural sources will not be acceptable for commercial usage as a suitable alternative.

C. urucurana bark extract was used as a natural dye source for dyeing cotton and wool fabric. The fastness properties (fastness to light, wash, perspiration, and color staining) were generally good. Aluminum potassium sulfate (alum) and ferrous sulfate (6% owf) were used in a meta-mordanting process to improve the fastness properties. Notably, alum treatment decreased cotton's light fastness, and ferrous sulfate showed better light fastness than the sample mordanted with alum. In all other fastness tests, the mordanted sample showed slightly better or similar fastness results [1]. Dyeing silk fabric with turmeric extract using potassium aluminum sulfate, copper sulfate, and ferrous sulfate mordant showed a golden-yellow color, brown color, and brownish-grey color, respectively [49]. Yusuf et al. [48] conducted a similar study where a natural dye was extracted from R. cordifolia roots and found that it can be applied to obtain radiant red shades on wool with or without mordanting. However, mordanting with $AlCl_3$ or $CaCl_2$ increased the overall fastness properties, and the former was more efficient than the latter. It was observed that woolen yarn can be dyed with gallnut extract with or without mordanting to produce a bright ivory to light brownish-yellow color where good fastness properties to light, rubbing, and washing could be seen [44].

Mixtures of red sandalwood and other natural dyes (jackfruit wood, sappan wood, manjistha, marigold, babool) were used to dye jute fabric pre-mordanted with myrobolan and then aluminum sulfate. For the use of the combinations of red sandalwood and babool, red sandalwood and marigold, and red sandalwood and sappan wood, a relatively lower wash fastness rating (grade 2–3) was observed. However, the wash fastness rating was relatively higher (typically grade 3–4) for the combinations of red sandalwood and manjistha and red sandalwood and jackfruit wood without any after-treatment [50]. The fastness properties of flax fabric dyed with natural colorants were also improved using mordanting. Cellulase-pretreated flax fabric dyed with an extract from chestnut shell showed fair to good fastness to light, crocking, and washing when it was mordanted with aluminum potassium sulfate and stannous chloride [8].

A similar approach used turmeric rhizomes to dye a bleached and mercerized cotton fabric. The fabric and turmeric powder were treated with gamma irradiation, but to increase color fastness, alum was used as a mordant [51]. In another study by Khan et al. [43], red calico leaf powder and cotton fabric cotton were irradiated. The surface modification converted the hydroxyl groups of the cotton molecule to a carboxylic group, and it helped to form a strong interaction with the dye molecule. In their study, it was found that using 1% copper solution and 1% tannic acid as a pre-mordant and post-mordant, respectively, helped to get slightly better results for fastness properties. Moreover, the irradiation of powder (calico leaves) and fabric (cotton) before dyeing reduced the amount of mordanting required to achieve an acceptable color fastness and color strength. A similar result was seen when mercerized cotton fabric was dyed with chicken gizzard extract. Here, it was found that iron (5%) and tannic acid (1%) as a pre- and post-mordant, respectively, gave the best result. Iron stabilized in the complex formed by irradiation due to its low reduction power. The enhanced color strength was due to the carboxylic group in the irradiated cotton and the phenolic group in the natural dye. Tannic acid also formed a firm complex on the fabric upon reaction with dye molecules. A conjugated system and benzene ring in colorant improved the resistance to heat, light, detergent, and rubbing. Gamma irradiation on mercerized cotton increased the color fastness rating and color strength, saving time, money, and labor [52].

In all these studies, the fastness properties were mostly improved by mordanting with metal salts, which has substantivity for both the fiber component and the dye molecules. They form an insoluble precipitate with the colorant on the fiber which results in better fastness properties [53].

3.6.2. Ultrasonic

The number of articles mentioning ultrasonic, ultrasonication, and ultrasound on their first page has been increasing steadily since 2007 (Figure 5). The conventional procedures are becoming less and less relevant due to their low extraction yield, prolonged use, degradation of the active ingredients, and poor fastness qualities. Modern extraction methods currently use gamma radiation, ultraviolet (UV) radiation, microwave radiation, ultrasonic radiation, and plasma treatment [54]. Because of its many advantages, one of these contemporary procedures, ultrasonic-aided extraction, is referred to as a "Green Process." Low temperatures produce the best results from the ultrasonic instrument, protecting the extract's thermally delicate bioactive components. The ultrasonic method delivers a good extraction yield at a lower temperature due to sound cavitation, which is more efficient at lower temperatures. Another advantage of the ultrasonic treatment is that it allows for improved functional component isolation thanks to mass transfer kinetics.

In a study by Zia et al. [55], the crude powder of neem bark was boiled for one hour in different solvents, including water, HCl (2%), and acidic methanol (2%). The mixtures were boiled and filtered, and the extracts were subjected to ultrasonic treatment for 15–60 min. Pristine and irradiated cotton samples were dyed at 75 °C by maintaining M:L = 1:25 using unirradiated and irradiated extracts. Adeel et al. [54] used a similar extraction method that showed promising results where ultrasonic treatment was employed to extract natural colorant from neem bark to dye silk fabric. Neem-bark-based tannin, a natural coloring agent for silk dyeing, was separated from 8 g of crude powder in a methanolic medium for 30 min followed by 30 min of ultrasound treatment. This treated powder was then used to dye ultrasound-treated silk for 65 min at 75 °C. Compared to chemical mordants employed under mild extraction and dyeing circumstances, biomordants such as quercetin from acacia, lawsone from Heena, curcumin from turmeric, and tannin from pomegranate yielded good to exceptional ratings of fastness and color strength. It was concluded that ultrasonic treatment improved the separation of the functional moiety (tannin) and decreased the size of the colorant molecule, both of which resulted in a reduction in processing time and solvent usage. The amount of powder required for colorant extraction decreased thanks to ultrasonic radiation [55].

In another study by Adeel et al. [56], arjun bark was used as a source of natural coloring agent, and extracts were prepared in various media. The extracts and silk fabrics were subjected to ultrasonic exposure of 100 W and 40 KHz for about 15–60 min at 60 °C. Irradiated silk fabric dyed with natural color in the presence of 0.3 g/L salts for 65 min at 65 °C showed good color strength. The color properties were improved with pre- and postchemical mordants such as 5% aluminum sulfate and 9% iron sulfate. Biomordants such as pomegranate and turmeric extracts (9%) as pre- and post-mordants produced good coloring properties. In contrast to the ultrasonic treatment of both the extracts and silk in a basic medium, ultrasonic-assisted dyeing for 15 min in an aqueous medium yielded the best color strength. However, irradiation did not impact dyeing when using an acidic medium.

After extracting natural dye from pomegranate peel using an ultrasonic technique, several mordants were applied to lyocell fabrics. Afterward, exhaust dyeing was used to color the samples of mordanted fabric. A volume of 200 mL of solvent made of 80 mL distilled water and 120 mL ethanol was added to a beaker containing 10 g of powdered pomegranate peel at an M: L of 1:20. After that, the beakers were placed in the ultrasonic bath and sonicated for 1 h at a temperature of 50 °C, a frequency of 27–30 MHz, and a supply voltage of 160 V. Then, using a rotary evaporator, the solvents were evaporated from the solutions after being filtered through Whatman filter paper [57].

Cotton did not show any affinity for the *P. quinquefolia* natural dye. To increase its dyeability, cationic groups were applied to cotton fibers using the cationic chemical Croscolor DRT (formaldehyde-free dye-fixing agent). Ultrasonic extraction of the natural dye enabled the dyeing of cotton fabric. The natural dye extraction from *P. quinquefolia* was performed utilizing ultrasonic energy at 500 W with a frequency of 20 kHz. A volume of 100 mL of water was added to a glass containing 5 g of P. quinquefolia fruits for extraction. This item was sonicated for 120 min in water. After complete extraction, the extract was run over filter paper [58]. Ultrasonic energy was used to dye cotton fabric with red cabbage in the study by Ticha et al. [59] where several cationizing agents were used to modify cotton, including the Rewin Os, Sera Fast, Denitex BC, and Acid Tannic. Ultrasonic power was used to carry out the dyeing process. pH 9 was maintained in the dye bath. The colorant was employed at a concentration of 30 g. The temperature was increased to 80 °C and held there for 60 min. Each of the investigated cationizing agents affected cotton. The sonicator dyeing tests were conducted in a glass beaker with a flat bottom equipped with a refrigerant. Ultrasonic power of 500 W at a 20 kHz frequency was employed. In a different approach, cotton fabric was pretreated with enzymes (pro-amyl, diasterase, lipase) before being dyed with the natural colorants catechu and tectona. The dye uptake capabilities of the fabrics treated with various enzymes were assessed, and the results were contrasted with a control sample. Protease and amylase were the enzymes for the catechu dye, but diasterase was best for tectona. Dye exhaustion increased by 39 and 52 percent with ultrasound. As a result, it was demonstrated that ultrasonography can be a useful technique for cleaner textile dyeing [60]. In other research, the dye uptake of cationized cotton fabric with lac dye by ultrasound was successful. The improved effect after equilibrium dyeing was approximately 66.5% greater than that of traditional heating. In addition to reducing processing time and energy consumption, this method positively affects the environment because it facilitates increased dye uptake and effective dye bath reuse [42].

The ideal conditions were used to extract almond shell powder (1 g/150 mL water) in an ultrasonic bath (Selecta, 40 kHz, 250 W) at 80 °C for 60 min. After being cooled to room temperature, the extracts were filtered to eliminate the insoluble residues. The ideal conditions for sonicator dyeing were an ultrasonic bath (Selecta, 40 kHz, 250 W) at 80 °C for 60 min. After thoroughly rinsing with water, the dyed samples were allowed to dry at room temperature [61]. In this study, it was concluded that the process enhanced the dye extraction efficacy but the obtained shade was lighter in ultrasonic-assisted dyeing and could be improved by mordanting and biomordanting. In the case of biomordanting, rosemary could be an alternative to alum which could be used in pre- and post-mordanting conditions. In contrast, in terms of fastness properties, pomegranate rind and valex were equal to metallic mordants, i.e., alum, iron II sulfate, copper II sulfate, and potassium dichromate. Other notable studies using a biomordant for the natural coloration of silk [62] and wool [63] have also been reported.

A study conducted by Baaka, Haddar et al. showed that wool fabrics could be dyed with the natural extract from grape pomace, and the use of ultrasound improved the dye exhaustion and fixation and ultimately the color yield (K/S) and fastness [64].

Finally, it can be said that ultrasonic treatment is a time-, cost-, energy-, and labor-effective strategy in addition to being more uniform, clean, and sustainable and can be used to isolate colorant from several new plants that produce dye and to achieve darker colors with appropriate fastness qualities for natural fabrics [54].

3.6.3. Ultraviolet (UV)

Due to their multipurpose qualities, such as UV protection, deodorizing performance, and antibacterial activity, natural dyes have recently sparked an increased interest in creating aesthetic and functional textiles [65]. Among these properties, UV protective finishing has attracted the attention of many researchers. The UV-A band (320–400 nm), the UV-B band (290–320 nm), and the UV-C band make up the UVR band (200–290 nm). Only a small portion of these dangerous radiations (UV-A 94%, UV-B 6%) [66] reach the earth's surface since the atmosphere absorbs a large quantity of them. Generally speaking, these radiations cause harm including wrinkles, skin damage, and even skin cancer [67]. Human skin's melanin pigment reduces the resulting harm. To further protect skin from damaging UV rays, clothing has been regarded as a great shield. Clothing dyed with natural colorants usually show increased UV protection as most natural colorants absorb both the UV and visible regions and have good UV radiation-blocking properties [68].

In a study, it was found that dyeing wool with marigold extract imparts excellent UV protection. Less than a 5 percent transmission rate for colored materials indicates adequate UV protection. All dyed wool fabric samples exhibit percentage transmittance values of 5 across the entire UV region. Still, undyed wool fabric exhibits poor UV protection with values of more than 10% in the UV-C area and rising to 40% in the UV-A region. The UV transmittance of wool is inversely correlated with the dye concentration; as the dye concentration grows, the transmittance decreases, and the protection increases. Alum and iron mordants reduced the UV transmittance; in the case of iron, it was found to be below 1.5% throughout the UV area. Undyed wool fabric has a 6.85 ultraviolet protection factor (UPF) rating, which is considered poor in terms of UV protection. Increased dye concentrations (10–20% o.w.f.) showed good 50+ UPF ratings, as the dyed materials' UPF proportionally correlates to the extract% [69], and even 5% o.w.f. marigold extract noticeably improved the UPF rating up to 35+ on wool. Due to the combined effects of the dye molecules and iron's UV-screening properties, colored wool that had been iron-mordanted was discovered to be highly UV-protective. Tin mordant was shown to have a lower UPF, even though it was over 40, which is considered excellent [67].

In another study that dyed cotton fabric with the extract of eucalyptus leaves, samples colored with extract concentrations of 20 g/L or more were considered to have good UV protection. Compared to samples treated with chitosan-untreated ones, the colored samples showed a considerable rise in their mean UPF values. Additionally, as the extract concentration in the dyeing increases, so do the UPF values. As a result, dyed materials (10–20 g/L extract) treated with chitosan had very good UPF indices, but they were excellent for specimens dyed with extracts at concentrations of 30 g/L or more. The mechanism involved in these two studies could be concluded as the increased uptake of the extract due to the chitosan treatment increasing the organic substrate, i.e., flavonoids increased the UPF rating [69]. Still, in the first case, the addition of the organic contents was increased by mordanting, and also these mordants had UV absorbance and dissipation properties [67]. Another approach to dyeing cotton fabric with tea extracts found that tea extract exhibits various behaviors depending on the type of tea being studied—green, red, or black. In terms of UPF, red and black tea displayed greater levels while green tea displayed the lowest value. Still, it must be noted that cotton fabrics colored with green tea have UPF values within the range where they can be considered to provide decent protection. Additionally, red and black tea extracts perform better when boiled than green tea extracts when cold [70].

Grifoni et al. [71] attempted to dye cotton and flax fabric using extracts from natural wild plants, including *D. gnidium* L. (daphne), *L. stoechas* L. (wild lavender), *R. peregrina* L. (wild madder), *H. italicum* (Roth) G. Don (curry plant), and *C. scolymus* L. (artichoke). Undyed flax fabrics had lower transmittance values than undyed cotton fabrics, although both cotton and flax fabrics displayed higher transmittance values at low wavelengths. Vegetable fibers such as cotton and flax are not excellent UV filters, although their UV transmittance qualities are generally the same. Alum mordant treatment modestly decreased transmittance in cotton and flax textiles; in contrast, tannin mordant application significantly decreased transmittance over the whole UV range. Helichrysum-dyed flax fibers and Rubia-dyed and alum-mordanted fabrics maintained good UV protection even after numerous washings, but cotton fabrics did not achieve UV protection.

Natural dyes derived from Rheum root and *L. erythrorhizon* root can successfully dye cotton fabric and silk. About 80% of the UV radiation is absorbed by the cotton and silk fabrics colored with these natural dyes. The fundamental explanation for the UV-protective qualities was that natural colors absorb UV light. These natural dyes were anticipated to be used in premium UV-protective clothing from cotton and silk materials [72]. Worsted wool was dyed using orange peel extract, with aluminum mordant producing yellower and brighter hues (pre-mordant, one bath, and post-mordant), and iron mordant producing deeper and bluer shades (pre-mordant, one bath, and after mordant). The wool sample dyed directly with orange peel extract had a UPF value around seven times higher than the UPF value of the wool sample treated with synthetic dyes. Even after 30 home laundering cycles, the wool samples dyed with orange peel extract outperformed wool colored with synthetic dyes in terms of UV protection, despite the latter's greater resistance to home laundering dyeing conditions [73].

In an attempt by Zhou et al. [65] to dye silk fabric with curcumin and modified curcumin, the UV absorber (2 g/L UV-Sun Cel, final concentration), sodium carbonate (2 g/L, final concentration), and curcumin (0.03 g, 0.08 mmol) were all added to a conical flask with a combined volume of 50 mL by adding distilled water. The mixture was then constantly shaken for 40 min at 60 °C in an XW-ZDR low-noise oscillated dyeing machine. The altered curcumin was then preserved in the dark for dyeing with silk. The original silk had a very low UPF of 4.91 and a high UV transmittance, indicating a poor UV protection capacity. After dyeing with modified curcumin, the silk demonstrated a high UPF of 50.65, which may be considered a "good protection" level compared to the UV absorber treatment. The silk dyed with both curcumin and modified curcumin displayed a high UPF of about 30 and maintained a "very good" UV protection performance after 30 washing cycles. Compared to undyed wool and silk, when dyed with a natural source (eucalyptus leaf) mordanted or unmordanted, wool fabric had better UV resistance properties due to its low porosity and high thickness and weight. Undyed silk and wool had a UPF value of 4.6 and 10.8, respectively, whereas treating them with eucalyptus extract increased it to 26 (unmordanted) and 53.3 (mordanted) in the case of silk and 53.1 (unmordanted) and 87.8 (mordanted) in the case of wool. The best result was obtained when samples dyed with natural extracts were mordanted with ferrous sulfate ($FeSO_4$) [74].

In the case of dyeing jute fabric with several natural sources such as babool, annatto, manjistha, and ratanjot, single mordanting was not enough to impart sufficient UV protection. Double mordanting with both biomordants—myrobolan (*T. chebula*) and pomegranate (*P. granatum*)—and chemical mordants—ferrous sulfate ($FeSO_4.7H_2O$) and potash alum (hydrated salt of potassium aluminum sulfate, K_2SO_4 $Al_2(SO_4)3$ 24 H_2O)—exhibited improved UPF ratings, and transmittance was between 4.2 and 6.7%. The pretreatment of myrobolan-ferrous sulfate provided the greatest UV protection. After pre-mordanting with a mixture of a biomordant and chemical mordant, any naturally dyed jute cloth generated exceptionally good UV protection qualities. The order of the natural-colored jute fabric's UV protection characteristics was babool > annatto > manjistha > ratanjot [75].

3.6.4. Antimicrobial

Medical and antimicrobial textiles protect users from hygienic issues brought on by contact with pathogenic or odor-producing bacteria [76]. Microorganism growth reduces functionality by causing unwanted aesthetic alterations or decaying damage [77]. Since ancient times, plant extracts have been utilized to color textile substrates. They have been researched and reintroduced as coloring and functional agents due to their biodegradable and environmentally friendly character [78]. Some of the natural dyes have lately been demonstrated to have good antibacterial action which can impede the growth of microorganisms without being harmful.

The antibacterial properties of four natural dyes—*K. lacca*, *A. catechu*, *R. cordifolia*, *Q. infectoria*, and *R. maritimus*—were the subject of an exploratory investigation. The common bacteria *E. coli*, *K. pneumoniae*, *B. subtilis*, *P. vulgaris*, and *P. aeruginosa* were tested on wool samples colored with these natural colors. The best antibacterial properties against all of the investigated microorganisms were demonstrated by the *Q. infectoria* dye, which was also the most effective and demonstrated the largest zone of inhibition. However, because these natural colors were absorbed below the minimum inhibitory concentration (MIC) in the textile material, it was noticed that the textile material impregnated with them displayed decreased antibacterial action. Another study found that a dye's antibacterial effectiveness varied depending on whether it was available in solution form or was held tightly by a textile material. The textile substrate less readily absorbed these natural dyes and their MIC values were lower. It was also discovered that cotton fabric might have increased antibacterial activity (50–90%) by using *Q. infectorie* extract in conjunction with copper and alum mordants [79].

In a study, 100% pure New Zealand semiworsted woolen yarn was dyed with extracts of T. arjuna dye mordanting with ferrous sulfate ($FeSO_4{\cdot}5H_2O$), stannous chloride ($SnCl_2{\cdot}2H_2O$), potash alum ($K_2Al_2(SO_4)4{\cdot}24H_2O$), and magnesium sulfate ($MgSO_4{\cdot}5H_2O$). Different bacterial strains such as *S. aureus*, *P. aeruginosa*, *E. coli*, and *B. subtilis* were used to test the effect of antimicrobial properties. The percentage of inhibition against all tested bacteria increased with the dye extract concentration from 5 mg/mL to 10 mg/mL, demonstrating a direct proportionality. Because of the interaction between functional groups and metal ions, the maximum activity was seen in unmordanted samples, followed by various metal-mordanted samples, resulting in minimal microbial–tannin interaction. After repeated washing, the mordanted specimen retained better antimicrobial activity than the other one. The most effective use of dyed woolen yarn against the bacterial isolates was against *B. subtilis*, followed by *S. aureus*, *E. coli*, and *P. aeruginosa* [80]. Utilizing a premordanting technique, 100% semiworsted 60-count wool yarn was dyed with powdered *R. emodi* L. (5% and 10%) using ferrous sulfate (5%), stannous chloride (1%), and alum (10%) as mordants, and the antimicrobial efficacy was measured against *E. coli*, *S. aureus*, *C. albicans*, and *C. tropicalis*. Wool yarn colored with 5% of the dye inhibits bacterial growth by up to 72–77% and fungal growth by up to 85–88%. When 10% dye was employed, a considerable increase was seen in antibacterial activity (82–90% in bacteria and 93–95% in fungi). When samples with dye were inspected after being mordanted, the %-age inhibition decreased. Wool yarn that had been mordanted with 5% ferrous sulfate and then dyed with 10% dye exhibited a %-age inhibition ranging from 50 to 78%, whereas with 1% stannous chloride and colored with the same %-age of dye it exhibited a %-age inhibition of 66–73%. Wool yarn with 10% alum added has the best percentage suppression (70–83%) of microbial growth [81]. In another approach to dyeing wool with natural dye henna, it was seen that dyeing solely with henna improved the antibacterial activities, and dyeing with pretreated chitosan further improved the performance [39].

Dried-up and de-gummed mulberry silk yarn was dyed using plant extracts made from discarded bark and leaves of the *S. asoca* and *A. lebbeck* species of plants. Later, the effectiveness of these substances' antibacterial characteristics was examined in vitro against *A. niger*, *K. pneumoniae*, and *C. albicans*. It was seen that A. lebbeck-dyed yarn had the greatest inhibitory effect on *K. pneumoniae* (50%) and *A. niger* (55%). The presence of all the yarns colored with different natural dyes made from the leaves and bark of both plants had the greatest impact on *A. niger's* growth. However, yarns colored with *A. lebbeck* bark extract did not hinder the growth of *C. albicans*, *K. pneumoniae*, or *E. coli*. The unmordanted colored yarns were initially treated with four cycles of washing in running water and soap solution. According to the findings, there was an average 5% reduction rate compared to yarns that just had one washing [82].

Cotton fabric with a plain weave was dyed with a sample of *Q. infectoria* dye, and its antimicrobial effectiveness against *B. subtilis* and *E. coli* was assessed. Fabshield AEM 5700, an antimicrobial agent, was used as a guide. It was clear that whereas cotton treated with 6% *Q. infectoria* had a fairly low level of inhibition (12%), when 12% *Q. infectoria* was applied, the activity was significantly increased (45% reduction) against *E. coli*. The inhibition increased to 73% with the addition of 5% alum and to 57% with 5% copper. However, there was absolutely no activity while using ferrous salt. In cotton treated with Fabshield, 75% of microbial colonies were inhibited. Thus, it may be concluded that 12% *Q. infectoria* combined with 5% alum can function effectively against Gram-negative bacteria *E. coli*. *Q. infectoria* exhibits comparable effects on the Gram-positive bacterium *B. subtilis*. Comparing the activity to that against *E. coli*, it is generally higher. Inhibiting microbial growth at 6% *Q. infectoria* concentration is ineffective, while at 12% *Q. infectoria* concentration, *B. subtilis* is 60% inhibited. When combined with 5% alum and copper salts, this rises to 84% and 89%. The samples that were post-mordanted with ferrous sulfate did not exhibit any action. After the first washing, the samples treated with *Q. infectoria* maintained roughly 50% of their activity, but after five launderings the action was almost lost. However, even after five launderings, the samples treated with *Q. infectoria* in conjunction with 1% copper sulfate or 5% alum retained more than 75% of their activity [83]. In another attempt to dye cotton fabric with Berberine (Natural Yellow 18) dye after pretreatment with a reactive anionic agent, the antimicrobial efficacy was assessed and evaluated with two methods: the AATCC Test Method 147–1998 and AATCC Test Method 100–1999. In the first method, the zone of bacterial suppression was not observed for the undyed control sample, which was solely treated with an anionic chemical. However, the zone of bacterial inhibition for Berberine coloring was plainly visible. This comparable result can be explained by the fact that the negatively charged bacterial cell membrane could be destroyed by the positively charged Berberine molecules, disrupting the equilibrium of charges in the cell membrane. At the same time, the Berberine-dyed sample exhibited robust antibacterial activity, with a 99.5% reduction in bacterial population compared to the undyed sample in the latter method [84]. Similar studies on cotton to impart antibacterial functional properties were carried out by Aminoddin Haji's group [85–87].

4. Future Perspectives

While natural dye applications have advanced significantly, there is still considerable advancement needed before plant-based colorants can be viewed as competitive alternatives to their synthetic counterparts. For commercial use, more research is required on the toxicity, safety, and quality of colorants derived from plants [78]. Textile coloration with natural resources is mainly based on natural fibers. However, there are a few reports of synthetic fiber dyeing with natural colorants by Aminoddin Haji et al. [88–90]. There seems to be a lack of kinetic studies of natural colorants used for textile coloration. However, Aminoddin Haji et al. [91] reported one such kinetic study where the isotherm and dyeing kinetics of a cationic natural dye was investigated during the coloration of crosslinked cotton fabric.

The primary challenges for the dyers and finishers using natural products in the textile industry include non-reproducibility, time-consuming extraction procedures, and poor fastness properties. Moreover, mordant and mordant assistants impact the shade and colorfastness of the dyed fiber. Mordants are anticipated to be replaced by more advanced, ecologically friendly treatments, such as plasma therapy [92]. Several studies have already been reported in which plasma technology was used, including the natural dyeing of plasma-treated cotton and chitosan [93–96] and the natural dyeing of plasma-treated wool [93–99]. Microwave treatment is another technique that has been increasingly employed in the natural dyeing of textiles [100–102].

The search for useful functional features including antibacterial and UV protection will drive future studies in this field. In addition to textile coloration applications, there is a growing interest in using natural dyes to dye hair, wood, and plastic. Moreover, the cosmetic and pharmaceutical industries have also shown interest in natural colorants. Exciting discoveries on recently found natural dye applications inspire high hopes for further investigation into the use of natural dyes in numerous sectors with an emphasis on potential industrial applications such as dye-sensitized solar cells, pH indicators, chemical sensors, and lithium-ion batteries.

This bibliometric analysis only included publications from Web of Science's Science Citation Index Expanded. Other databases, such as Scopus, can also be searched for articles.

Self-citations of the published documents were not counted and analyzed. Different results may have been obtained if self-citations were removed from the citation count.

5. Conclusions

From 1991 to 2020, SCI-EXPANDED saw a sharp increase, specifically from 2002, in the amount of research published on textile coloration with natural resources. The field of fastness is where natural dyeing research has been focused so far, together with the use of mordants and biomordants, in search of environmentally friendly extraction techniques such as ultrasonic, gamma irradiation, etc. Textile materials made of cotton, wool, jute, silk, lyocell, and flax have been the main focus of this application. Mordanting was utilized to increase or improve the UV protection characteristics as well as the fastness of the dyed substrates. Pre- or post-mordanting with chemical mordants or, in some cases, biomordanting proved useful in these situations. It has been observed that treatments like gamma irradiation reduce the quantity of mordant needed. Due to its inherent UV absorption properties, mordanting imparted enhanced efficiency in UV protective coatings. When used as an antibacterial, non-mordanted materials performed better, while mordanted materials demonstrated longevity.

Articles on natural dyeing were published mainly in the category of Materials Science, Textiles in the last decade. Multidisciplinary categories such as Materials Science, Textiles; Polymer Science, Chemistry, Applied; Engineering, Chemical; and Green and Sustainable Science and Technology have become popular in recent years. Of the 1141 natural dyeing articles from 58 countries, 84% were produced by a single nation, while 16% resulted from international cooperation. The top ten list of publications included six Asian, two African, one transatlantic, and one American nation. Italy, the most productive nation in Europe, came in at number 12. Before 2009, less than ten articles were published annually for each nation, with India publishing most of them. With a significantly rising annual number of articles that reached 30 articles in 2021, India dominated natural dyeing research. The first article was released in Thailand in 2007. Moreover, 36% of the papers were contributed by a single institution, while 64% resulted from institutional collaboration. India published 5 of the top 10 articles with the most citations, followed by Egypt (3 articles), and 1 each by France, Singapore, and Pakistan. Jamia Millia Islamia in India published four of the top ten most frequently cited articles with the highest CPP_{2021} of 42.9.

These articles were written in a total of nine different languages. English was the most prevalent language, making up 98.6% of all articles. Compared to all non-English articles, which had a CPP_{2021} of 6.8, those published in English had a substantially higher CPP_{2021}, which was 13. English-language articles had a higher APP of 4 than non-English-language articles, with a lower APP of 3.1. Except for a few sporadic increases, CPP_{2021} has been decreasing since 2005, but TP has risen quicker, reaching 165 in 2021. This suggests that experts have given natural dyeing a lot of thought overall. As more papers are published each year, it may be anticipated that the CPP_{year} will rise in the near future.

Author Contributions: M.T.I., A.H. and M.R.R. conceptualized the review topic and reviewed and edited the manuscript; M.A.A.M. and M.T.I. extracted data, ran data analysis, and drafted the 'data and bibliometric method' and 'result' (except research focuses) sections; M.H.M. drafted the rest of the sections of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. dos Santos Silva, P.M.; Fiaschitello, T.R.; de Queiroz, R.S.; Freeman, H.S.; da costa, S.A.; Leo, P.; Montemor, A.F.; da Costa, S.M. Natural dye from *Croton urucurana* Baill. bark: Extraction, physicochemical characterization, textile dyeing and color fastness properties. *Dye. Pigm.* **2020**, *173*, 107953. [CrossRef]
2. Halim, A.F.M.F.; Islam, M.T.; Hoque, M.M.U. Chemistry of sustainable coloration of textile materials. In *Green Chemistry for Sustainable Textiles*; Ibrahim, N., Hussain, C.M., Eds.; Woodhead Publishing: Sawston, UK, 2021; pp. 57–67.
3. Hoque, M.T.; Mazumder, N.-U.-S.; Islam, M.T. Enzymatic Wet Processing. In *Sustainable Practices in the Textile Industry*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 87–110.
4. Islam, M.T. Environment-friendly reactive dyeing process for cotton to substitute dyeing additives. *Clean Technol. Environ. Policy* **2016**, *18*, 601–608. [CrossRef]
5. Islam, M.T.; Mazumder, N.-U.-S.; Asaduzzaman, S. Optimization of Vat Dyeing with an Orange Peel Extract Reducing Agent using Response Surface Methodology. *AATCC J. Res.* **2020**, *7*, 1–9. [CrossRef]
6. Islam, M.T.; Khan, S.H.; Hasan, M.M. *Aloe vera* gel: A new thickening agent for pigment printing. *Color. Technol.* **2016**, *132*, 255–264. [CrossRef]
7. Islam, M.T.; Asaduzzaman, S. Environmentally-Friendly Textile Finishing. In *Textiles and Clothing*; Wiley Online Library: Hoboken, NJ, USA, 2019; pp. 101–129. [CrossRef]
8. Zhao, Q.; Feng, H.; Wang, L. Dyeing properties and color fastness of cellulase-treated flax fabric with extractives from chestnut shell. *J. Clean. Prod.* **2014**, *80*, 197–203. [CrossRef]
9. Yusuf, M.; Shabbir, M.; Mohammad, F. Natural Colorants: Historical, Processing and Sustainable Prospects. *Nat. Prod. Bioprospecting* **2017**, *7*, 123–145. [CrossRef]
10. Duval, J.; Pecher, V.; Poujol, M.; Lesellier, E. Research advances for the extraction, analysis and uses of anthraquinones: A review. *Ind. Crop. Prod.* **2016**, *94*, 812–833. [CrossRef]
11. Islam, M.T.; Farhan, M.S.; Faiza, F.; Halim, A.F.M.F.; Sharmin, A.A. Pigment Coloration Research Published in the Science Citation Index Expanded from 1990 to 2020: A Systematic Review and Bibliometric Analysis. *Colorants* **2022**, *1*, 38–57. [CrossRef]
12. Ho, Y.-S.; Halim, A.F.M.F.; 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.* **2021**, *9*, 795341. [CrossRef] [PubMed]
13. Ho, Y.-S.; Al Sharmin, A.; Islam, M.T.; Halim, A.F. Future direction of wound dressing research: Evidence From the bibliometric analysis. *J. Ind. Text.* **2022**, *52*, 15280837221130518. [CrossRef]
14. Ho, Y.-S. Comments on "Mapping the scientific research on non-point source pollution: A bibliometric analysis" by Yang et al. (2017). *Environ. Sci. Pollut. Res.* **2018**, *25*, 30737–30738. [CrossRef]
15. Ho, Y.S. Rebuttal to: Ma et al. "Past, current, and future research on microalga-derived biodiesel: A critical review and bibliometric analysis", vol. 25, pp. 10596–10610. *Environ. Sci. Pollut. Res.* **2020**, *27*, 7742–7743. [CrossRef] [PubMed]
16. Garfield, E. KeyWords Plus-ISI's breakthrough retrieval method. 1. Expanding your searching power on current-contents on diskette. *Curr. contents* **1990**, *32*, 5–9.
17. Fu, H.-Z.; Ho, Y.-S. Top cited articles in thermodynamic research. *J. Eng. Thermophys.* **2015**, *24*, 68–85. [CrossRef]
18. Li, Z.; Ho, Y.-S. Use of citation per publication as an indicator to evaluate contingent valuation research. *Scientometrics* **2008**, *75*, 97–110. [CrossRef]
19. Ho, Y.-S. A bibliometric analysis of highly cited articles in materials science. *Curr. Sci.* **2014**, *107*, 1565–1572.
20. Ho, Y.-S. Top-cited Articles in Chemical Engineering in Science Citation Index Expanded: A Bibliometric Analysis. *Chin. J. Chem. Eng.* **2012**, *20*, 478–488. [CrossRef]
21. Wang, M.-H.; Ho, Y.-S. Research articles and publication trends in environmental sciences from 1998 to 2009. *Arch. Environ. Sci.* **2011**, *5*, 1–10.
22. Hsieh, W.-H.; Chiu, W.-T.; Lee, Y.-S.; Ho, Y.-S. Bibliometric analysis of Patent Ductus Arteriosus treatments. *Scientometrics* **2004**, *60*, 105–215. [CrossRef]
23. Ho, H.-C.; Ho, Y.-S. Publications in dance field in Arts & Humanities Citation Index: A bibliometric analysis. *Scientometrics* **2015**, *105*, 1031–1040. [CrossRef]
24. Rizwanullah, A.R.; Firasat, H.; Ihsan, A.; Javed, M.; Alia, G.; Hazrat, H.; Mushtaq, A.G.; Muhammad, I.; Mohammad, K. Biological Investigation on Novel Natural Dye Extracted from the Bark of *Calligonum polygonoides* L. and Their Application on Cotton Fiber. *Pol. J. Environ. Stud.* **2021**, *31*, 3789–3796. [CrossRef]
25. Shahid, M.; Shahid-ul-Islam; Mohammad, F. Recent advancements in natural dye applications: A review. *J. Clean. Prod.* **2013**, *53*, 310–331. [CrossRef]
26. Ihsan, S.U.; Shahid, M.; Mohammad, F. Perspectives for natural product based agents derived from industrial plants in textile applications–a review. *J. Clean. Prod.* **2013**, *57*, 2–18.
27. Long, X.; Huang, J.-Z.; Ho, Y.-S. A historical review of classic articles in surgery field. *Am. J. Surg.* **2014**, *208*, 841–849. [CrossRef] [PubMed]
28. Han, S.; Yang, Y. Antimicrobial activity of wool fabric treated with curcumin. *Dye. Pigment.* **2005**, *64*, 157–161. [CrossRef]
29. Kamel, M.; El-Shishtawy, R.M.; Yussef, B.; Mashaly, H. Ultrasonic assisted dyeing: III. Dyeing of wool with lac as a natural dye. *Dye. Pigment.* **2005**, *65*, 103–110. [CrossRef]
30. Cristea, D.; Vilarem, G. Improving light fastness of natural dyes on cotton yarn. *Dye. Pigment.* **2006**, *70*, 238–245. [CrossRef]

31. Usman, M.; Ho, Y.-S. A bibliometric study of the Fenton oxidation for soil and water remediation. *J. Environ. Manag.* **2020**, *270*, 110886. [CrossRef]
32. Ho, Y.-S. The top-cited research works in the Science Citation Index Expanded. *Scientometrics* **2012**, *94*, 1297–1312. [CrossRef]
33. Ho, Y.-S.; Satoh, H.; Lin, S.-Y. Japanese Lung Cancer Research Trends and Performance in Science Citation Index. *Intern. Med.* **2010**, *49*, 2219–2228. [CrossRef]
34. Hsu, Y.-H.E.; Ho, Y.-S. Highly Cited Articles in Health Care Sciences and Services Field in Science Citation Index Expanded. *Methods Inf. Med.* **2014**, *53*, 446–458. [CrossRef] [PubMed]
35. Joshi, M.; Ali, S.W.; Purwar, R.; Rajendran, S. Ecofriendly antimicrobial finishing of textile using bioactive agents based on natural products. *Indian J. Fibre Text. Res.* **2009**, *34*, 295–304.
36. Vankar, P.S.; Shanker, R.; Verma, A. Enzymatic natural dyeing of cotton and silk fabrics without metal mordants. *J. Clean. Prod.* **2007**, *15*, 1441–1450. [CrossRef]
37. Li, J.; Zhang, Y.; Wang, X.; Ho, Y.-S. Bibliometric Analysis of Atmospheric Simulation Trends in Meteorology and Atmospheric Science Journals: Update. *Croat. Chem. Acta* **2009**, *91*, 695–705. [CrossRef]
38. Ho, Y.-S.; Kahn, M. A bibliometric study of highly cited reviews in the *Science Citation Index expanded*™. *J. Assoc. Inf. Sci. Technol.* **2014**, *65*, 372–385. [CrossRef]
39. Dev, V.R.G.; Venugopal, J.; Sudha, S.; Deepika, G.; Ramakrishna, S. Dyeing and antimicrobial characteristics of chitosan treated wool fabrics with henna dye. *Carbohydr. Polym.* **2009**, *75*, 646–650. [CrossRef]
40. Nagia, F.A.; El-Mohamedy, R.S.R. Dyeing of wool with natural anthraquinone dyes from Fusarium oxysporum. *Dye. Pigment.* **2007**, *75*, 550–555. [CrossRef]
41. Yusuf, M.; Ahmad, A.; Shahid, M.; Khan, M.I.; Khan, S.A.; Manzoor, N.; Mohammad, F. Assessment of colorimetric, antibacterial and antifungal properties of woollen yarn dyed with the extract of the leaves of henna (*Lawsonia inermis*). *J. Clean. Prod.* **2012**, *27*, 42–50. [CrossRef]
42. Kamel, M.; El-Shishtawy, R.M.; Youssef, B.; Mashaly, H. Ultrasonic assisted dyeing. IV. Dyeing of cationised cotton with lac natural dye. *Dye. Pigment.* **2007**, *73*, 279–284. [CrossRef]
43. Khan, A.A.; Iqbal, N.; Adeel, S.; Azeem, M.; Batool, F.; Bhatti, I.A. Extraction of natural dye from red calico leaves: Gamma ray assisted improvements in colour strength and fastness properties. *Dye. Pigment.* **2014**, *103*, 50–54. [CrossRef]
44. Shahid, M.; Ahmad, A.; Yusuf, M.; Khan, M.I.; Khan, S.A.; Manzoor, N.; Mohammad, F. Dyeing, fastness and antimicrobial properties of woolen yarns dyed with gallnut (*Quercus infectoria* Oliv.) extract. *Dye. Pigment.* **2012**, *95*, 53–61. [CrossRef]
45. Wang, C.-C.; Ho, Y.-S. Research trend of metal & ndash;organic frameworks: A bibliometric analysis. *Scientometrics* **2016**, *109*, 481–513. [CrossRef]
46. Islam, M.T.; Rahman, M.M.; Mazumder, N.-U.-S. Polymers for Textile Production. In *Frontiers of Textile Materials*; John Wiley & Sons: Honoken, NJ, USA, 2020; pp. 13–59.
47. Mazumder, N.-U.-S.; Islam, M.T. *Flame Retardant Finish for Textile Fibers, in Innovative and Emerging Technologies for Textile Dyeing and Finishing*; Wiley Online Library: Hoboken, NJ, USA, 2021; pp. 373–405.
48. Yusuf, M.; Mohammad, F.; Shabbir, M. Eco-friendly and effective dyeing of wool with anthraquinone colorants extracted from Rubia cordifolia roots: Optimization, colorimetric and fastness assay. *J. King Saud Univ. Sci.* **2017**, *29*, 137–144. [CrossRef]
49. Ghoreishian, S.M.; Maleknia, L.; Mirzapour, H.; Norouzi, M. Antibacterial properties and color fastness of silk fabric dyed with turmeric extract. *Fibers Polym.* **2013**, *14*, 201–207. [CrossRef]
50. Samanta, A.K.; Agarwal, P.; Singhee, D.; Datta, S. Application of single and mixtures of red sandalwood and other natural dyes for dyeing of jute fabric: Studies on colour parameters/colour fastness and compatibility. *J. Text. Inst.* **2009**, *100*, 565–587. [CrossRef]
51. Bhatti, I.A.; Adeel, S.; Jamal, M.A.; Safdar, M.; Abbas, M. Influence of gamma radiation on the colour strength and fastness properties of fabric using turmeric (*Cur-cuma longa* L.) as natural dye. *Radiat. Phys. Chem.* **2010**, *79*, 622–625. [CrossRef]
52. Batool, F.; Adeel, S.; Azeem, M.; Khan, A.A.; Bhatti, I.A.; Ghaffar, A.; Iqbal, N. Gamma radiations induced improvement in dyeing properties and colorfastness of cotton fabrics dyed with chicken gizzard leaves extracts. *Radiat. Phys. Chem.* **2013**, *89*, 33–37. [CrossRef]
53. Zarkogianni, M.; Mikropoulou, E.; Varella, E.; Tsatsaroni, E. Colour and fastness of natural dyes: Revival of traditional dyeing techniques. *Color. Technol.* **2011**, *127*, 18–27. [CrossRef]
54. Adeel, S.; Zia, K.M.; Abdullah, M.; Rehman, F.-U.; Salman, M.; Zuber, M. Ultrasonic assisted improved extraction and dyeing of mordanted silk fabric using neem bark as source of natural colourant. *Nat. Prod. Res.* **2019**, *33*, 2060–2072. [CrossRef]
55. Zia, K.M.; Adeel, S.; Rehman, F.U.; Aslam, H.; Khosa, M.K.; Zuber, M. Influence of ultrasonic radiation on extraction and green dyeing of mordanted cotton using neem bark extract. *J. Ind. Eng. Chem.* **2019**, *77*, 317–322. [CrossRef]
56. Adeel, S.; Rehman, F.U.; Iqbal, M.U.; Habib, N.; Kiran, S.; Zuber, M.; Zia, K.M.; Hameed, A. Ultrasonic assisted sustainable dyeing of mordanted silk fabric using arjun (*Terminalia arjuna*) bark extracts. *Environ. Prog. Sustain. Energy* **2019**, *38*, S331–S339. [CrossRef]
57. Rehman, F.; Sanbhal, N.; Naveed, T.; Farooq, A.; Wang, Y.; Wei, W. Antibacterial performance of Tencel fabric dyed with pomegranate peel extracted via ultrasonic method. *Cellulose* **2018**, *25*, 4251–4260. [CrossRef]

58. Ticha, M.B.; Meksi, N.; Attia, H.E.; Haddar, W.; Guesmi, A.; Jannet, H.B.; Mhenni, M.F. Ultrasonic extraction of Parthenocissus quinquefolia colorants: Extract identification by HPLC-MS analysis and cleaner application on the phytodyeing of natural fibres. *Dye. Pigm.* **2017**, *141*, 103–111. [CrossRef]
59. Ticha, M.B.; Haddar, W.; Meksi, N.; Guesmi, A.; Mhenni, M.F. Improving dyeability of modified cotton fabrics by the natural aqueous extract from red cabbage using ultrasonic energy. *Carbohydr. Polym.* **2016**, *154*, 287–295. [CrossRef]
60. Vankar, P.S.; Shanker, R. Ecofriendly ultrasonic natural dyeing of cotton fabric with enzyme pretreatments. *Desalination* **2008**, *230*, 62–69. [CrossRef]
61. Erdem İşmal, Ö.; Yıldırım, L.; Özdoğan, E. Valorisation of almond shell waste in ultrasonic biomordanted dyeing: Alternatives to metallic mordants. *J. Text. Inst.* **2015**, *106*, 343–353. [CrossRef]
62. Amin, N.; Rehman, F.-U.; Adeel, S.; Ahamd, T.; Muneer, M.; Haji, A. Sustainable application of cochineal-based anthraquinone dye for the coloration of bio-mordanted silk fabric. *Environ. Sci. Pollut. Res.* **2019**, *27*, 6851–6860. [CrossRef]
63. Haji, A. Functional Dyeing of Wool with Natural Dye Extracted from *Berberis vulgaris* Wood and *Rumex Hymenosepolus* Root as Biomordant. *Iran. J. Chem. Chem. Eng. Int. Engl. Ed.* **2010**, *29*, 55–60.
64. Baaka, N.; Haddar, W.; Ben Ticha, M.; Amorim, M.T.P.; MHenni, M.F. Sustainability issues of ultrasonic wool dyeing with grape pomace colourant. *Nat. Prod. Res.* **2017**, *31*, 1655–1662. [CrossRef]
65. Zhou, Y.; Tang, R.-C. Modification of curcumin with a reactive UV absorber and its dyeing and functional properties for silk. *Dye. Pigment.* **2016**, *134*, 203–211. [CrossRef]
66. Mongkholrattanasit, R.; Kryštůfek, J.; Wiener, J.; Vikova, M. UV protection properties of silk fabric dyed with eucalyptus leaf extract. *J. Text. Inst.* **2011**, *102*, 272–279. [CrossRef]
67. Shabbir, M.; Rather, L.J.; Mohammad, F. Economically viable UV-protective and antioxidant finishing of wool fabric dyed with Tagetes erecta flower extract: Valorization of marigold. *Ind. Crop. Prod.* **2018**, *119*, 277–282. [CrossRef]
68. Alam, I.K.; Moury, N.N.; Islam, M.T. Synthetic and Natural UV Protective Agents for Textile Finishing. In *Sustainable Practices in the Textile Industry*; Wiley Online Library: Hoboken, NJ, USA, 2021; pp. 207–235. [CrossRef]
69. da Silva, M.G.; de Barros, M.A.S.D.; de Almeida, R.T.R.; Pilau, E.J.; Pinto, E.; Soares, G.; Santos, J.G. Cleaner production of antimicrobial and anti-UV cotton materials through dyeing with eucalyptus leaves extract. *J. Clean. Prod.* **2018**, *199*, 807–816. [CrossRef]
70. Bonet-Aracil, M.Á.; Díaz-García, P.; Bou-Belda, E.; Sebastiá, N.; Montoro, A.; Rodrigo, R. UV protection from cotton fabrics dyed with different tea extracts. *Dye. Pigment.* **2016**, *134*, 448–452. [CrossRef]
71. Grifoni, D.; Bacci, L.; Di Lonardo, S.; Pinelli, P.; Scardigli, A.; Camilli, F.; Sabatini, F.; Zipoli, G.; Romani, A. UV protective properties of cotton and flax fabrics dyed with multifunctional plant extracts. *Dye. Pigment.* **2014**, *105*, 89–96. [CrossRef]
72. Feng, X.; Zhang, L.; Chen, J.; Zhang, J. New insights into solar UV-protective properties of natural dye. *J. Clean. Prod.* **2007**, *15*, 366–372. [CrossRef]
73. Hou, X.; Chen, X.; Cheng, Y.; Xu, H.; Chen, L.; Yang, Y. Dyeing and UV-protection properties of water extracts from orange peel. *J. Clean. Prod.* **2013**, *52*, 410–419. [CrossRef]
74. Mongkholrattanasit, R.; Kryštůfek, J.; Wiener, J.; Viková, M. Dyeing, fastness, and UV protection properties of silk and wool fabrics dyed with eucalyptus leaf extract by the exhaustion process. *Fibres Text. East. Eur.* **2011**, *19*, 94–99.
75. Chattopadhyay, S.; Pan, N.C.; Roy, A.K.; Saxena, S.; Khan, A. Development of natural dyed jute fabric with improved colour yield and UV protection character-istics. *J. Text. Inst.* **2013**, *104*, 808–818. [CrossRef]
76. Islam, M.T.; Ali, A.; McConnell, M.; Laing, R.; Wilson, C. Mechanisms and kinetics of silver nanoparticle release from polyvinyl alcohol/keratin/chitosan electrospun nanofibrous scaffold. In Proceedings of the AUTEX2019–19th World Textile Conference on Textiles at the Crossroads, Ghent, Belgium, 11–15 June 2019.
77. Emam, H.E. Antimicrobial cellulosic textiles based on organic compounds. *3 Biotech* **2019**, *9*, 29. [CrossRef]
78. Mohammad, F. Natural Colorants in the Presence of Anchors So-Called Mordants as Promising Coloring and Antimicrobial Agents for Textile Materials. *ACS Sustain. Chem. Eng.* **2015**, *3*, 2361–2375. [CrossRef]
79. Babu, K.M.; Ravindra, K. Bioactive antimicrobial agents for finishing of textiles for health care products. *J. Text. Inst.* **2015**, *106*, 706–717. [CrossRef]
80. Rather, L.J.; Islama, S.U.; Azamb, M.; Shabbira, M.; Bukharia, M.N.; Shahida, M.; Khan, M.A.; Haqueb, Q.M.R.; Mohammad, F. Antimicrobial and fluorescence finishing of woolen yarn with *Terminalia arjuna* natural dye as an eco-friendly substitute to synthetic antibacterial agents. *RSC Adv.* **2016**, *6*, 39080–39094. [CrossRef]
81. Khan, S.A.; Ahmad, A.; Khan, M.I.; Yusuf, M.; Shahid, M.; Manzoor, N.; Mohammad, F. Antimicrobial activity of wool yarn dyed with *Rheum emodi* L. (*Indian Rhubarb*). *Dye. Pigment.* **2012**, *95*, 206–214. [CrossRef]
82. Baliarsingh, S.; Panda, A.K.; Jena, J.; Das, T.; Das, N.B. Exploring sustainable technique on natural dye extraction from native plants for textile: Identification of colourants, colourimetric analysis of dyed yarns and their antimicrobial evaluation. *J. Clean. Prod.* **2012**, *37*, 257–264. [CrossRef]
83. Gupta, D.; Laha, A. Antimicrobial activity of cotton fabric treated with Quercus infectoria extract. *Indian J. Fibre Text. Res.* **2007**, *32*, 88–92.
84. Kim, T.-K.; Son, Y.-A. Effect of reactive anionic agent on dyeing of cellulosic fibers with a Berberine colorant—Part 2: Anionic agent treatment and antimicrobial activity of a Berberine dyeing. *Dye. Pigment.* **2005**, *64*, 85–89. [CrossRef]
85. Haji, A. Eco-friendly dyeing and antibacterial treatment of cotton. *Cellul. Chem. Technol.* **2013**, *47*, 303–308.

86. Haji, A.; Nasiriboroumand, M.; Qavamnia, S.S. Cotton Dyeing and Antibacterial Finishing Using Agricultural Waste by an Eco-friendly Process Optimized by Response Surface Methodology. *Fibers Polym.* **2018**, *19*, 2359–2364. [CrossRef]
87. Haji, A. Antibacterial Dyeing of Wool with Natural Cationic Dye Using Metal Mordants. *Mater. Sci.* **2012**, *18*, 267–270. [CrossRef]
88. Haji, A.; Shoushtari, A.M.; Mirafshar, M. Natural dyeing and antibacterial activity of atmospheric-plasma-treated nylon 6 fabric. *Color. Technol.* **2013**, *130*, 37–42. [CrossRef]
89. Rehman, F.U.; Adeel, S.; Memoona, P.; Aminoddin, H.; Wafa, H.; Muhammad, H.; Nimra, A.; Ahlem, G. Microwave Induced Sustainable Isolation of Laccaic Acid from Lac Insect for Nylon Dyeing. *Iran. J. Chem. Chem. Eng.* **2021**, *40*, 1849–1859.
90. Haji, A.; Vadood, M. Environmentally Benign Dyeing of Polyester Fabric with Madder: Modelling by Artificial Neural Network and Fuzzy Logic Optimized by Genetic Algorithm. *Fibers Polym.* **2021**, *22*, 3351–3357. [CrossRef]
91. Haji, A.; Bidoki, S.M.; Gholami, F. Isotherm and Kinetic Studies in Dyeing of Citric Acid-Crosslinked Cotton with Cationic Natural Dye. *Fibers Polym.* **2020**, *21*, 2547–2555. [CrossRef]
92. Kasiri, M.B.; Safapour, S. Natural dyes and antimicrobials for green treatment of textiles. *Environ. Chem. Lett.* **2014**, *12*, 1–13. [CrossRef]
93. Haji, A.; Ashraf, S.; Nasiriboroumand, M.; Lievens, C. Environmentally Friendly Surface Treatment of Wool Fiber with Plasma and Chitosan for Improved Coloration with Cochineal and Safflower Natural Dyes. *Fibers Polym.* **2020**, *21*, 743–750. [CrossRef]
94. Sajed, T.; Haji, A.; Mehrizi, M.K.; Boroumand, M.N. Modification of wool protein fiber with plasma and dendrimer: Effects on dyeing with cochineal. *Int. J. Biol. Macromol.* **2018**, *107 Pt A*, 642–653. [CrossRef]
95. Molakarimi, M.; Khajeh Mehrizi, M.; Haji, A. Effect of plasma treatment and grafting of β-cyclodextrin on color proper-ties of wool fabric dyed with Shrimp shell extract. *J. Text. Inst.* **2015**, *107*, 1314–1321. [CrossRef]
96. Haji, A.; Payvandy, P. Application of ANN and ANFIS in prediction of color strength of plasma-treated wool yarns dyed with a natural colorant. *Pigment. Resin Technol.* **2020**, *49*, 171–180. [CrossRef]
97. Ansari, B.; Mehrizi, M.K.; Haji, A. Dyeing of Oxygen Plasma Treated Wool Fibers with *Rhuem ribes* L. Flowers. *J. Color Sci. Technol.* **2015**, *9*, 135–143.
98. Haji, A. Application of D-optimal design in the analysis and modelling of dyeing of plasma-treated wool with three natural dyes. *Color. Technol.* **2019**, *136*, 137–146. [CrossRef]
99. Haji, A.; Mehrizi, M.K.; Akbarpour, R. Optimization of β-cyclodextrin grafting on wool fibers improved by plasma treatment and assessment of antibacterial activity of berberine finished fabric. *J. Incl. Phenom. Macrocycl. Chem.* **2015**, *81*, 121–133. [CrossRef]
100. Buyukakinci, B.; Karadag, R.; Torgan Güzel, E. Organic cotton fabric dyed with dyer’s oak and barberry dye by microwave irradiation and conventional methods. *Ind. Text.* **2021**, *72*, 30–38. [CrossRef]
101. Kiran, S.; Adeel, S.; Yousaf, M.S.; Habib, N.; Hassan, A.; Qayyum, M.A.; Abdullah, M. Green dyeing of microwave treated silk using coconut coir based tannin natural dye. *Ind. Textila* **2020**, *71*, 227–234. [CrossRef]
102. Rabia, S.; Samad, B.A.; Mazhar, H.P.; Alvira, A. A An efficient ultrasonic and microwave assisted extraction of organic Henna dye for dyeing of synthetic poly-ester fabric for superior color strength properties. *Ind. Text.* **2019**, *70*, 303–308. [CrossRef]