Journal of Advanced Environmental Research and Technology

Vol. 1, No.4
page 53-69 ,fall 2023
***
Received 05 augest 2023
Accepted 21 augest 2023

Global trends of the scientific literature on detergents: A bibliometric analysis during 2000-2022

Mohammadreza Hajbabaie, Mohammad Reza Sabour*, Hamid Zarrabi, Ghorbanali Dezvareh, Amir Mostafa Hatami.

Faculty of Civil Engineering, K. N. Toosi University of Technology, Tehran, Iran.

[DOI: 10.22034/JAERT.1.4.53]

Abstract

Detergents are a part of human life and are consumed for different purposes, particularly hygiene. In recent years, the detergent industry has experienced significant changes as a result of environmental concerns, the availability, and cost of raw resources and energy, consumer preferences, demographic and sociological trends, as well as global economic and political factors. Several review papers have been published on detergents, but no bibliometric research has been conducted in this field. This study aims to assess the trend of detergent research and show the related hotspots by conducting a bibliometric analysis based on 37650 published articles from Scopus from 2000 to 2022. Numerous significant aspects of these articles, such as subject categories, journals, authors, countries, and keywords, were examined systematically. According to the findings, the number of detergent-related papers has increased significantly over the past two decades. The United States was the leading country in terms of both quality and quantity, followed by China and Brazil. In addition, Detmann, E. from Sweden was the most productive author. Keyword analysis suggests that current research has focused on the development of effective cleaning products that are safe for humans and the environment.

key words

Bibliometric analysis

Cleaning products

Detergent

Environmental impacts

Social network analysis

Surfactant

*To whom correspondence should be addressed:
mrsbr@hotmail.com

Introduction

Definition of detergent

The term “detergent” is used in a variety of contexts. The word “detergent” is derived from the Latin word “detergent,” which means to remove or wipe off, although its actual usage encompasses more than just cleaning. According to the Detergents Regulation, a detergent is “any substance or preparation containing soaps and/or other surfactants intended for washing and cleaning processes.” It is essential to note that “Detergents” and “Surfactants” are two distinct concepts that should not be used interchangeably (not all surfactants are detergents, but detergents contain surfactants and some other chemical constituents) [1].

History of detergents

The history of personal hygiene dates back to ancient times. Since water is necessary to live, the earliest humans lived near bodies of water and were aware of its cleaning capabilities. A soap-like substance discovered in clay cylinders during the excavation of ancient Babylon proves that soapmaking occurred as early as 2800 B.C. Inscriptions on the cylinders indicate that the fats were boiled with ash, which is a procedure for manufacturing soap. Evidence suggests that ancient Egyptians frequently bathed. Ebers Papyrus, a medical text from approximately 1500 B.C., discusses blending animal and vegetable oils with alkaline salts to create a soap-like substance that was used to heal skin problems and for washing. Based on an ancient Roman story, soap gained its name from Mount Sapo, where animals were sacrificed. Along the Tiber, rainfall poured a combination of melted animal fat or tallow and wood ashes into the clay soil. Women discovered that washing their clothes with this clay combination required significantly less labor. As Roman culture developed, so did bathing. The earliest of the famed Roman baths fed by their aqueducts was constructed in 312 B.C. Galen, a Greek physician of the second century A.D., suggested soap for both therapeutic and washing reasons [2]. Much of Europe faced the effects of filth following the fall of the Western Roman Empire in 476 A.D. The consequent drops in bathing routines negatively affected public health. However, by the seventh century, soapmaking was an accepted profession in Europe. Soapmakers combined vegetable and animal oils, plant ashes, and scents into their products. Gradually, new forms of soap became available for shaving, shampooing, bathing, and laundering. Due to their abundant availability of raw ingredients such as olive oil, Italy, Spain, and France were the earliest hubs for soap production. The English began producing soap in the 12th century. In 1608, numerous soapmakers arrived in Jamestown, Virginia, marking the beginning of commercial soapmaking in the American colonies [3]. In 1791, Nicholas Leblanc, a French chemist, developed a method for producing soda ash, or sodium carbonate, from table salt, which was a significant development in the commercial soapmaking industry. Soda ash is the alkali produced when ashes are combined with fat to produce soap. The Leblanc procedure produced large amounts of affordable soda ash of superior quality. Twenty years later, another French chemist, Michel Eugene Chevreul, discovered the chemical nature and interrelationship of fats, glycerin, and fatty acids. With this discovery, the science of modern soapmaking was founded. The mid-1800s innovation of the ammonia process by the Belgian chemist Ernest Solvay, which utilized ordinary table salt (sodium chloride) to produce soda ash, was also crucial to the development of soap technology. In 1850, these scientific breakthroughs made soapmaking one of the most rapidly expanding industries in the United States. Simultaneously, its widespread availability transformed soap from a luxury good into a daily necessity. Also, softer soaps for bathing and soaps for use in washing machines were developed in response to the increased usage of washing machines [4]. The chemistry of soap production remained virtually unchanged until 1916 when Germany created the first synthetic detergent in response to a scarcity of soap-making fats caused by World War I. Synthetic detergents, commonly referred to as “detergents,” are non-soap washing and cleaning chemicals that are chemically assembled from a diversity of raw materials. Detergents were developed due to the requirement for a cleaning agent that, unlike soap, would not react with the mineral salts in water to generate soap curd [5]. The United States began manufacturing household detergents in the early 1930s. The initial detergents were primarily used for hand dishwashing and the laundry of fine fabrics. In 1946, the first “built” detergent (consisting of a surfactant/builder combination) was released in the United States, marking a milestone in the development of detergents for general-purpose laundry usage [6]. By 1953, detergent sales in this region had overtaken soap sales and detergents nearly completely supplanted soap-based products for laundry, dishwashing, and home cleaning. After these early accomplishments in the detergent industry, various products were de-

[DOI: 10.22034/JAERT.1.4.53]

veloped, which are mentioned below:

- In the 1960s, enzyme-based stain removers and laundry detergents were marketed.
- In the 1970s, liquid hand soaps and fabric softeners were marketed.
- In the 1980s, cold water washing detergents, liquids for the dishwasher, and concentrated laundry powders were marketed.
- In the 1990s, concentrated powders and liquids, fabric softeners, dishwashing gels, and cleaning product refills were marketed.

Finally, in the 20th century, there was an emphasis on producing biodegradable and environmentally friendly products [7].

Applications of detergents

Detergents are utilized in various industrial processes and constitute one of the most significant industries with an annual global investment of approximately $60 billion [8]. Typically, detergents are used for distinct purposes, which are described below:

- Personal and household cleaning: In domestic applications, detergents refer to home cleaning solutions such as laundry detergents and dish detergents, which are complicated mixes of several compounds [9].
- Fuel additives: Detergents are utilized as fuel additives because they maintain fuel system components clean and prevent carbon buildup in engine combustion systems. It is because detergents can eliminate polar species from surfaces. Therefore, the existing polar compounds cannot aggregate and form larger groups, which would result in the formation of insoluble deposits and gums [10].
- Degradation: Biological detergents are often applied to break the bipolar lipid membranes of cells to liberate and solubilize membrane-bound proteins. Furthermore, some detergents can dissolve recombinant proteins, whereas others are intended to stabilize, crystallize, or denature proteins [11].

Chemical constituents of detergent

Based on their characteristics and functions in the final product, the chemical components of detergent generally fall into five classes: surfactants, builders, bleaching agents, enzymes, and minors, each of which will be examined in further detail below:

- Surfactants: Surfactant is an abbreviation for the phrase surface-active-agent. They represent a class of molecules that can alter the interfacial characteristics of the liquids in which they are present. The most significant characteristic of a surfactant is its efficacy in wetting and soil removal. Environmental effects and costs must also be addressed, especially for high-volume consumer items such as laundry detergents, floor cleaners, and dishwashing supplies [12].
- Builders: The functionalities of builders are diverse and continuously changing. In addition, they rely on the culture of each major detergent manufacturer and even the region in which they operate. However, the most crucial roles of a builder system are to minimize the negative impacts of water hardness, to provide an alkaline buffer, and to avoid soil redeposition [13].
- Bleaching agents: Occasionally, the surfactants or builders are unable to completely remove specific soils, such as blood, fruit, wine, coffee, and tea stains. In such cases, Bleaching agents (oxidizing chemicals), which are based on peroxygen or halogens are necessary to remove such stains [14].
- Enzymes: Enzymes are more frequently used in laundry powders than in liquid detergents as they are less stable. Modern laundry detergents contain a combination of enzymes that break down protein, starch, and even oily soils. They are not often employed in hand-use products due to their instability under processing conditions and their tendency to irritate the skin [15].
- Minors ingredients: In most formulations, fragrance and color are categorized as “minor ingredients” since they do not contribute to the technical elements of the performance. However, on certain occasions, the fragrance plays an active role, and fragrance components have indicated bactericidal capabilities [16].

Different types of surfactants based on molecular structure

Surfactants are organic molecules with structural diversity. In general, surfactant molecules are composed of two constituents: an extended, hydrophobic hydrocarbon moiety and a polar or charged headgroup. In its simplest form, the hydrocarbon component of a surfactant is an unbranched, saturated alkane. Furthermore, the lipophilic group of surfactants may include unsaturated or branched-chain alkanes, aromatic hydrocarbons, or steroid moieties, occasionally in combination. The variability of the hydrophilic headgroup is significantly higher [17]. Surfactants are divided into four

[DOI: 10.22034/JAERT.1.4.53]

classes based on the features of the hydrophilic pole, which will be discussed in further detail below [18]:

- Anionic Surfactants: Historically, anionics are the first and most prevalent type of surfactant. The majority of them are affordable and manufactured in large quantities. They are especially advantageous due to their effective deterrent effect and their ability to remove dirt particles. This advantage derives from the fact that several substrates are negatively charged. Anionic surfactants typically include a sodium, potassium, or ammonium group. In addition, linear chains are preferable since they are more effective and degradable than branching chains [19].
- Cationic Surfactants: Cationic surfactants have a positively-charged nitrogen atom and at least one hydrophobic, long-chain substituent. They are widely utilized as conditioning agents in hair care and fabric care products (e.g., dialkyl or diester quaternary ammonium salts in rinse fabric softeners). Also, certain cationics, such as dodecyl dimethyl benzyl ammonium chloride, and cetyl trimethyl ammonium chloride, are also employed as germicides (bactericides and fungicides) [20].
- Non-ionic Surfactants: Non-ionic surfactants do not ionize in solution. They are particularly beneficial due to their resistance to water hardness and pH. They are also effective in removing oily types of soil. Due to their compatibility with charged molecules, they may be easily combined with other ionics to form relationships that are frequently advantageous (ex., non-ionics can assist dissolve calcium or magnesium salts of anionics). The most common non-ionic surfactants are those based on ethylene oxide, referred to as "ethoxylated" [21].
- Amphoteric Surfactants (zwitterionic Surfactants): This type of surfactant is an ionic surfactant that, depending on the pH value, can switch between anionic properties, the isoelectric neutral stage, and cationic properties. Since the optimal surface action of amphoterics occurs at a neutral pH, they are highly valued in personal care products for their gentleness and friendliness with the skin. Amphoterics have features of resistance to electrolytes, acids, alkalis, and hard water [22].

The impacts of detergents on the environment

Currently, there has been considerable attention given to the environmental impacts that arise from both the manufacturing and utilization of detergent products. In response, the detergent industry has exhibited a burgeoning interest in the creation of environmentally friendly products, which have progressively occupied a larger portion of the market, particularly with the emergence of biotech industries. The necessity for sustainability has instigated a transformation within the detergent industry that may result in a deviation from synthetic surfactants towards more sustainable alternatives, commonly known as green surfactants [23]. The following are some of the environmental impacts caused by detergents:

- The impacts of detergents on aquatic ecosystems: Based on the literature, the long-term stability of non-biodegradable compounds in detergents generates foam in the environment that spreads with water and wind resources and can ultimately transport pollution over large distances. This layer of foam limits the rate of oxygen penetration from the air into water, causing aquatic organisms to improperly absorb dissolved oxygen [24]. Eventually, an increase in the concentration of organic compounds as a consequence of the death and decomposition of algae, which leads to a decrease in dissolved oxygen levels, is a crucial factor in the death of aquatic organisms and the loss of biodiversity in an ecosystem [25].
- The impacts of detergents on terrestrial ecosystems: The entry of detergent-contaminated water (containing high concentrations of salts and surfactants) causes progressive destruction of the soil structure and adversely affects the health of plants. Furthermore, the pH of the soil increases when detergent is added. Increasing the pH of the soil leads to the separation of soil components, a change in the biological activity levels of the soil, and the loss of organic compounds from the soil [26]. It is important to note that soil irrigation with water that contains detergents increases the electrical conductivity of the soil, which increases soil salinity over time [27].
- The effects of detergents on wastewater treatment: High chemical concentrations in wastewater generated by domestic and industrial detergent consumption are sources of several environmental issues (this type of wastewater contains large amounts of ammonia, sulfates, and methylene blue active substances) [28]. Depending on their chemical structures, different types of synthetic detergents have varying effects on effluent treatment. Due to the low ratio of biological oxygen demand (BOD)5 to chemical oxygen demand (COD), the biodegradability of wastewater containing detergent is often low [29].

[DOI: 10.22034/JAERT.1.4.53]

The objective of this study

Detergents have been the topic of numerous studies. However, few attempts have been made to provide a comprehensive overview of detergent research, but no bibliometric articles have been published in this field since 2000. Consequently, the objective of this paper is to discuss the significance of detergents from several perspectives and to conduct a comprehensive analysis of all articles published on this subject between 2000 and 2022. This research will lead to a better understanding of the existing and future state of detergent research worldwide.

Material and Methods

Bibliometric method

This investigation employed a descriptive quantitative methodology in conjunction with bibliometric analysis. The discipline of bibliometrics relies on mathematical and statistical methodologies to effectively assess qualitative and quantitative transformations within a corpus of documents and other various forms of media. The expression "bibliometric analysis" pertains to a methodology of a quantitative nature that can be utilized to scrutinize bibliographic information in articles and journals. It is customary to undertake the present analysis to scrutinize the allusions to scientific publications cited in a journal, delineate the scientific domain of the periodical, and categorize scientific articles based on their respective fields of study. This particular approach proves to be advantageous across a range of social fields encompassing sociology, the humanities, communication, and marketing. The present study comprises bibliometrics, which is the culmination of several components such as the selection of data from a vast database, the conversion of data into bibliometric software, and the evaluation of data utilizing statistical analysis and network visualization maps. These components are expounded in greater detail in the ensuing sections. Throughout this investigation, a multitude of factors was examined, encompassing the number of publications, document type, subject area, scientific journals, prominent institutions, and nations, as well as the most frequently used keywords in the field [30].

Social Network Analysis (SNA)

Social network analysis refers to a collection of normative methodologies that are employed to assess social relationships and structures. The emergence of sociometrics has led to the development of this field. The focus is directed toward the interrelationships among individuals rather than their traits. The study utilizes network structures that are founded on the inner connections existing among diverse social actors. The nodes in this investigation embody the countries and phrases, and the links demonstrate the interdependencies among the nodes. In this study, the VOSviewer 1.6.19 application, which is commonly considered a highly valuable instrument for Social Network Analysis (SNA), was employed [31].

Data collection

The Scopus database was employed to identify research on detergents. Scopus, the foremost repository of abstracts and citations of scholarly articles (encompassing scientific journals, books, and conference papers), stands as the largest collection of its kind in the world [32]. In this study, bibliometric data from all detergent-related journal papers published between 2000 and 2022 were investigated and carefully examined; publications with the word "Detergent" in the "Title," "Abstract," or "Keywords" were carefully examined and scrutinized. On July 4, 2023, all the data needed for this article was gathered.

Only published scientific articles were examined for this study, though 44520 scientific documents on the topic of detergents were published between 2000 and 2022. There are 35 distinct languages represented in the articles. Fig. 1 demonstrates the variety of languages utilized in the publication of articles. Among the 37,650 published articles, 92.35 percent (34771) were written in English, followed by Portuguese at 2.8 percent (1053), Chinese at 2.3 percent (869), and Spanish at 1.02 percent (385).

Results and Discussion

Publication growth trend analysis

Fig. 2 illustrates the trend of publications, encompassing the number of scientific articles published in journals and citations per year. Detergents have been a hot topic for many years, with research dating back to 1903. In the year 2000, there were 1372 articles published, and in the year 2022, there were 2008 pieces published, demonstrating a tendency toward a slightly increased number of articles being published. In 2020, the COVID-19 pandemic created a worldwide health crisis. Several precautions have been recommended to prevent the spread of the pandemic, such as disinfection. One of the disinfection techniques is mechanical treatment which includes the disinfection of surfaces

[DOI: 10.22034/JAERT.1.4.53]

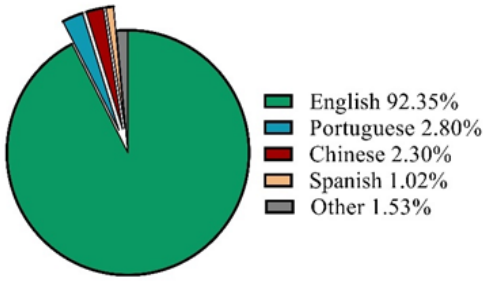

Figure 1. Distribution of publication language

by detergent action. Due to this, the COVID-19 pandemic prompted significant changes in the detergent industry and a substantial increase in the number of papers published in this sector in 2020. Moreover, according to the data provided by MarketsandMarketsTM, it is predicted that the industry of cleaning products worldwide shall attain a growth rate of $46.8 billion in the year 2019. Further estimates suggest that this value shall increase to $58.3 billion by the year 2024, and the annual growth rate is expected to be around 4.5% [23]. Consequently, it is reasonable to expect that there will be a significant increase in research related to detergent products in the next few years. This particular perspective is based on various elements, including the increasing cognizance of the populace globally concerning matters about health, sanitation, and tidiness.

Upon examining the comprehensive citation chart and taking into account the high quality of detergent publications released in previous years, it is evident that there has been a notable escalation in the number of citations for each year. Articles published in 2003 received the highest number of citations (75338). The declining trend in citations in recent years can be linked to the fact that publications are becoming less well-known and have therefore received less exposure.

Subject categories

This section examines the subject categories of the selected papers. Detergents play a role in many aspects of life and are continually present in people's daily lives. Accordingly, articles in this field cover a wide range of disciplines. As shown in Fig. 3, only the subject categories that account for more than 3% of the selected articles are discussed in this article. Moreover, it should be noted that an article might cover more than one subject category. The main subject categories are biochemistry, genetics, and molecular biology, which comprise around 23% of all published works. Subsequently, Agricultural and Biological Sciences are responsible for 19 percent of all publications, and medicine is responsible for approximately 8 percent of all articles. The remaining subject categories together account for 13% of the total and include fields such as pharmacology, toxicology, and pharmaceutics, as well as physics and astronomy, energy, and other related topics.

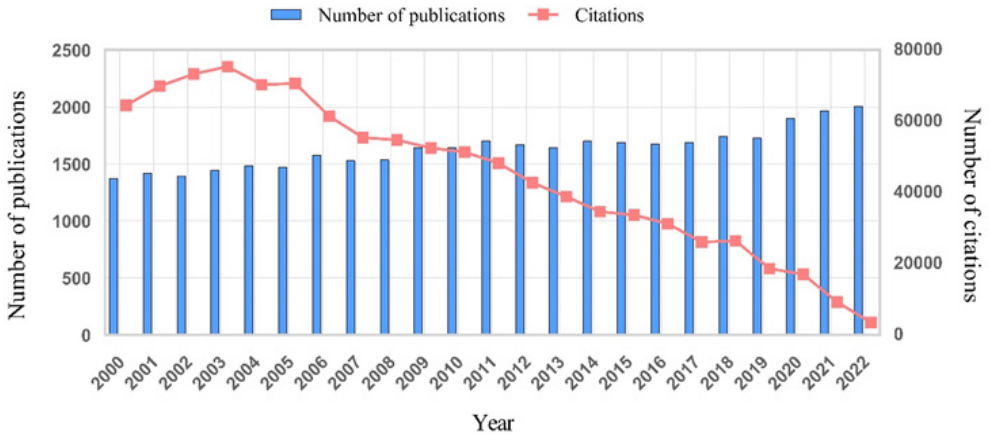

Figure 2. Trends in the number of publications and citations

Journals

According to Table 1, 5399 papers were published in the 10 most productive journals between 2000 and 2022. The "Journal of Biological Chemistry" is the most productive journal, with 1006

[DOI: 10.22034/JAERT.1.4.53]

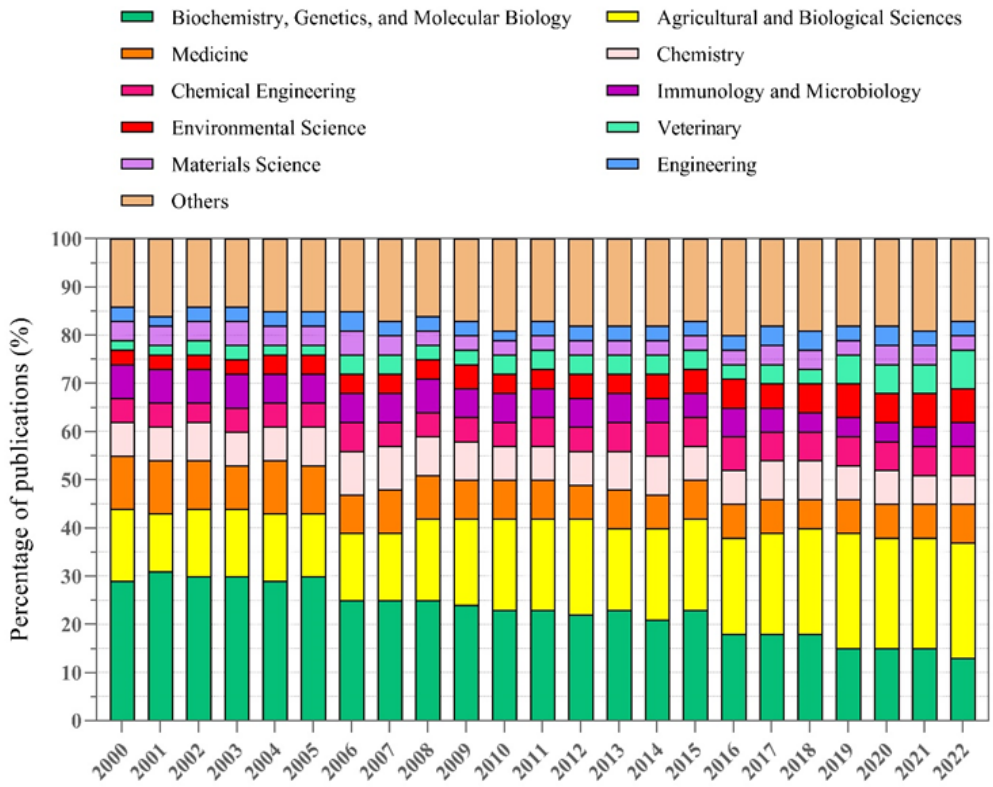

Figure 3. The annual percentage of the most significant subject categories during 2000-2022

publications. As can be seen, the United States is a pioneer in this field of study, with approximately 63 percent of publications published in the top 10 journals, followed by the Netherlands (21%), Brazil (11%), and South Korea (5%).

The diversity of publications in the H-index, as well as the years since the first issue was published, are two of the most intriguing features of the table. As previously stated, detergents have been one of the most important topics in the past. The second-ranked journal in this ranking is the Journal of Dairy Science, which has been published for over a century. In addition, 5 journals are over 50 years old, whereas new journals that have only been published for a short period have been eligible for inclusion in this chart. For example, Plos One, a journal launched in the early years of the twenty-first century, is regarded as one of the top publications in the field of detergents, ranking sixth. Furthermore, as a magazine's popularity grows, higher ranks are likely. It is worth noting that the journal has an h-index of 404, which is a good number given the short time since its founding. Another noteworthy point of this table is the "Proceedings of the National Academy of Sciences of the United States of America" ranked 9 with an h-index of 838 and an IF of 12.779.

Al Fig. 4 demonstrates the trends in the five journals with the highest number of publications. The "journal of biological chemistry" was a pioneer in this field until the year 2007, but since then, the "journal of dairy science" has published the most articles in this field, making it the leading publication in this field.

Authors

Table 2 lists the top ten productive authors in this field of research. It also includes other bibliometric factors like country of work affiliation and h-index to assist in understanding each author's productivity. The number of articles containing detergents keyword between 2000 and 2022 is displayed in the third column. Between these years, the top 10 authors have written a total of 717 articles. According to the fifth column, approximately 27% of the 717 articles were published by researchers in Brazil (the vast majority of which were carried out by the Federal University of Vicosa (UFV)), followed by Canada and Sweden with 21% and 19% respectively. It is worth noting that no journals from Canada or Sweden are in the top 10 journals. Detmann, E. from Sweden maintaining the top spot by a significant margin (almost twofold) over the authors who follow him. T.A. McAllister holds a prominent position at the table. He possesses the maximum h-index score of 82.

Fig. 5 illustrates the annual trends in the publica-

[DOI: 10.22034/JAERT.1.4.53]

Table 1. Top ten most productive journals within the dataset

#	journal	journal #	H-index	country	IF 2022
1	Journal of Biological Chemistry	1006	544	USA	5.5
2	Journal of Dairy Science	1001	216	USA	3.5
3	Animal Feed Science and Technology	791	134	Netherland	3.2
4	Revista Brasileira De Zootecnia	568	59	Brazil	1
5	Biochemistry	506	269	USA	2.9
6	Plos One	417	404	USA	3.7
7	Biochimica Et Biophysica Acta Biomembranes	344	200	Netherland	3.4
8	Asian Australasian Journal of Animal Sciences	267	0	South Korea	2.694
9	Proceedings of the National Academy of Sciences of The United States of America	258	838	USA	12.779
10	Protein Expression and Purification	241	94	USA	1.6

tions of the top five most productive authors. The year 2011 had the highest number of publications. Between 2008 and 2014, "Detmann" held the top rank for publishing the most articles among the top five authors researching detergents throughout that time.

According to the co-authorship analysis achieved by VOSviewer software, the author collaborations are shown in Fig. 6. To be taken into account, each author must have published at least 30 publications. Ten clusters were produced from 136 items and 1430 links.

Countries

Fig. 7 displays the global distribution of publications linked to detergents published between 2000 and 2022 and divides the world's 195 countries into nine categories. The United States of America is the only territory in the world to have written more than four thousand articles on detergents.

Table 3 shows the top 10 countries in terms of the number of published articles on detergents. These countries are determined by the nationality of at least one of the authors; therefore, one article may belong to multiple countries based on the nationality of the authors. Among the 10 countries listed in the table, the United States ranked first, with 9424 articles, followed by China, Brazil, Germany,

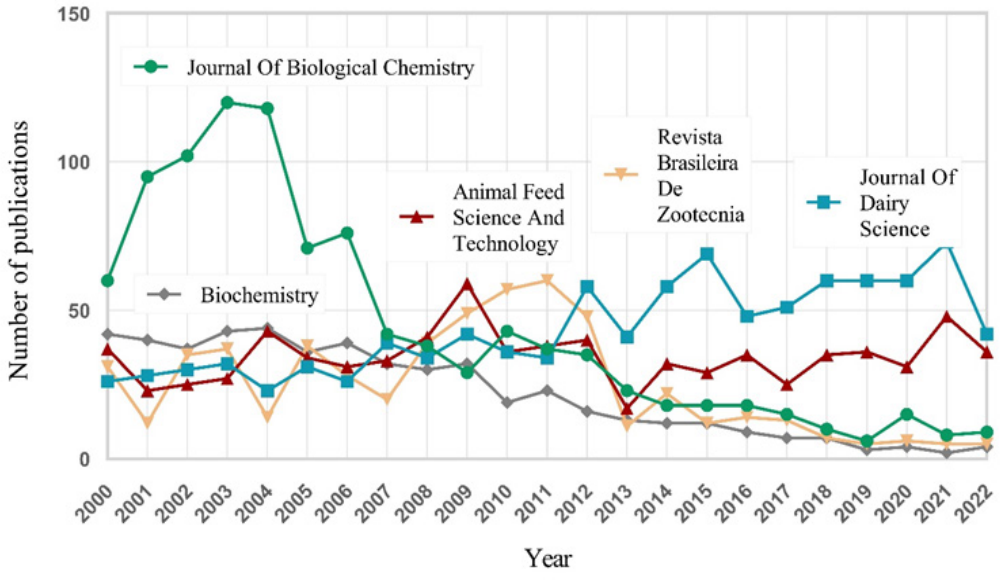

Figure 4. Comparison of publications of the top 5 journals in detergents research

[DOI: 10.22034/JAERT.1.4.53]

Table 2. Top ten most productive authors within the dataset

#	Author	Total number of documents	Affiliation	Country	H-index
1	Detmann, E.	140	Sveriges lantbruksuniversitet	Sweden	35
2	Beauchemin, K.A.	81	Lethbridge Research and Development Centre	Canada	77
3	Paulino, M.F.	81	Universidade Federal de Vicosa	Brazil	30
4	McAllister, T.A.	67	University of Manitoba	Canada	82
5	Huhtanen, P.	65	Natural Resources Institute Finland (Luke)	Finland	55
6	Dijkstra, J.	58	Wageningen University & Research	Netherland	65
7	Wanapat, M.	58	Khon Kaen University	Thailand	40
8	Oliveira, R.L.	57	Universidade Federal da Bahia	Brazil	21
9	Silva, R.R.	56	Universidade Estadual do Sudoeste da Bahia	Brazil	21
10	Chae, P.S.	54	Hanyang University ERICA Campus	South Korea	28

and the United Kingdom, with 3281, 3039, 2707, and 2337 articles, respectively. The number of independent and collaborative papers generated by these nations has also been presented. Independent publications were written entirely by a single nation. The United States, which occupies the top position in this ranking, published around 68 percent of its publications independently, while 32 percent were published in collaboration with other countries. Developed European countries such as the United Kingdom, and France have published more than half of their publications in collaboration with other countries. For instance, the United Kingdom has published over 53% of its publications in collaboration with foreign academics, whereas India has published only about 14 percent of its articles in collaboration with foreign researchers. In addition, approximately 83 percent of Brazilian articles have been published in partnerships with native academics. The United States has the most citations of any country with 422450, followed by Germany and the United Kingdom with 108327 and 95473 citations, respectively, indicating that studies from the United States have been better welcomed by

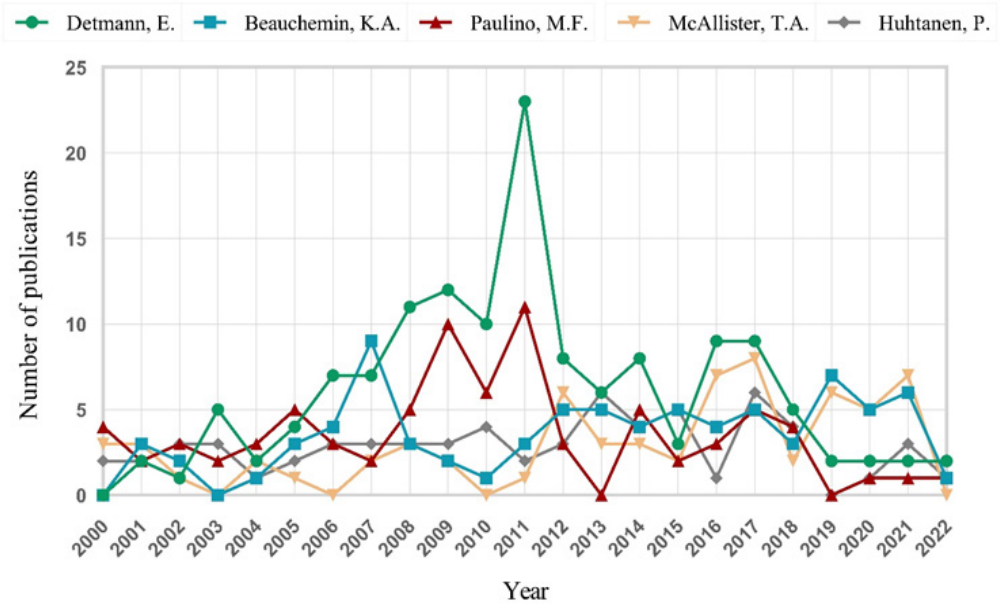

Figure 5. Comparison of publications of the top 5 authors in detergents research

[DOI: 10.22034/JAERT.1.4.53]

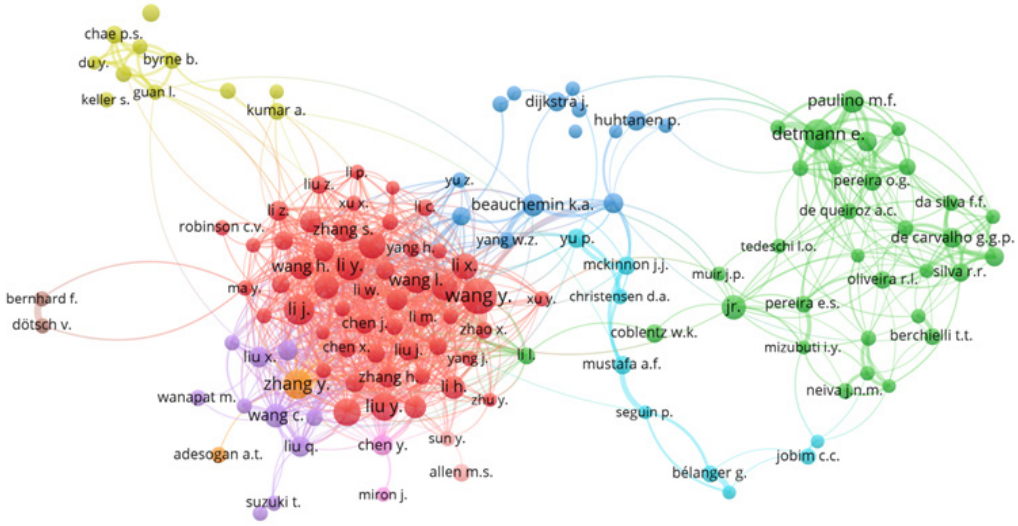

Figure 6. Collaborations of authors based on the co-authorship relations

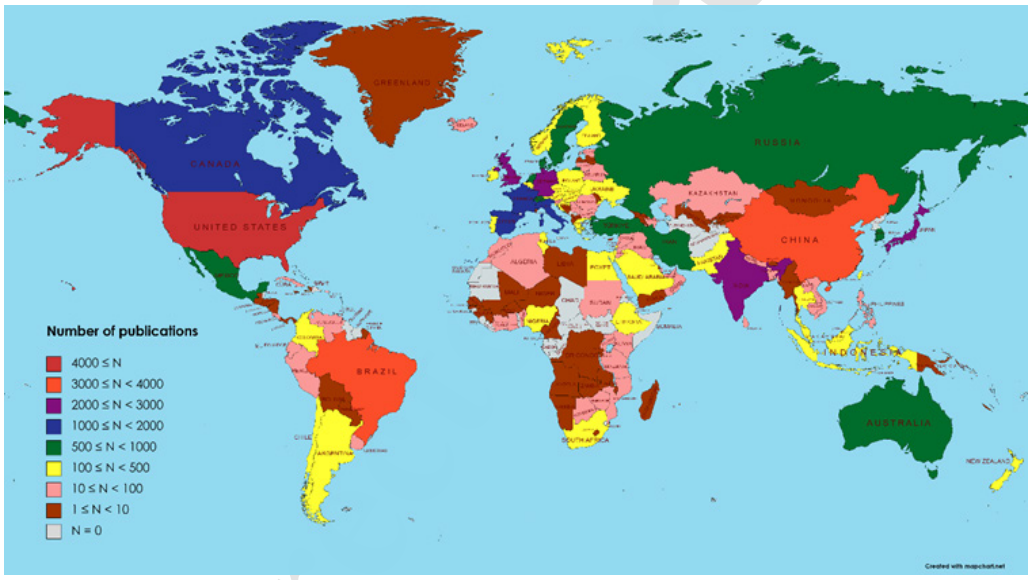

Figure 7. Geographical distribution of detergents research

other academics.

Fig. 8 shows the annual trends of the top 5 most productive countries. As can be seen, the United States consistently ranks first until 2022. However, it should be emphasized that the gap with other countries has narrowed in recent years. In this graph, we can also see the growth of China and Brazil, both of which have seen large increases in the number of publications on detergents in recent years, and for the first time, China was ranked first in 2022.

The co-authorship network analysis between countries in detergent studies is depicted in Fig. 9. As can be seen, 63 items and 1115 links make up 8 clusters. Some of these countries (such as the United States) are at the center of the network, implying that they are more likely to cooperate with other countries. Each node in this graph symbolizes a country and the lines connecting the two nodes (countries) illustrate their cooperation. The strength of the relationship is measured by the number of times the two countries have collaborated. The total number of times a country has collaborated with other countries is the overall connection strength. The United States and China are the most notable circles due to their high number of publications and link strengths of 3037 and 796 respectively.

Table 4 lists the countries with the highest number of collaborations. The United States has consistently been one of the countries with the highest levels

[DOI: 10.22034/JAERT.1.4.53]

Table 3. Top ten most productive authors within the dataset

#	Country	Documents	Independent		Joint		Citations
			Number	٪	Number	٪	
1	United states	9424	6330	67.16	3094	32.84	422450
2	China	3281	2468	75.22	813	24.78	44084
3	Brazil	3039	2530	83.25	509	16.75	38014
4	Germany	2707	1360	50.24	1347	49.76	108327
5	United Kingdom	2337	1079	46.17	1258	53.83	95473
6	Japan	2209	1570	71.07	639	28.93	63655
7	India	2085	1832	87.86	253	14.14	37637
8	Canada	1732	911	52.59	821	47.41	56289
9	France	1714	836	48.77	878	51.23	65531
10	Italy	1202	691	57.48	511	42.52	36726

of cooperation. This could be related to the fact that the US has conducted far more research than other countries. As a result, it is logical that the majority of cooperation would be with the United States. In addition, with 382 articles, the United States and the United Kingdom had the most cooperation.

Table 5 summarizes the leading detergent manufacturers worldwide. Notably, the countries in which these companies are located have conducted the most research in this field. It is also worth noting that most companies in this ranking are multinational. The presence of a significant number of prominent detergent firms in the North American region, all of which are continuously researching and creating new and innovative products, has resulted in an expansion of this region's detergent market. Furthermore, owing to the rising demand for personal hygiene products and cosmetics, Europe appears to contribute significantly to the growth of the detergent industry.

Authors keywords

The co-occurrence of keywords was studied using networking maps and VOSviewer. Each node represents a keyword and each curve represents

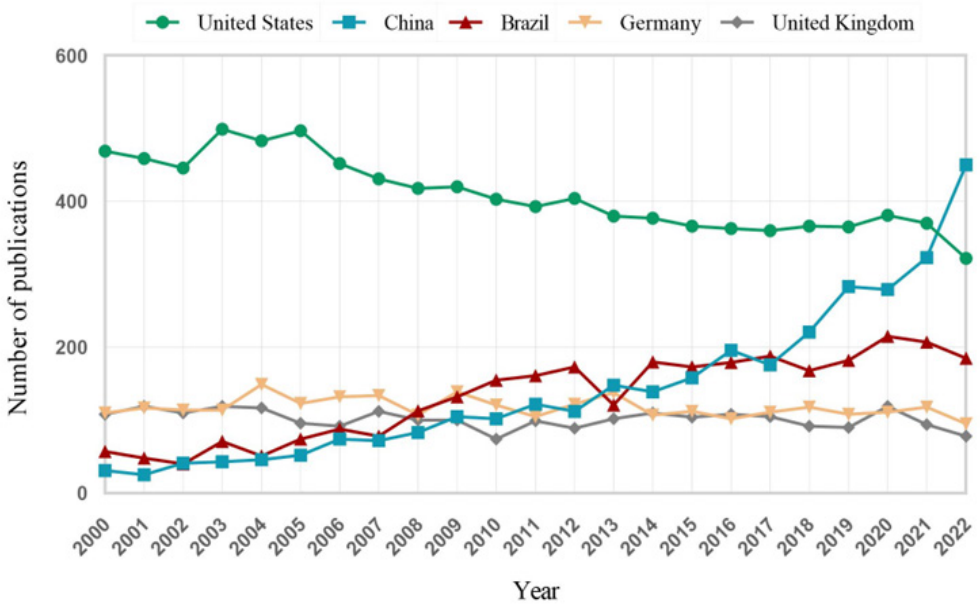

Figure 8. Comparison of publications of the top 5 countries in detergents research

[DOI: 10.22034/JAERT.1.4.53]

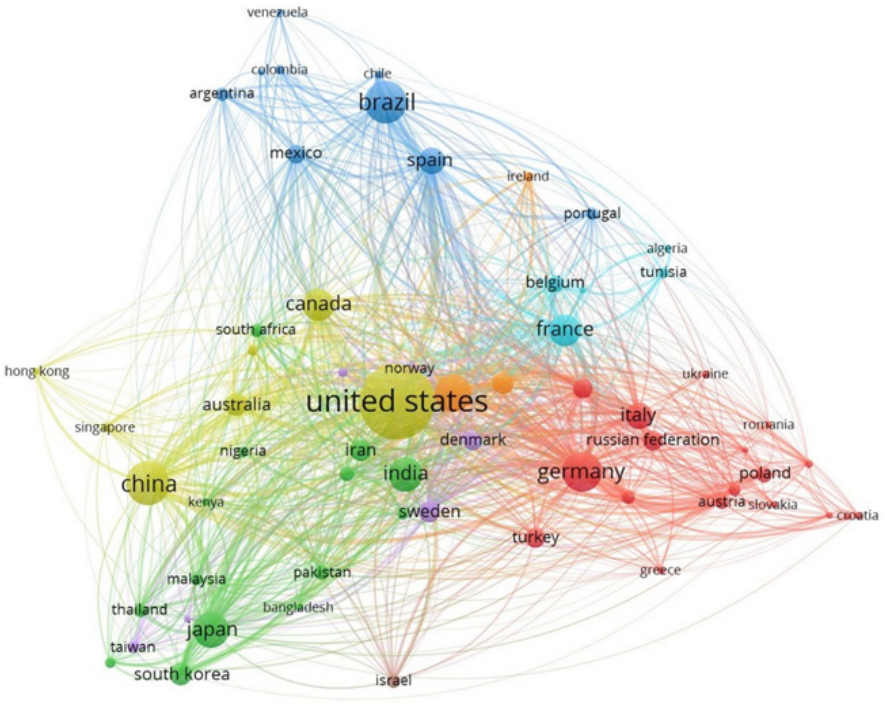

Figure 9. Collaborations of countries based on the co-authorship relations

Table 4. Countries with the highest number of collaborations

Rank	1st country	2nd country	number of publications
1	United States	United Kingdom	382
2	United States	Canada	353
3	United States	Germany	335
4	United States	China	288
5	United States	Japan	216

a link between two linked keywords. To analyze Authors' keywords in VOSviewer software, the minimum number of occurrences was set to 50. As shown in Fig.10, 5687 links, and 234 items generated six clusters.

Table 6 lists the keywords with the highest occurrences in each cluster. The word "digestibility" appears 1310 times, followed by "detergent" and "detergents" 955 and 619 times, respectively. The first cluster includes terms such as membrane proteins, lipid rafts, and mitochondria, which are largely related to cells and their interactions with chemicals. The detergents and cleaners are placed together in the second cluster to constitute the field of study. The third cluster is related to dairy and livestock products. The fourth cluster includes foodstuffs, such as proteins, fibers, and animal fodder, which are all clustered together. The distinction between this cluster and the third cluster is that the third cluster discusses dairy products, whereas the third cluster discusses raw food. The fifth cluster focuses on chemicals, such as crude protein, neutral detergent fiber, starch, NDF, and lignin. Finally, the sixth cluster is concerned with cellular tissue, the majority of which is concerned with decellularization.

Fig. 11 depicts the overlay visualization of author keywords. The issues highlighted in yellow are more recent, whereas those highlighted in blue are older. Most of the keywords were from 2010 to 2016. In recent years, topics such as decellularization, growth performance, fermentation quality,

[DOI: 10.22034/JAERT.1.4.53]

Table 5. The leading detergent manufacturers worldwide

Company	Country	Headquarters
AkzoNobel	Dutch Multinational Company	Amsterdam, Netherlands
Huntsman Corporation	American Multinational Company	Texas, United States
Solvay S.A.	Belgium	Brussels, Belgium
BASF SE	German Multinational Company	Ludwigshafen, Germany
Dow Chemicals	American Multinational Company	Michigan, United States
Tata Chemicals	India	Mumbai, India
Procter & Gamble	American Multinational Company	Ohio, United States
Dial Corp	United States	Arizona, United States
Clariant AG	Swiss Multinational Company	Muttenz, Switzerland
Unilever	British Multinational Company	London, United Kingdom
Shell Chemicals	United States	Texas, United States
Airedale Chemicals	United Kingdom	Keighley, United Kingdom
Colgate	American Multinational Company	New York, United States
International Detergent Chemicals Ltd	Ireland	Cork, Ireland
Condea Servo LLC	United States	Illinois, United States

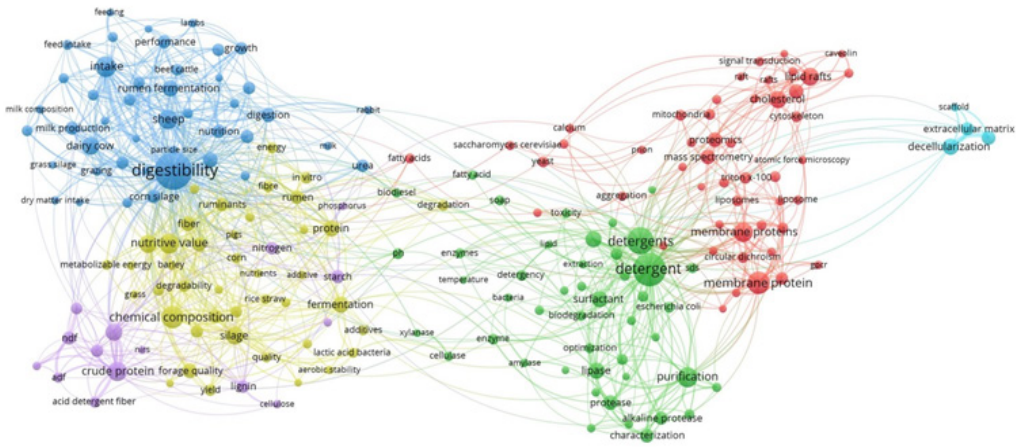

Figure 10. Co-occurrence network of author keywords

and feed efficiency have become trendy. In addition, the review of keywords reveals that the focus of recent research has been on the development of cleaning products that are effective, user-friendly, and safe for consumers and the environment.

Conclusion

Detergents have been one of the most vital aspects of human life for centuries. In this study, bibliometric analysis was used for the first time to perform a comprehensive literature review on detergents. Research trends and future directions of detergent studies were identified using bibliometric indicators. The results demonstrated that detergent

[DOI: 10.22034/JAERT.1.4.53]

Figure 10. Co-occurrence network of author keywords

Cluster	Keyword	Occurrence	Total link strength	Color
Cluster 1	Membrane protein	429	218	Red
	Membrane proteins	331	170	
	Lipid rafts	260	132	
	Cholesterol	234	153	
	Mass spectrometry	186	103	
	Proteomics	173	91	
	Lipid raft	165	81	
	NMR	133	85	
	Triton x-100	131	71	
	Mitochondria	111	52	
Cluster 2	Detergent	955	534	Green
	Detergents	619	261	
	Purification	346	238	
	Lipase	249	155	
	Surfactants	229	112	
	Surfactant	228	132	
	Protease	189	126	
	Characterization	178	135	
	Alkaline protease	154	92	
	Cleaning	117	57	
Cluster 4	Digestibility	1310	1085	Yellow
	Intake	362	333	
	Sheep	336	284	
	Rumen fermentation	282	212	
	Dairy cow	265	170	
	Methane	201	165	
	Performance	184	144	
	Digestion	173	143	
	Milk production	165	136	
	Nutrition	158	115	
Cluster 5	composition	351	293	Purple
	Nutritive value	255	213	
	Silage	154	125	
	Forage	145	132	
	Protein	144	117	
	Fermentation	134	108	
	Forage quality	133	123	
	Fiber	128	108	
	Gas production	113	102	
	Rumen	97	96	

[DOI: 10.22034/JAERT.1.4.53]

Cluster 6	Decellularization	282	191	Light blue
	Tissue engineering	187	136	
	Extracellular matrix	164	118	
	Scaffold	56	45	

research has advanced significantly throughout the examined period, and the number of publications on this subject has grown dramatically. The analysis of the subject categories illustrates the multidisciplinary nature of this field. “Biochemistry, genetics, and molecular biology” make up 23 percent of the 37650 selected articles, which is more than any other subject category. The most productive journal is “Journal of Biological Chemistry,”

Acknowledgements: The authors would like to acknowledge K. N. Toosi University of Technology for their valuable supports throughout this study.

Authors contributions: Mohammadreza Hajbabaie, Mohammad Reza Sabour, Hamid Zarrabi, Ghorbanali Dezvareh, and Amir Mostafa Hatami have contributed equally. All authors read and approved the final manuscript.

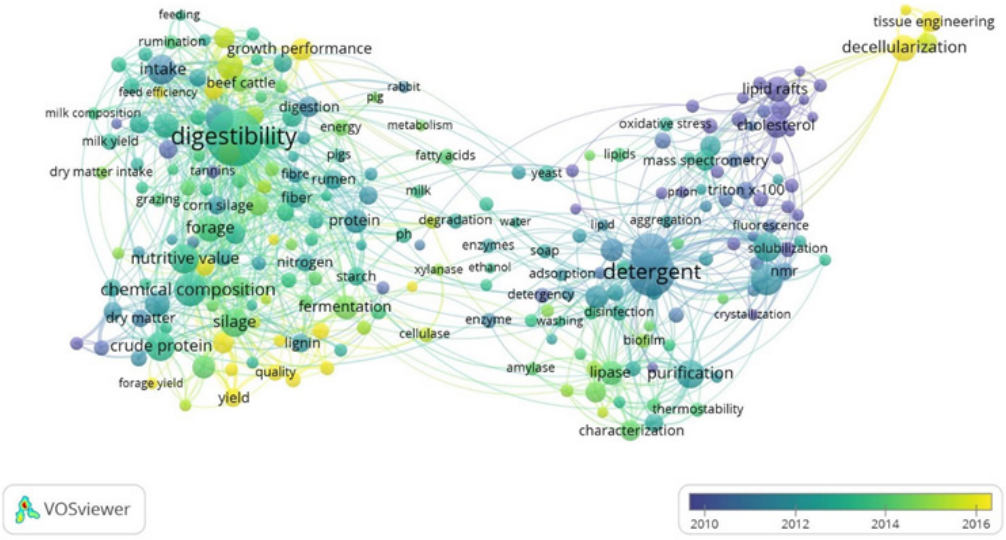

Figure 11. Overlay visualization of author keywords

with 1006 published papers. The top researchers are “Detmann, E.,” “Beauchemin, K.A.,” and “Paulino, M.F.,” with 140, 81, and 81 documents, respectively. The United States, China, and Brazil are the top three contributing countries in this field of research, respectively. The existence of many leading detergent companies in North America, all of which are actively researching and developing new and creative products, has led to the expansion of the detergent market in this region. According to the analysis of the keywords, “digestibility,” “detergent,” “detergents,” “membrane protein,” “chemical composition,” and “Nutritive value” were the most frequently occurring keywords from 2000 to 2022. Recent research has emphasized the development of cleaning products that are effective, user-friendly, and safe for consumers and the environment.

[DOI: 10.22034/JAERT.1.4.53]

References

[1] S. M. John, J. D. Johansen, T. Rustemeyer, P. Elsner, and H. I. Maibach, Kanerva ' s Occupational Dermatology. 2020.

[2] L. Spitz, Soap Technology for the 1990's. American Oil Chemists' Society, 1990.

[3] M. Willcox, "454 Poucher's Peifumes, Cosmetics and Soaps," pp. 453–465, 2000.

[4] T. A. Aboul-Kassim and B. R. T. Simoneit, "Detergents: A review of the nature, chemistry, and behavior in the aquatic environment. Part I. Chemical composition and analytical techniques," Crit Rev Environ Sci Technol, vol. 23, no. 4, pp. 325–376, Jan. 1993, doi: 10.1080/10643389309388456.

[5] Soap and D. Association, Soaps and Detergents. SDA, 1994. [Online]. Available: https://books.google.com/books?id=hxgeywEACAAJ

[6] E. Smulders, W. Rähse, W. von Rybinski, J. Steber, E. Sung, and F. Wiebel, "Household laundry products," Laundry Detergents, pp. 98–120, 2003.

[7] H. Ranji, B. Babajanzadeh, and S. Sherizadeh, "Detergents and surfactants: a brief review," Open Access Journal of Science, vol. 3, no. 2, pp. 94–99, 2019, doi: 10.15406/oajs.2019.03.00138.

[8] M. Giagnorio, A. Amelio, H. Grüttner, and A. Tiraferri, "Environmental impacts of detergents and benefits of their recovery in the laundering industry," J Clean Prod, vol. 154, pp. 593–601, 2017, doi: 10.1016/j.jclepro.2017.04.012.

[9] M. Showell, Handbook of detergents, part D: formulation. CRC Press, 2016.

[10] S. Zabarnick and R. R. Grinstead, "Studies of Jet Fuel Additives using the Quartz Crystal Microbalance and Pressure Monitoring at 140 °C," Ind Eng Chem Res, vol. 33, no. 11, pp. 2771–2777, 1994, doi: 10.1021/ie00035a029.

[11] E. Dauty, J. S. Remy, T. Blessing, and J. P. Behr, "Dimerizable cationic detergents with a low cmc condense plasmid DNA into nanometric particles and transfect cells in culture," J Am Chem Soc, vol. 123, no. 38, pp. 9227–9234, 2001, doi: 10.1021/ja015867r.

[12] H. I. Maibach, "Surfactants: Classification Louis Oldenhove de Guertechin," in Handbook of Cosmetic Science and Technology, CRC Press, 2009, pp. 787–804.

[13] D. Joubert, R. Gresser, and J.-P. Cuif, "Properties of Builders: Nonphosphate Builders," in Handbook of Detergents, Part A, CRC Press, 1999, pp. 511–558.

[14] V. Croud, "Oxygen bleaches," in Handbook of Detergents, Part A, CRC Press, 1999, pp. 597–618.

[15] A. Crutzen and M. L. Douglass, "Detergent enzymes: a challenge!," in Handbook of Detergents, Part A, CRC Press, 1999, pp. 639–690.

[16] J. Ramsbotham, "Perfumes in detergents," in Handbook of Detergents, Part A, CRC Press, 1999, pp. 691–720.

[17] D. Linke, Chapter 34 Detergents. An Overview, 1st ed., vol. 463, no. C. Elsevier Inc., 2009. doi: 10.1016/S0076-6879(09)63034-2.

[18] M. X. Quintanilla-Carvajal and S. Matiacevich, "Role of surfactants and their applications in structured nanosized systems," Food Engineering Series, no. May 2015, pp. 177–186, 2015, doi: 10.1007/978-3-319-13596-0_10.

[19] H. W. Stache, Anionic surfactants: organic chemistry, vol. 56. CRC Press, 1995.

[20] D. Rubingh, Cationic surfactants: physical chemistry, vol. 37. CRC Press, 1990.

[21] D. Bajpai and V. K. Tyagi, "Laundry detergents: an overview.," J Oleo Sci, vol. 56, no. 7, pp. 327–340, 2007, doi: 10.5650/jos.56.327.

[22] J. E. Coligan, "Commonly Used Detergents," Curr Protoc Protein Sci, vol. 11, no. 1, pp. 3–5, 1998, doi: 10.1002/0471140864.psa01bs11.

[23] C. B. B. Farias et al., "Production of green surfactants: Market prospects," Electronic Journal of Biotechnology, vol. 51, pp. 28–39, 2021.

[24] D. S. Rajan, "An evaluation of the effect of a detergent on dissolved oxygen consumption rate of Anabas testudineus," Int. J. Fish. Aquat. Stud, vol. 2, no. 6, pp. 46–48, 2015.

[25] S. Rejeki, D. Desrina, and A. R. Mulyana, "Chronic affects of detergent surfactant (linear alkylbenzene sulfonate/LAS) on the growth and survival rate of sea bass (Lates calcalifer Bloch) larvae," Journal of Coastal Development, 2008.

[DOI: 10.22034/JAERT.1.4.53]

[26] A. Wiel-Shafran, Z. Ronen, N. Weisbrod, E. Adar, and A. Gross, "Potential changes in soil properties following irrigation with surfactant-rich greywater," Ecol Eng, vol. 26, no. 4, pp. 348–354, 2006.

[27] B. Sawadogo, M. Sou, N. Hijikata, D. Sangare, A. H. Maiga, and N. Funamizu, "Effect of detergents from grey water on irrigated plants: Case of Okra (Abelmoschus esculentus) and Lettuce (Lactuca sativa)," Journal of Arid land studies, vol. 24, no. 1, pp. 117–120, 2014.

[28] P. Pandey and B. Gopal, "Effect of detergents on the growth of two aquatic plants: Azolla pinnata and Hydrilla verticillata," Environment \& We: An International Journal of Science and Technology, vol. 5, pp. 107–114, 2010.

[29] A. Papadopoulos, C. Savvides, M. Loizidis, K. J. Haralambous, and M. Loizidou, "An assessment of the quality and treatment of detergent wastewater," Water science and technology, vol. 36, no. 2–3, pp. 377–381, 1997.

[30] A. M. Hatami, M. R. Sabour, E. Alam, H. Zarrabi, and M. Hajbabaie, "A Systematic Analysis of Life Cycle Assessment Studies during 2000-2022," Environmental energy and economic research, vol. 8, no. 2, 2024.

[31] M. R. Sabour, A. M. Hatami, E. Alam, and H. Zarrabi, "A systematic analysis of Sustainable Urban Development research during 2002-2021," Journal of Advanced Environmental Research and Technology, vol. 1, no. 3, pp. 45–55, 2023.

[32] M. R. Sabour, H. Zarrabi, and M. Hajbabaie, "A systematic analysis of research trends on the utilization of life cycle assessment in pharmaceutical applications," International journal of environmental science and technology, vol. 20, no. 10, pp. 10921–10942, 2023.

[DOI: 10.22034/JAERT.1.4.53]