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Past, Current and Future Trends of Salicylic Acid and its Derivatives: A Bibliometric Review of Papers from The Scopus Database Published from 2000 to 2021

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ABSTRACT

Theoretical and practical interest in salicylic acid and its derivatives has increased over the last two decades, and with it, academic study in the field has been burgeoning. Most scientometric studies have only focused on a specific property of the topic compounds. None, however, are discussed in the origination progress and prospects of SA and its derivatives. The present study makes a bibliometric review of 2010 papers published during 2000-2021 which were indexed by Scopus in the sub-discipline of salicylic and salicylates. Periodic trends in publishing, as well as prominent research sub-fields, are detected, as are citation patterns, published journal areas of focus, major research institutions, funding organizations, significant research personalities, and the extent to which they interact with one another in research networks. Used keywords indicated the exact publication timeline. Before 2010, the majority of research focused on the synthesis, structure, chemical, and physical properties of salicylic acid and its derivatives. In the past decade, scientists have dedicated significant attention to identifying the bio-properties of the investigated substances.

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1. INTRODUCTION

Hydroxybenzoic acids are considered polyphenolic acids (Zeb, 2021), and these acids and their derivatives show antipathogenic (Ailincai et al., 2016; Gao *et al.,* 2021, 2022a, 2022b), antimicrobial (Ailincai *et al.,* 2016; Sathiyendran & Anitha, 2018; Fathima *et al.,* 2019; Zhang *et al.,* 2020), anticancer (Durai *et al.,* 2014; Salehi *et al.,* 2019; Slaihim *et al.,* 2019; Shen *et al.,* 2020), antiviral (Mortikov *et al.,* 1991; Gao *et al.,* 2022b), etc. It is known that every day new compounds are synthesized by scientists and discovered in their physicochemical and biological properties. But why this acid and its derivatives have not lost their actuality? Why are scholars in developed countries conducting experiments on these objects continuously?

Bibliometric is effective at providing researchers, stakeholders, and other policymakers with data that may be applied to enhance the quality of research (Hamidah *et al.,* 2020; Husaeni & Nandiyanto, 2022). Thus yet, no scientometric analysis of the trend of salicylic acid and its derivatives as chemical compounds has been performed. More thorough literature-based information will assist the community. Therefore, our research is intended to understand the past, present, and future of SA acid and its derivatives as an important substance.

2. METHODS

Global library of salicylic acid and its derivatives analyzed in the Scopus database from 2000 to 2021 years. Firstly, we searched “salicylic” as a keyword within the article title, abstract and keyword section and found 34,765 published documents between the abovementioned time frames. During the skimming process, we identified that most papers are not fully devoted to the chemistry of salicylic acid (SA) and its derivatives. Then applied the following filters as a retrieval strategy on September 27, 2022: TITLE (salicylic OR salicylate OR 2-hydroxybenzoic OR 2-hydroxybenzoate OR o-hydroxybenzoic OR o-hydroxybenzoate) AND PUBYEAR>1999 AND PUBYEAR <2022 AND (LIMIT-TO (SUBJAREA, "CHEM")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (PUBSTAGE, "final")) (**Figure 1**). Through this refinement, we finally recorded 2010 papers and converted them to CSV and RIS extension. VOSviewer (version 1.6.18; Centre for Science and Technology Studies, Leiden University: Leiden, The Netherlands) (Van Eck & Waltman, 2010) is used to analyze bibliographic coupling, themes, co-authorship, co-occurrence, citation, and co-citations. English is a universal language, therefore, the literature in English is more standard and meaningful than literature in other languages.

3. RESULTS AND DISCUSSION

3.1. Published papers on salicylic acid and its derivatives

To understand the development of salicylic acid and its derivatives in the chemical field, annual publication and citation trends were analyzed shown in **Figure 2.** The publication on salicylic acid and its derivatives research come from 89 countries scattered all over the globe. The figure indicates that from 2000 to 2021, from 42 papers in 2000 to 139 papers in 2021, there is a general upward trend with a slight decrease in the 2016-2020 years. We deduced that researchers are paying high concentration to salicylic acid and its derivatives in the chemical sector.

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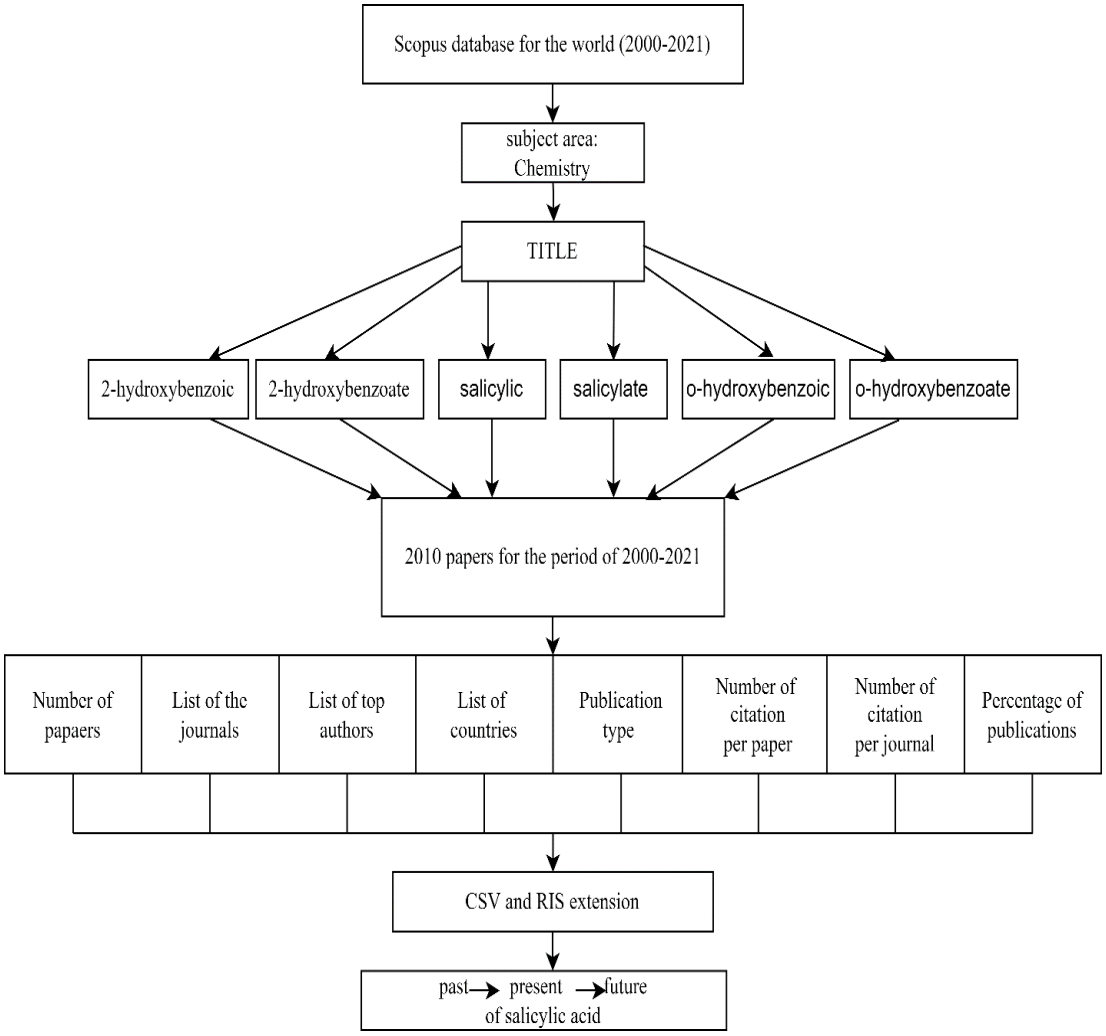

Figure 1. Flowchart of the methodology.

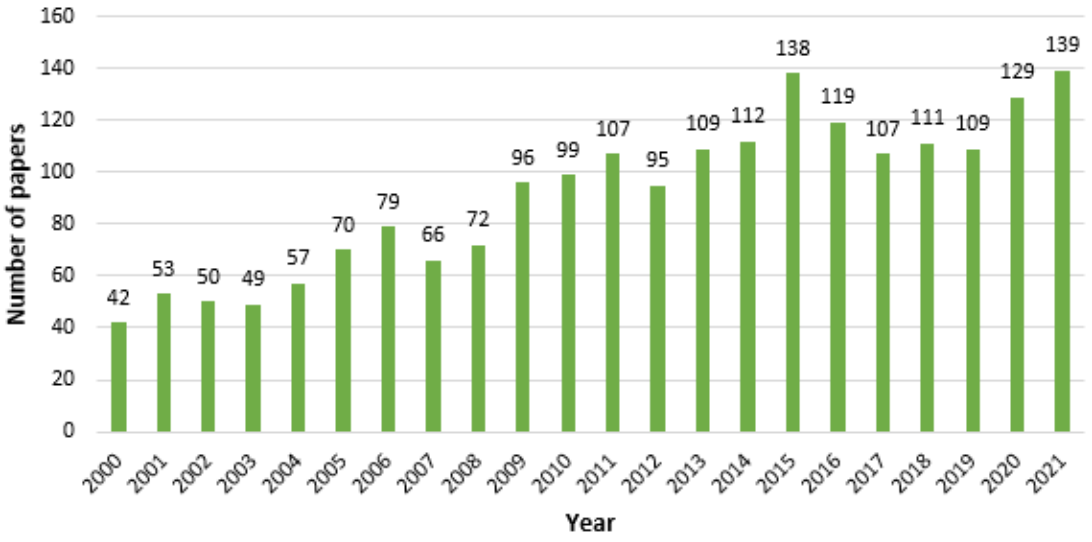

Figure 2. Number of papers on SA and its derivatives by the year of publication in the world.

3.2. Journals on SA and its derivatives

A wide variety of journals in different parts of the world are used by scholars to publish their research. The communication patterns of the scholars indicate that the total output was

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distributed across 159 journals published in 145 countries. 15 journals published 418 (20.8%) papers and the remaining 79.2% of papers were published in other journals. **Table 1** lists the name of the 51 journals which published a minimum of 10 and a higher number of papers during the abovementioned period. The second analyzing criterion is the name of the publishing country and the impact factor of the top 15 journals (**Table 2**). Five journals were published in the Netherlands, four of them from the US, three articles in the UK, and two papers from MDPI journals publish in Switzerland. The average impact factor of the journals with the highest number of articles was 5.23. Among the 15 journals the Chemical Engineering Journal had the highest impact factor, and the International Journal of Molecular Sciences had the highest number of publications in this field.

Table 1. List of the top journals on SA and its derivatives in the world.

Scopus Source title	Number of papers	Scopus Source title	Number of papers
International Journal of Molecular Sciences	44	Journal Of Physical Chemistry B	15
Journal Of Agricultural and Food Chemistry	36	Bioscience Biotechnology and Biochemistry	14
RSC Advances	35	Electrochimica Acta	14
Journal Of Molecular Liquids	34	Journal Of Thermal Analysis and Calorimetry	14
Spectrochimica Acta Part A	28	Langmuir	14
Chemical Engineering Journal	27	Chem. And Pharmaceutical Bulletin	13
Food Chemistry	27	Inter. Journal of Chemtech Research	13
Journal Of Molecular Structure	27	Tetrahedron	13
Asian Journal of Chemistry	25	Bulletin Of the Korean Chem. Society	12
Journal of Physical Chemistry A	25	Chemistry A European Journal	12
Crystal Growth and Design	23	Inorganic Chemistry Communications	12
Journal Of Chem. And Engin. Data	23	Journal Of Inorganic Biochemistry	12
Molecules	23	Chinese Journal of Chemistry	11
Acta Crystallographica Section E	21	Chromatographia	11
Talanta	20	Jiegou Huaxue	11
Analytica Chimica Acta	18	Journal Of Dispersion Science and Technology	11
Crystengcomm	18	New Journal of Chemistry	11
Journal Of Pharmaceutical and Biomedical Analysis	18	Russianrnal Of General Chemistry	11
Chemical Communications	17	Tetrahedron Letters	11
Chemosphere	17	Thermochimica Acta	11
Colloids And Surfaces a Physic. And Engineering Aspects	17	Analytical Sciences	10
Inorganica Chimica Acta	17	Chemistryselect	10
Journal Of Applied Polymer Science	17	Industrial And Engineering Chemistry Research	10
Analytical Letters	16	Journal Of Chromatography B Anal. Tech. In the Biomedical And Life Sciences	10
Bioorg. And Medicinal Chemistry	16	Physical Chemistry Chemical Physics	10
Journal of the Indian Chemical Society	16		

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Table 2. Distribution of research output in prolific journals.

Journal	TNP (%)	Publishing country	IF
International Journal of Molecular Sciences	2.18%	Switzerland	6.010
Journal Of Agricultural and Food Chemistry	1.79%	USA	5.500
RSC Advances	1.74%	UK	3.730
Journal Of Molecular Liquids	1.69%	Netherlands	6.210
Spectrochimica Acta Part A Mol. And Biom. Spectroscopy	1.39%	Netherlands	4.830
Chemical Engineering Journal	1.34%	Netherlands	16.740
Food Chemistry	1.34%	UK	9.230
Journal Of Molecular Structure	1.34%	Netherlands	3.840
Asian Journal of Chemistry	1.24%	India	0.490
Journal Of Physical Chemistry A	1.24%	USA	2.720
Crystal Growth and Design	1.14%	USA	3.690
Journal Of Chemical and Engineering Data	1.14%	USA	3.100
Molecules	1.14%	Switzerland	4.927
Acta Crystallographica Section E Structure Reports Online	1.04%	UK	0.910
Talanta	1.00%	Netherlands	6.550
Total:	20.80%		

3.3. Top authors on SA and its derivatives

There is no doubt that authors play an important role in the development of a particular field of research in any region of the world. By analyzing authors with the most publications, this section provides insight into the research contributions of individuals. **Table 3** illustrates a total of 15 different top authors who worked to publish papers on the chemistry of salicylic and its derivatives during the last two decades. According to statistical information, Khan is a top contributing author with 27 publications from the University of Malaya (Malaysia), whereas Huang J. and Rasmuson A.C. are the most cited researchers. Regardless of 9 papers, Wang, X. is cited 31.3 times for each of his works. Huang J., Khan M.N., and Rasmuson A.C. have the most publications and higher H-index, which extends their position as the leading experts in salicylic acid and its derivatives in the chemical field.

Table 3. List of top productive authors in research on SA and its derivatives issue in the world.

No.	Author	TP(R)	H- Index	Total citations	Avg citation/item	T.C./ year
1.	Khan, M.N.	27	12	278	23.2	12.64
2.	Langer, P.	18	6	147	24.5	9.80
3.	Huang, J.	14	14	385	27.5	35.00
4.	Ismail, E.	14	10	209	20.9	9.50
5.	Rasmuson, A.C.	12	12	318	26.5	19.90
6.	Yan, Y.	11	10	223	22.3	18.60
7.	Fischer, C.	9	8	62	7.75	4.13
8.	Meng, M.	9	8	139	17.4	15.44
9.	Wang, X.	9	7	219	31.3	19.90
10.	Gurina, D.L.	8	5	47	9.4	3.36
11.	Yuan, R.	8	5	69	13.8	3.63
12.	Antipova, M.L.	7	5	44	8.8	6.30
13.	Furia, E.	7	5	87	17.4	4.58
14.	Lubes, V.	7	4	30	7.5	2.50
15.	Petrenko, V.E.	7	5	44	8.8	5.50

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3.4. Top countries on SA and its derivatives

A region's internationalization can be measured by the number of countries participating in research activities on a particular topic. Total of more than 96 countries jointly worked on SA and its derivatives in the world from 2000-2021. **Figure 3** highlights the geographical location of the top 15 countries that participated in the publishing of at least 45 and more publications. On the figure with a huge difference, China holds a dominant by 448 research documents representing 22.3% of overall publications, followed by India (281; 14%), the USA (178; 8.85%), Iran, and Japan at are same level (107; 5.32%). Researchers from these top five countries participated in the publication of 55.8% of the total papers.

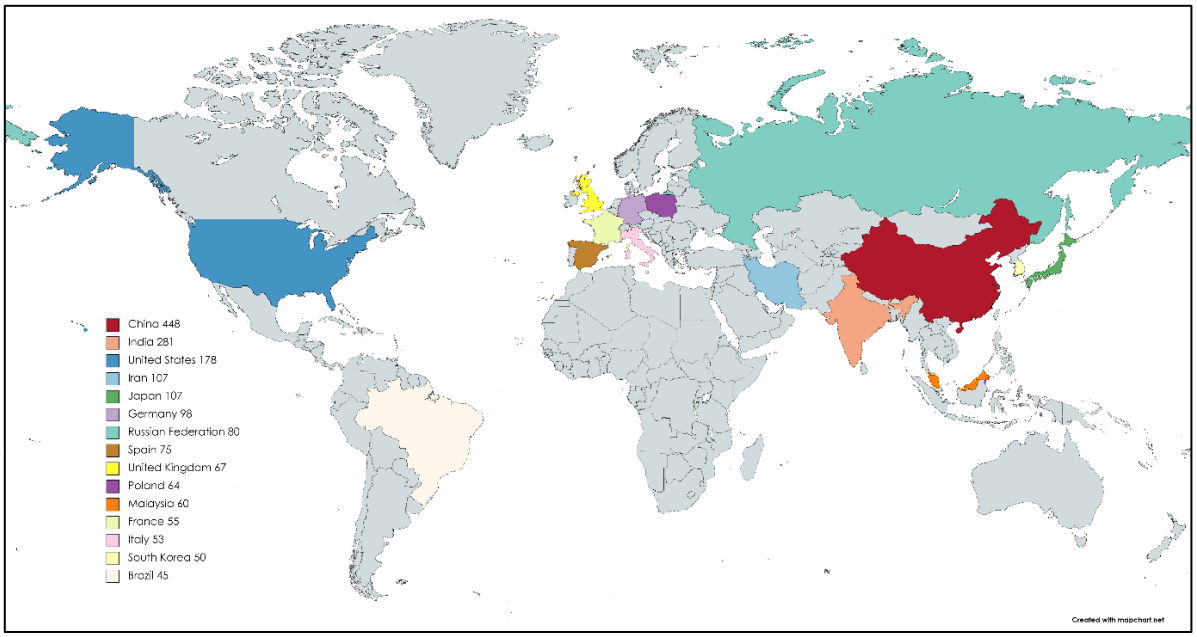

Figure 3. List of top 15 countries on SA and its derivatives in the world.

3.5. Top institutions on SA and its derivatives

Generally, institutions are ranked as a result of the quality of the papers published by their researchers. 160 different institutions worked in cooperation to publish 2010 papers on SA and its derivatives over the world from 2000 to 2021. To identify the most influential and productive institutions in salicylic acid and its derivatives chemistry, we have analyzed the top 15 institutes' publications. As indicated in **Figure 4**, of the 15 institutions, seven of them were from China, two were from Russia, and one each was from Malaysia, France, Germany, Ukraine, Brazil, and Iran. These prolific institutions contributed around 17.3% of the total output. Among these, the Ministry of Education China occupies the 1st position in record rank (49 records), followed by the Russian and Chinese Academy of Sciences (46 records).

3.6. Most important funding sponsors

A funding sponsor is an organization or program that provides funding to researchers to conduct research. Several of them are related to the chemistry of SA and its derivatives (**Figure 5**). Thus, we start scrutinizing these systems according to the number of published articles. The National Natural Science of Foundation of China is in the first position with 204 articles, and second place would go to the National Science Foundation, but at a great distance from the above, with 36 articles published about the chemistry of SA and its derivatives. The Japan Society for the Promotion of Science is close behind, with 28 articles.

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Some literature (Prahani *et al.,* 2022) remark such activity of the NSFC because of the funding improvement - longer duration and larger grant - has increased research output, as measured by the number of publications.

By country, there are four funding sponsors from China, representing one-third of this ranking. It is followed by the USA with three institutions or programs. The European Union (EU), Brazil, Japan, and India have two funding sponsors.

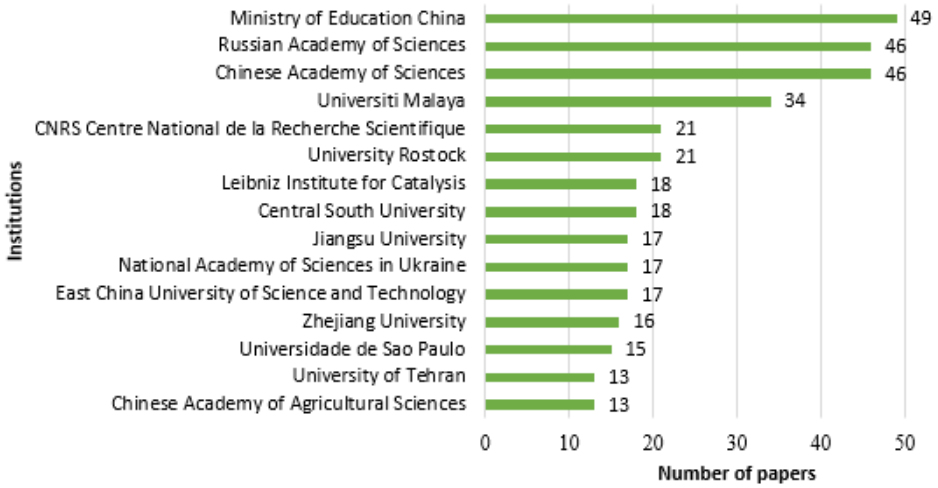

Figure 4. List of top institutions on SA and its derivatives issue in Central Asia.

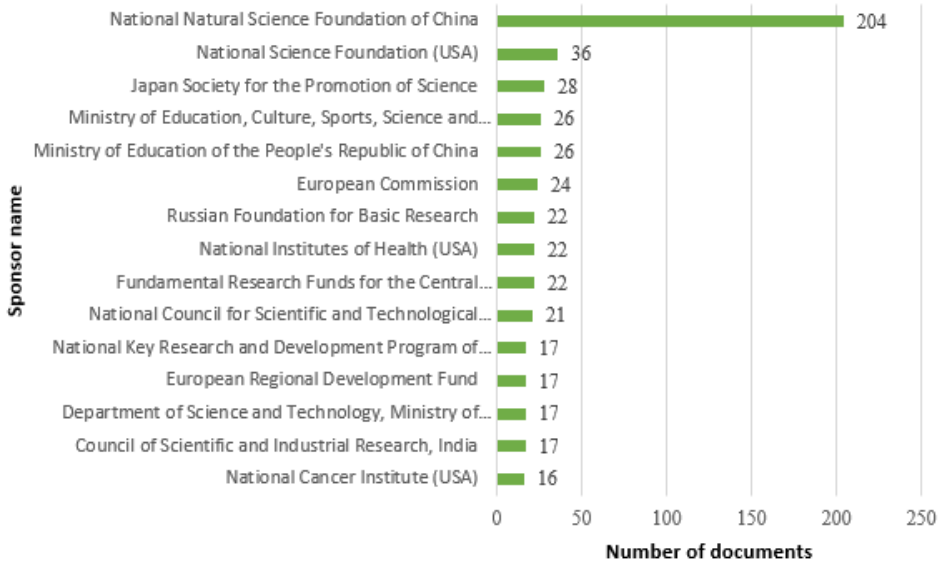

Figure 5. Main funding sponsors in SA and its derivatives.

3.7. Top cited papers on SA and its derivatives

There is a correlation between the number of citations and the quality and novelty of the research conducted. Fifteen mostly cited papers on SA and its derivatives are shown in **Table 4** (Shen & Porco, 2000; Ranjit *et al.,* 2001; Colon *et al.,* 2001; Lewandowski *et al.,* 2005; Babalar *et al.,* 2007; Shi & Shi, 2007; Chan *et al.,* 2007; Bica *et al.,* 2010; Egorov *et al.,* 2010; Sayyari *et al.,* 2011; Scarabelli *et al.,* 2013; Liu *et al.,* 2014; Liu *et al.,* 2016; Essandoh *et al.,* 2015; Li *et al.,* 2019). 22,426 citations were given to 2010 publications on SA and its derivatives for the given period. 15 documents are cited 2652 times and represent 11,83% of total citations. Of these 15 papers, USA and China have four representations, Spain reserves second place with

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three corresponds whereas Iran, Ireland, Russia, and Poland have one participant each in the list of most cited works. Surprisingly, despite the 13th position, Huang`s paper named "Signaling crosstalk between salicylic acid and ethylene/Jasmonate in plant defense: Do we understand what they are whispering?" had the highest annual citation trend with 51 citations per year. There is almost no difference between the IF of the Journals of Organic Letters (6.06) and the International Journal of Molecular Structures (6.01, MDPI). There are several possible explanations for this result. Firstly, Organic Letters is not free access journal and, in this case, MDPI journals might have attracted more attention from scientists with their full accession. Secondly, R. Shen`s paper is devoted to synthesizing sections only. However, L.J. Huang and others discussed both experimental and bio-properties on the topic and this factor may have made the article more readable and informative.

Table 4. List of top-cited publications on SA and its derivatives in the world.

No	Title	Journal	Corr. author	Country	PY	TC	TC/ Y
1.	Synthesis of enamides related to the salicylate antitumor macrolides using copper-mediated vinylic substitution	Org. Letters	Shen	US	2000	236	10.73
2.	Lanthanide oxide doped titanium dioxide photocatalysts: Effective photocatalysts for the enhanced degradation of salicylic acid and t-cinnamic acid	J. Catalysis	Ranjit	US	2001	229	10.90
3.	Sorptive removal of salicylic acid and ibuprofen from aqueous solutions using pine wood fast pyrolysis biochar	Chem. Eng. J.	Mlsna	US	2015	224	32.00
4.	Unconventionally secreted effectors of two filamentous pathogens target plant salicylate biosynthesis	Nature Comm.	Dou	China	2014	203	25.40
5.	Vapour treatments with methyl salicylate or methyl jasmonate alleviated chilling injury and enhanced antioxidant potential during postharvest storage of pomegranates	Food Chem.	Valero	Spain	2011	176	16.00
6.	Effect of pre- and postharvest salicylic acid treatment on ethylene production, fungal decay and overall quality of Selva strawberry fruit	Food Chem.	Asghari	Iran	2007	173	11.53
7.	In search of pure liquid salt forms of aspirin: Ionic liquid approaches with acetylsalicylic acid and salicylic acid	Phy. Chem. Chem. Physics	Rogers	Ireland	2010	166	15.10

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Table 4 (continue). List of top-cited publications on SA and its derivatives in the world.

No.	Title	Journal	Corr. author	Country	PY	TC	TC/ Y
8.	Photocatalytic deactivation of commercial TiO2 samples during simultaneous photoreduction of Cr(VI) and photooxidation of salicylic acid	J. of Photochem. and Photobio. A: Chem.	Navio	Spain	2001	161	7.67
9.	The synthesis of chromenes, chromanes, coumarins and related heterocycles via tandem reactions of salicylic aldehydes or salicylic imines with α,β-unsaturated compounds	Org. Biomol. Chem.	Shi	China	2007	158	10.53
10.	Proteome approach to characterize proteins induced by antagonist yeast and salicylic acid in peach fruit	J. Proteome Res.	Tian	China	2007	157	10.47
11.	Salicylic acid receptors activate jasmonic acid signalling through a non-canonical pathway to promote effector-triggered immunity	Nature Comm.	Dong	US	2016	156	26.00
12.	Tuning gold nanorod synthesis through prereduction with salicylic acid	Chem. of Mater.	Liz-Marzán	Spain	2013	156	17.33
13.	Signaling crosstalk between salicylic acid and ethylene/Jasmonate in plant defense: Do we understand what they are whispering?	Int. J. Mol. Sci.	Huang	China	2019	153	51.00
14.	Task-specific ionic liquid trioctylmethylammonium salicylate as extraction solvent for transition metal ions	Talanta	Pletnev	Russia	2010	153	13.91
15.	The influence of metals on the electronic system of biologically important ligands. Spectroscopic study of benzoates, salicylates, nicotinates and isoorotates. Review	J. Inorganic Biochem.	Lewandowski	Poland	2005	151	13.73

3.8. Top cited journals on SA and its derivatives

A minority of scientific journals publish the majority of scientific papers and receive the majority of citations (Ioannidis, 2006). In the above, we analyzed the top journals which published the most papers. However, despite the fever number of papers, some journals gathered more citations from 2000 to 2021. Taking into consideration this factor we decided to investigate top-cited journals on SA and its derivatives in the chemical branch. Firstly, we sorted source names alphabetically of the Excel extension file of 2010 documents. Then step by step total papers` citations are summarized by each journal. Interestingly, as a result, we got updating the list with potential journal names. The initial 15 journals were selected and shown in **Figure 6.**

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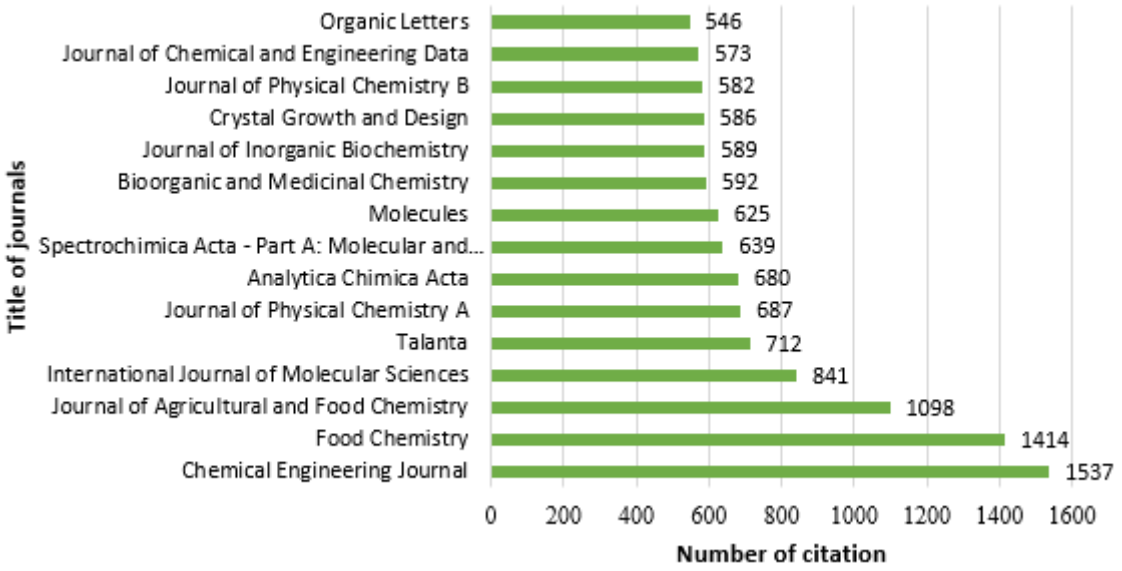

Figure 6. List of top-cited journals on SA and its derivatives in the world.

Almost 32% (11701 citations) of total citations were given to papers published in these 15 journals. As a result of the number of citations, the 6th ranked journal with 27 documents by publication rate emerged as the best journal (**Table 1 and 2**). Instead of five 1-5 journals in **Table 2**, Analytica Chimica Acta, Bioorganic and Medicinal Chemistry, Journal of Physical Chemistry B, Organic Letters, and Journal of Inorganic Biochemistry are ranked as top-cited journals on the chemistry of SA and its derivatives.

3.9. Publications by keywords on SA and its derivatives

Co-authorship, keyword co-occurrences, citations, bibliographic coupling, and co-citation maps can be generated using VOSviewer based on bibliographic data. File formats supported include .txt, .ris, and .csv from databases such as Web of Science, Scopus, and PubMed (Jalal, 2019). The raw file was imported into VOSviewer and a map of keyword co-occurrences (shown in **Figure 7**) was created using the software. There are 1000 items distributed over five clusters: cluster 1 (407 items), cluster 2 (217 items), cluster 3 (167 items), cluster 4 (164 items), and Cluster 5 (45 items). When we divide the period into 3-time lapses, used keywords showed the actual chronology of publishing directions.

The synthesis, structure, chemical, and physical properties of salicylic acid and its derivatives are studied mainly until 2010. In the last decade, much attention has been paid by scientists to the identification of the bio-properties of the studied compounds. This may have occurred because wide investigating has been done on structural, chemical, and physical parameters of the topic compounds.

3.10. Visualization of co-authorship countries

International collaboration is becoming increasingly important in scientific research. It is **Figure 8** demonstrates a VOSviewer (version 1.6.18) of visualization of the 60 most co-authorship countries in eight clusters. The minimum number of documents of a country and the number of citations of a country is set as 3. As demonstrated in **Figure 7**, the co-authorship study of countries illustrates the collaboration relationship among countries throughout this subject, as well as the level of cooperation. The thicker and longer links between nodes show cooperative interaction between countries, while the larger nodes represent the most productive nations.

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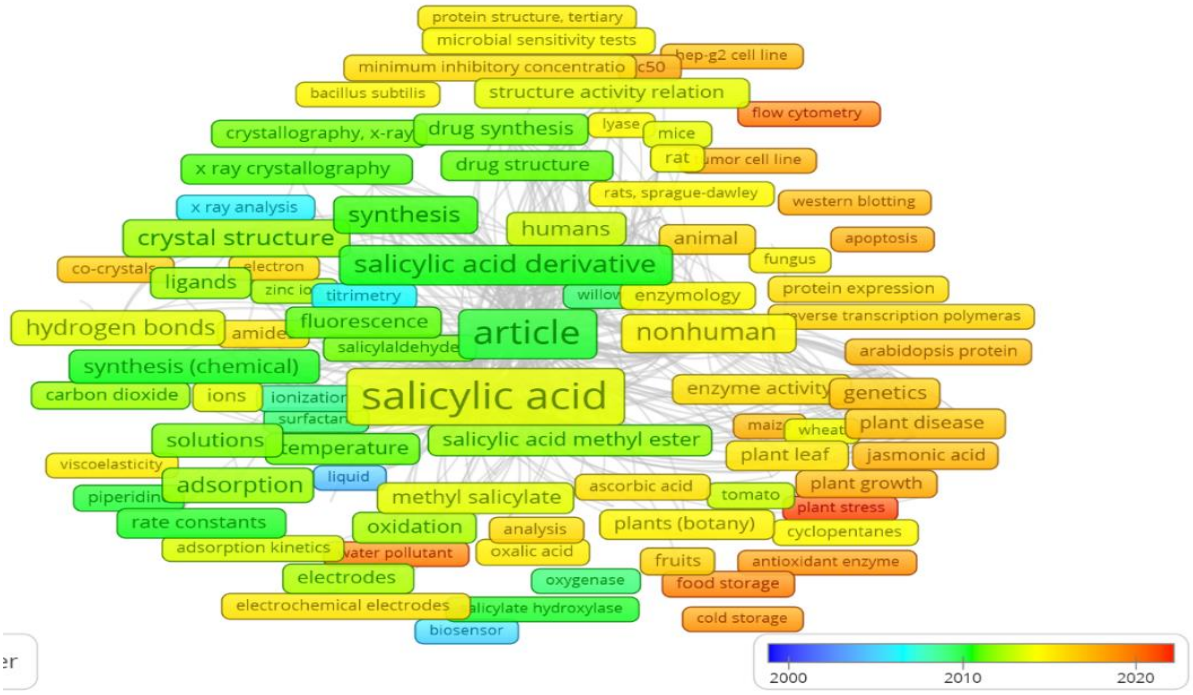

Figure 7. Keyword co-occurrences VOSviewer analysis based on scopus.

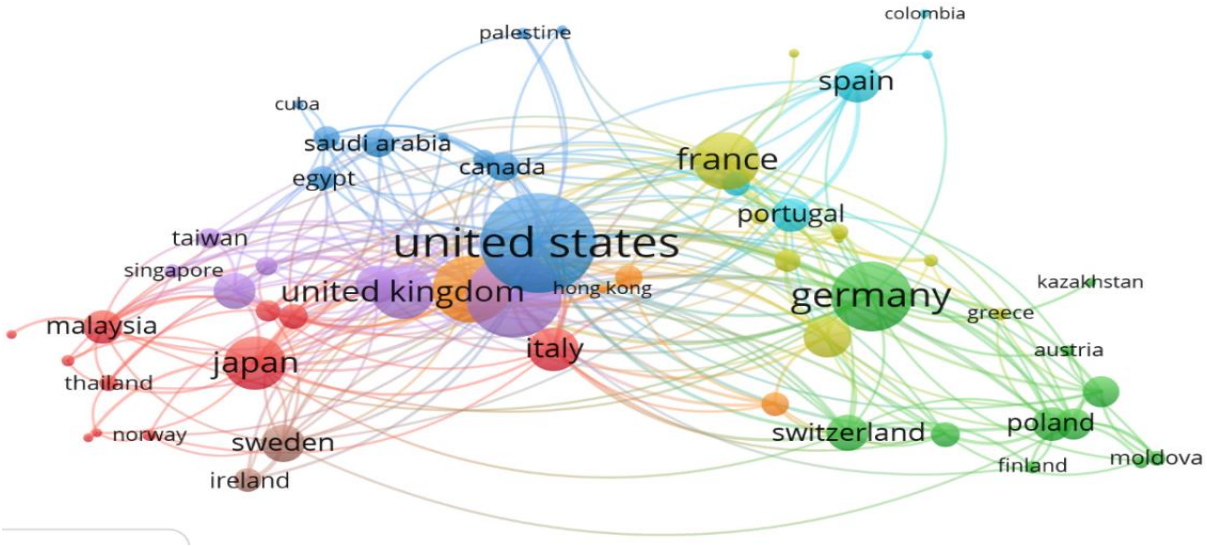

Figure 8. Structure map of countries' co-authorships on SA and its derivatives.

The countries with the highest total link strength (TLS) were the USA with 178 documents and a link strength of 601 (collaborated with 35 countries) followed by India with 78 TLS (collaborated with 28 countries) and 281 documents. Germany was in the third position with 98 documents and a TLS of 62 (collaborated with 28 countries). Regardless of 448 papers, China occupied the 4th position with a link strength of 60 and 25 collaborating ties from 2000 to 2021 (**Table 5**).

3.11. Co-Authorship analysis of authors

6,591 authors participated in the publication of SA and its derivatives. In this survey, all authors filtered at least 3 announced papers, and a total of 468 authors were found

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automatically by VOSviewer. Instead of all items the 235 largest sets of connected items were shown to measure total link strength. The 14 most significant clusters of total authors were categorized. The largest cluster consisted of 30 authors and the last one ended with 8 authors. Calculated links equal 1485, this means that the articles published jointly by 235 scientists (at least two authors) amounted to 1485. **Figure 9** demonstrates a density visualization of the total link strength of co-authorship collaborations.

Table 5. Countries' co-authorships on SA and its derivatives.

Country	Docs	TLS	Country	Docs	TLS	Country	Docs	TLS
United States	182	102	S. Arabia	20	19	Greece	11	6
India	282	78	Belgium	15	15	Romania	14	6
Germany	98	62	Pakistan	24	15	Slovenia	9	6
China	451	60	Egypt	37	14	Austria	7	5
France	55	49	Iran	107	14	Indonesia	12	5
Japan	108	44	Ireland	16	14	Norway	7	5
United Kingdom	67	44	Netherlands	16	14	Palestine	6	5
Italy	53	33	South Africa	16	14	Argentina	17	4
Czech Republic	20	30	Mexico	20	13	Bangladesh	3	4
Spain	75	29	Slovakia	12	13	Israel	6	4
Australia	29	27	Turkey	39	12	Tunisia	5	4
Sweden	23	26	Taiwan	39	11	Vietnam	4	4
South Korea	51	25	Brazil	45	10	Cuba	3	2
Switzerland	11	25	New Zealand	7	10	Hong Kong	5	2
Malaysia	60	23	Thailand	24	9	Hungary	10	2
Poland	64	23	Moldova	7	8	Kazakhstan	4	2
Portugal	27	23	Serbia	12	8	Nigeria	6	2
Russian Federation	80	21	Croatia	7	7	Algeria	8	1
Ukraine	27	21	Singapore	7	7	Colombia	4	1
Canada	28	19	Finland	6	6	Venezuela	8	0

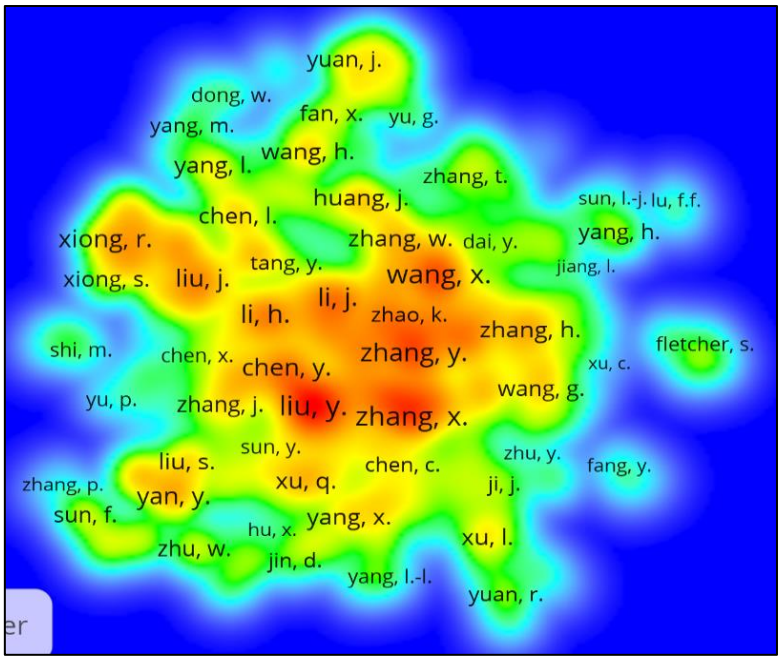

Figure 9. Density visualization map of co-authorship.

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4. CONCLUSION

The chemistry of SA and its derivatives is a crucial topic for the science and engineering sector. Based on the Scopus database we tried to analyze papers published on the abovementioned compounds in English for the whole world over 2 decades by the bibliometric method. Developing countries, especially China, have more publications, institutions, and funding sponsors. Several industrial nations, such as the United States, India, Japan, and Malaysia, have progressed well, however, there is still a significant gap between China and the rest of the countries. Based on the current trend in citations to published manuscripts, we conclude that researchers will continue to investigate the bio-features of the title compounds for usage in the agricultural, food, and manufacturing industries.

5. ACKNOWLEDGMENT

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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