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Allelopathy Research in Global Perspective: A Scientometric Study of Academic Productivity over a Period of 25 Years (1995 - 2019)

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Abstract: This research is concerned with the Allelopathy research literature published from 1995 to 2019 obtained from SCOPUS, and studied to identify the trends in research publication in terms of various document types, annual growth, share of publication, citation growth, average citation per paper, most productive country, authors, journals, highly cited articles during this period. These factors were identified and compared for their research impact over a period of 25 years.

Method: Data for this study were obtained from the SCOPUS multidisciplinary database for the period from 1995 to 2019. The database was searched for the keywords "Allelopathy" OR "Allelochemicals" OR "Allelochemical" in the title, abstract, and keywords fields. And further analyzed using an Excel spreadsheet to achieve the objectives of the study. The citation count was taken as the number of citations scored by each article and for each author to get citation analysis of articles and authors.

Results: There were a total of 7483 documents retrieved during this period of study 1995 - 2019. A total of 6422 published as Journal Articles which covers 85.85% and followed by 453 reviews as 6.05%, 328 as conference papers 4.38%, 205 book chapters 2.74%, 17 notes, 14 editorials, 12 books, 12 Short Surveys, 8 Erratum, 6 letters, 2 retracted, 1 conference review, 1 data paper, and 2 documents were not classified in any of the documents types. Twenty languages were used for publishing 7483 documents on Allelopathy. English was the most common mode of communication with 6844 of the total articles published in the English language, followed by Chinese 424, Portuguese 217, etc.

Keywords: Allelopathy, Allelochemicals, Scientometrics, Citation analysis, Research Trends

Introduction:

Allelopathy is a common biological phenomenon in which biochemicals that affect the growth, survival, development, and reproduction of other organisms are created by one organism. These biochemicals are referred to as allelochemicals and have effects on target species that are beneficial or harmful. Plant Allelopathy is one of the ways in which receptor and donor plants interact and can have beneficial effects. The concept of Allelopathy was first used by Molisch in 1937 to denote all the effects that directly and indirectly arise from the transfer of biochemical substances from one plant to another (*MOLISCH, 1937*). The concept "any direct or indirect harmful or beneficial effect by one plant (including microorganisms) on another through the production of chemical compounds that escape into the environment" was refined by Rice (1984) (Rice, 2012). Allelochemicals, which are non-nutritive substances mainly produced as secondary metabolites of plants or decomposition products of microbes, are active agents of Allelopathy.

Allelopathy, a concept well over 2000 years old, but the term was recently coined in 1937. The eminent Austrian plant physiologist Ian Molisch coined the term "Allelopathie" in German in his book "Der Einfluss einer pflanz auf die andere - Allelopathie". The word comes from the Greek roots, "allelon" meaning "suffering," "feeling" and each other. Brief: Alllelopathy is a study of the interaction of plants with chemical substances called allelochemicals.

The research of Allelopathy as a discipline has a long and often contentious history. Since the word was coined by Hans Molisch before World War II, research on allelopathy has evolved from a

trickle of papers before 1970 to a burgeoning subdiscipline of chemical ecology represented annually by hundreds of papers. The study and patterns and effects of research activities in Allelopathy Research using traditional metric methodologies will be highly remarkable.

Scientometrics Study:

Publications are the evidence to the evaluation and structure of the research process in a field. The published research in the form of articles or papers must be evaluated and assessed in order to make update and move forward to develop and further growth of the subject. Investigating the current state and development of the research field is becoming increasingly necessary. Quantitative studies evaluating and analyzing science behaviors are a form of study widely known as Scientometrics (*Rice, 1979*). By providing a view on a research field from a meta-perspective *(S.J. Rizvi, 1992*), (*Chou, 2006*), Scientometric studies facilitate the development and improvement of an academic discipline (*Rice, 1979*), (*Chou, 1999*) serving as a vital basis for defining and debating future research agendas (*Suresh, 2019*). Scientometric studies apply analytical measures to evaluate research output from a particular field in order to better understand the dynamics and structure of its growth, assuming that scientific activities are expressed in scientific publications. Thus, the body of publications can be thoroughly explored, such as observing citation patterns, number and types of citations, number and structure of authors, etc. In addition, the Scientometric study provides some indication of research activities in general, such as knowledge sharing, quality of research, socio-organizational structures, influential countries/affiliations/authors, key topic growth, institutional change, and research economic effects. Methods of bibliometrics and scientomtrics are generally used as a tool for evaluating scientific advancement in a field through literature analysis.

Literature Review:

(*Tan et al., 2019*) states that Allelopathy has been discovered, because of its high effectiveness, security and economy, as a result of resolving this issue. Allelopathy can suppress microalgae growth by impairing algal cell structure, photosynthesis and enzyme activity. *(Macias, Mejias, & Molinillo, 2019*) defined Allelopathy is the biological phenomenon of chemical reactions in the environment between living organisms and must be considered in addressing the problem of pests and weeds in sustainable agriculture. Allelopathy is a multidisciplinary science, but aspects of its

chemistry are ignored in certain situations, despite the need for a detailed understanding of the chemical structural characteristics of allelochemicals to promote the production of new herbicides.

(Al-Samarai, Mahdi, & Al-Hilali, 2018)The current study shows the possibility of using plant-based natural products as an alternative to chemical herbicides as one of the means of biocontrol agents to minimize contamination in the environment. (Jandova, Dostal, Cajthaml, & Kamenik, 2015) findings indicate that intraspecific heterogeneity in allelopathy research should be recognized and suggest that metabolic profiling offers an efficient method in which unknown metabolites are involved in the study of chemically mediated seed-plant interactions. (Tang et al., 2014) states that the rooting rate, root number, root length , root activity, growth rate for cutting with increasing concentrations of tissue extracts was significantly inhibited by aquatic extracts from rhizospheric soil; the chlorophyll content of the seedlings was decreased, but the MDA content was increased; and the POD, IPO and IAAO activity of the seedlings was affected. Rhizospheric Pogostemon cablin aquatic extracts have different degrees of inhibitor effects on normal rooting and stem cutting growth.

(Grover & Wang, 2014) states that the presence of many attractors with high resources indicates that blooms of harmful algae that contain allelopathic toxins may be difficult to predict in such wealthy circumstances. (Durrett & Levin, 1997) In a homogeneously mixed E coli, colicin-production and colicin-sensitive strategies for certain parameters may be evolutionarily stable with the consequence of competition established by initial conditions. In comparison, there is a special ESS for a particular set of parameters in spatially-structured populations, as the result is determined by the cost-effectiveness of allelopathy. Moreover, the dynamic balance between a colicin-sensitive type, a colicine-producing type, and a "cheater" which spends less on colicin production but is resistant, can be maintained in a spatially structured environment.

(Fujii & Hiradate, 2007) states than the main aim of Allelopathy is the promotion of climate, forest and sustainable agriculture. The goal is to eliminate synthetic chemical products and optimize the use of locally available natural resources while increasing crop production, forestry and the climate. In recent years scientific institutions throughout the world have produced, evaluated, and produced technology advancements in Allelopathy science. (Ferguson & Rathinasabapathi, 2003) Allelopathy refers, to the beneficial or harmful effects of one plant to another plant both weed and

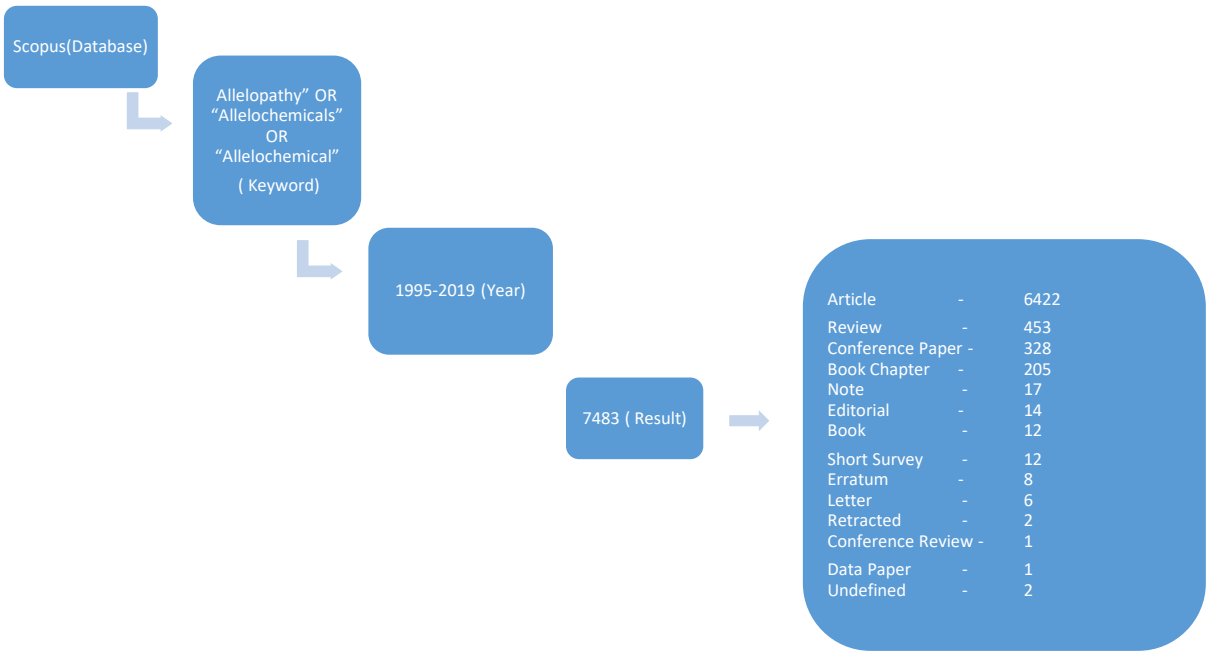
crop species, from the release of biochemical from plant parts by leaching, root exudation, volatilization, residue decomposition, and other processes of both natural and agricultural systems.

(Ram S, 2019) carried out a bibliometric study on the publishing trends of Carpel Tunnel syndrome (CTS) of 35 years research with the help of SCOPUS database. A total of 13187 articles on CTS was retrieved covering the period of 1982 - 2017.These articles were published in 11 different document types. Articles had accumulated 206266 citations till December 2017. USA was the most productive country with 37.14% of the global publication share of the global publication share on CTS during the study period. Papers published from the USA on CTS research accumulated the highest number of citations. The study shows that "Journal of Hand Surgery American Volume" was the most productive journal which published 38.07% share of the total global publication on CTS. The study reveals that there is a progressive increase in the number of articles published during the 35-year period

Data sources and methodology:

The data for the present study are derived from Scopus database and the allegiance papers published between1995 and 2019 were carried out. Collected the data using keywords to search for "Allelopathy" or "Allelochemicals" or "Allelochemical" and the Excel spreadsheet was used to further evaluate the goals of the analysis. The number of citations counted by each article and for every author to be quoted from the article and the authors has been considered.

Figure 1.



Publication Trends:

Table 1 shows the growth of the research publications from 1995to 2019. A total of 7483 articles showed a progressive increase in the number of articles published over the 25-year period.

It is observed the continued and extensive growth of Allelopathy research literature. These 7483 articles accumulated a total of 167207 citations till 2019. The articles published during 2015-2019 scored the highest number of citations (75763 citations) with an Average Citation Per Paper (ACPP) of 33.88 citations. The articles published between 1995-1999 had an Average Citation Per Paper (ACPP) of 2.86 citations. The overall ACPP was 22.34 during the study period (1995-2019).

Table 1: Publication Trend

Time Period	Total Publication	APGR	Total citation	ACPP
1995-1999	607	-	1738	2.86
2000-2004	889	4.64	8300	9.33

2005-2009	1744	9.61	27754	15.91
2010-2014	2007	1.50	53652	26.73
2015-2019	2236	1.14	75763	33.88
1995-2019	7483		167207	22.34

*APGR= Annual Publication Growth Rate; ACPP= Average citation per paper

Table 2. Authorship Collaboration pattern

Year	Single Author	Double Authors	Three Authors	Four Authors	Five and Above Authors	Total
1995	14	62	57	44	37	214(0.70%)
1996	29	82	102	48	76	337(1.10%)
1997	28	92	123	76	75	394(1.29%)
1998	9	58	99	76	111	353(1.16%)
1999	19	90	96	76	133	414(1.36%)
2000	19	74	87	132	104	416(1.36%)
2001	29	86	123	136	167	541(1.77%)
2002	27	72	132	140	224	595(1.95%)
2003	29	110	123	148	294	704(2.31%)
2004	19	78	129	140	317	683(2.24%)
2005	21	120	213	224	449	1027(3.36%)
2006	44	144	204	232	495	1119(3.66%)
2007	30	136	243	272	595	1276(4.18%)
2008	38	136	303	320	797	1594(5.22%)
2009	29	150	219	300	741	1439(4.71%)
2010	22	138	237	348	780	1525(4.99%)
2011	32	112	246	348	896	1634(5.35%)
2012	30	136	243	320	914	1643(5.38%)
2013	34	150	273	368	1081	1906(6.24%)
2014	17	112	171	288	1022	1610(5.27%)
2015	19	130	222	344	1303	2018(6.61%)
2016	19	110	210	248	1285	1872(6.13%)
2017	16	86	225	332	1614	2273(7.44%)
2018	16	114	285	316	1706	2437(7.98%)
2019	11	52	219	296	1931	2509(8.22%)
Grand Total	600 1.97%	2630 8.61%	4584 15.01%	5572 18.25%	17147 56.16%	30533 100

Table 2 described the year wise authorship distribution of publication published related to Allelopathy. During the period of study reveals that the highest 150 number of double authored articles published in year 2009 & 2013. The highest number of articles with n=44 published by single author in year 2006 and least number of single author publication in 1998 with n=9. In year 2008 highest number of three authored publication with n=303 articles published, in year 2013 highest 368 articles published by four authors and in year 2019 got author percent in the total analysis with 8.22% (n=2509)

Table 3: Countrywide collaborations

Country	**Total Publications**	**Percentage of Share**	**Rank**	***SCP**	***ICP**	**Total Citations**	***ACPP**
China	1616	21.6	1	1343	273	19865	12.29
United States	1361	18.19	2	896	465	66954	49.19
India	594	7.94	3	497	97	11914	20.05
Brazil	586	7.83	4	505	81	7487	12.77
Japan	555	7.42	5	366	189	10746	19.36
Germany	334	4.46	6	137	197	14601	43.71
Australia	295	3.94	7	137	158	9789	33.18
Pakistan	278	3.72	8	180	98	3365	12.10
Spain	271	3.62	9	138	133	9494	35.03
Italy	229	3.06	10	136	93	5724	24.99
France	199	2.66	11	91	108	8068	40.54
Canada	196	2.62	12	119	77	7282	37.15
Poland	155	2.07	13	122	33	2357	15.20
United Kingdom	152	2.03	14	48	104	7268	47.81
Iran	150	2	15	128	22	1110	7.4
Egypt	120	1.6	16	63	57	1462	12.8
South Korea	119	1.59	17	55	64	3360	28.23

Netherlands	110	1.47	18	40	70	6509	59.17

*SCP= Single Country Publications; ICP= Internationally Collaborated Publications; ACPP= Average Citation Per Paper

Publication by country:

Table 3 presents the contribution of the most productive countries that published more than 100 papers of Allelopathy research. Six indicators have been used to measure the research performance by a country. These include total publications, the share of publications and rank, independent single country publications (SCP) and rank, international collaboration publications (ICP) and rank, total citations (TC) and rank, average citation per paper (ACPP) and rank. The 18 countries contributed more than 100 research were represented by 7 European countries, and six Asian countries, 3 countries from American continent and one Australia. China ranked the first in terms of productive countries (1616 articles; 21.6% share), followed by USA (1361 articles; 18.19% share), and India (594 articles; 7.94% share). China had the highest single country publications (1343 articles) followed by USA (896 articles) and Brazil (505 articles). In terms of international collaborations, USA had the highest number of articles published as internationally collaborated studies (465 articles), followed by China (273 articles), and Germany (197 articles). Articles published in the USA had the highest citation count of 66954 with an ACPP of 49.19 citations (2nd rank in productivity), followed by the China with 19865 citations and an ACPP of 12.29 citations (1st rank in productivity) and Germany with 14601 citations with an ACPP of 43.71 citations (6th rank in productivity). However, papers published from Netherlands ranked 1st in terms of average citation per paper with 59.17 citations, and papers published from United States ranked 2nd with ACPP of 49.19 citations.

Table 4: Top 15 Author's productivity

Author	**Total publication**	**Total citations**	**ACPP***
Kato-Noguchi, H.	140	1633	11.66
Fujii, Y.	81	1619	19.98

Macías, F.A.	71	2617	36.85
Molinillo, J.M.G.	55	2062	37.49
Inderjit	54	4060	75.18
Duke, S.O.	49	3205	65.40
Callaway, R.M.	48	7344	153
Kong, C.H.	47	1160	24.68
An, M.	45	1326	29.46
Xuan, T.D.	44	1300	29.54
Reigosa, M.J.	42	1772	42.19
Dayan, F.E.	40	2646	66.15
Varela, R.M.	40	1358	33.95
Suenaga, K.	39	229	5.87
Farooq, M.	37	1033	27.91

*ACPP= Average Citation Per Paper

Author's productivity:

The author's contribution and research impact were analyzed based on the total publication (TP), total citation (TC), average citation per paper (ACPP). The frequency of the top fifteen authors in terms of total publication is presented in Table 4 with more than 37 publications. Kato-Noguchi, H. has been found to be the most productive author with 140 articles, followed by Fujii, Y. (81 articles) and Macías, F.A. (71 articles). Regarding the parameter of citation impact, Callaway, R.M. was more impactful with the highest number of citations (7344 citations) followed by Inderjith (4060 citations) and Duke, S.O. (3205 citations). Callway, RM. had higher average citations per paper of 153 citations compared to all other authors, followed by Inderjith 75.18 and then Dayan, F.E. 66.15.

Table 5: Most productive Journals

Sources	**Total publications**	**Percentage**	**IF* (2019)**	**SNIP* 2019**	**SJR* (2019)**
Allelopathy Journal	904	12.08	1.275	0.530	0.253

Journal Of Chemical Ecology	266	3.55	2.117	1.125	1.03
Journal Of Agricultural And Food Chemistry	101	1.35	4.192	1.388	1.09
Chinese Journal Of Applied Ecology	97	1.3	0.800	0.385	0.29
Planta Daninha	94	1.26	0.460	0.521	0.23
Plant And Soil	92	1.23	3.299	1.285	1.21
Shengtai Xuebao Acta Ecologica Sinica	86	1.15	0.620	0.390	0.23
Phytochemistry	78	1.04	3.044	1.494	0.76
Weed Biology And Management	68	0.91	0.892	0.625	0.4
Weed Science	65	0.87	2.258	1.493	0.77
Harmful Algae	61	0.82	3.707	1.879	1.97
Crop Protection	57	0.76	2.381	1.372	0.81
Plos One	55	0.73	2.740	1.205	1.02
Chinese Journal Of Ecology	53	0.71	0.290	0.247	0.29
Plant Ecology	50	0.67	1.509	0.782	0.72

*IF = Impact Factor; *SNIP = Source Normalized Impact per Paper; *SJR = Scimago Journal Ranking

Most productive Journals publishing Allelopathy research:

Table 5 presents the 15 most productive journals publishing Allelopathy research. These journals have shared a total of 28.43 % (2127articles) of the global output during the period 1995 - 2019.

Of these most productive journals, the "Allelopathy Journal" published 904 articles on Allelopathy (12.08% share; IF2019=1.275). The other productive journals included "Journal of Chemical Ecology" (266 articles; IF2019=2.117), "Journal of Agriculture and Food Chemistry" (101 articles; IF2019=4.192), "Chinese Journal Of Applied Ecology" (97 articles; IF2019=0.800), "Planta Daninha" (94 articles; IF2019=0.460), "Plant And Soil" (92 articles; IF2019=3.299) "Shengtai Xuebao/Acta Ecologica Sinica" (86articles; IF2019=0.620), "Phytochemistry" (78 articles; IF2019=3.044), "Weed biology and Management" (68 articles; IF2019=0.892), "Weed Science" (65 articles; IF2019=2.258), "Harmful Algae" (61 articles; IF2019=3.707), "Crop

Protection" (57 articles; IF2019=2.381), "Plos one" (55 articles; IF2019=2.740), "Chinese Journal of Ecology" (53 articles; IF2019=0.290 and "Plant Ecology" (50 articles; IF2019=1.509).

Different methodologies are adopted to assess the value of the journals publishing research articles in the given field. The parameters included in the assessment by different database aggregators provide a platform where authors can assess the value of the journal and submit their research for probable publication. One such method given by *Hank Moed* is "Source Normalized Impact Per Paper (SNIP)" which is the contextual measure of the impact of the journal in similar subjects. Harmful Algae (SNIP.1.873), Phytochemistry (SNIP.1.494) and Weed Science (SNIP.1.393). These journals scored the first three positions in SNIP ranking. Likewise another methodology adopted is Scimago Journal Ranking (SJR) which measures the scientific influence of scholarly journals that accounts for both the number of citations received by a journal and the importance of the journals in that field. "Harmful Algae" has an SJR ranking 1.97 followed by the "Plant and Soil" (1.21) and "Journal of Agricultural and Food Chemistry" (1.09).

Table 6: Most cited articles

No	Article	SIF 2019*	Citation received
1	Bais, H.P., Weir, T.L., Perry, L.G., Gilroy, S., Vivanco, J.M. The role of root exudates in rhizosphere interactions with plants and other organisms. Annual Review of Plant Biology, V.57, 2006	19.540	2070
2	Cho, I., Blaser, M.J., The human microbiome: At the interface of health and disease. Nature Reviews Genetics. V.14 (4), 2012	33.133	1413
3	Callaway, R.M. Positive interactions among plants. The Botanical Review, V.61 (4), 1995	2.960	1156
4	Levine, J.M., Vilà, M., D'Antonio, C.M., Dukes, J.S., Grigulis, K., Lavorel, S., Mechanisms underlying the impacts of exotic plant invasions. Proceedings of the Royal Society B: Biological Sciences, V.270 (1517)	4.637	1049

5	Li, X., Schuler, M.A., Berenbaum, M.R., Molecular mechanisms of metabolic resistance to synthetic and natural xenobiotics. Annual Review of Entomology, V.52, 2007.	13.796	1010
6	Callaway, R.M., Aschehoug, E.T., Invasive plants versus their new and old neighbors: A mechanism for exotic invasion. Science, V.290 (5491), 2000.	41.845	971
7	Smayda, T.J., Harmful algal blooms: Their ecophysiology and general relevance to phytoplankton blooms in the sea. Limnology and Oceanography, V.42 (5II)	3.778	800
8	Bertin, C., Yang, X., Weston, L.A., The role of root exudates and allelochemicals in the rhizosphere. Plant and Soil, V. 256 (1), 2003	3.299	790
9	Bais, H.P., Vepachedu, R., Gilroy, S., Callaway, R.M., Vivanco, J.M. Allelopathy and exotic plant invasion: From molecules and genes to species interactions. Science., V.301 (5638), 2003	41.845	767
10	Dayan, F.E., Cantrell, C.L., Duke, S.O., Natural products in crop protection. Bioorganic and Medicinal Chemistry., V.17 (12), 2009	3.073	666
11	Warnock, D.D., Lehmann, J., Kuyper, T.W., Rillig, M.C. Mycorrhizal responses to biochar in soil - Concepts and mechanisms. Plant and Soil., V.300 (2Jan.)	3.299	618
12	Hopkins, R.J., Van Dam, N.M., Van Loon, J.J.A., Role of glucosinolates in insect-plant relationships and multitrophic interactions. Annual Review of Entomology, V.54 , 2009	13.796	530

*SIF = Source Impact Factor

Characteristics of most cited articles:

The most cited articles published on Allelopathy was analyzed based on the total number of citations scored by these articles till December 2019. Out of 7483 articles, 6712 (73.88%) articles have been cited at least one time. The top cited articles which are cited at least 500 times are given in the Table 6. These articles are distributed throughout the study period starting from 1995 to 2019. The article Bais, H.P., Weir, T.L., Perry, L.G., Gilroy, S., Vivanco, J.M.., scored the highest citations (2070 citations) published in "Annual Review of Plant Biology. V.57, 2006" IF2019=19.540. The other article with second highest citations was by Cho, I., Blaser, M.J., (2012) that was cited 1413 times, published in "Nature Reviews Genetics. V.14 (4), 2012" (IF2019=33.133). The third highest paper by Callaway, R.M.., (1156 citations) was published in "The Botanical Review, V.61 (4), 1995" (IF2019=2.960).

Conclusion:

A literature analysis through bibliometric investigation of articles on Allelopathy was carried out for a period of 25 years. A total of 7483 articles were published that were indexed in the SCOPUS multidisciplinary database from 1995 to 2019. These articles were published in 14 different document types, where 85.85% were published as journal articles. These 7483 articles had accumulated 167207 citations till December 2019, wherein articles published during 2015-2019 scored the highest number of citations. Kato-Noguchi, H. was the most productive author and Callaway, R.M. got the highest citation. There were 12 articles which were most frequently cited. China was the most productive country with 21.6% of the global publication share. Papers published from the USA on Allelopathy research accumulated the highest number of citations (66954 citations). "Journal of Allelopathy" was the most productive journal which published 12.08% share of the total global publication on Allelopathy. On the parameter of Average Citation Per Paper, articles published from Netherlands had the highest average measure (ACPP=59.17).

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