The Evolution of Metaheuristic Research: A Bibliometrics Analysis of Research Trends in Computer Sciences

Muhammad Afiq Ariffin[1]*, Mazidah Mat Rejab[1], Rosziati Ibrahim[1] Hairulnizam Mahdin[1]

[1] Faculty of Computer Science and Information Technology,
University Tun Hussein Onn Malaysia (UTHM), 86400 Batu Pahat, Johor, MALAYSIA

*Corresponding Author: gi210018@student.uthm.edu.my

Abstract

The purpose of this paper is to examine the development of research trends and to propose potential future paths by conducting a bibliometric analysis of metaheuristic studies. Enhancing the sector's importance and giving readers a clear understanding of its development. The research uses a bibliometric approach, collecting its information from the Scopus database. Articles published in academic journals on metaheuristic research between the years 2015 and 2023 will be analyzed for this study. Data is collected, analyzed, and interpreted to draw conclusions. Important insights into the development of metaheuristic studies emerge from the analysis. Global optimization, heuristic approaches, scheduling, genetic algorithms, evolutionary algorithms, and benchmarking are only a few of the overarching research issues that this study reveals. There is a growing interest in new fields of study, such as adaptive neuro-fuzzy inference, forecasting, feature selection, biomimetic, and the exploration-exploitation trade-off. The results shed light on the current state of the field of metaheuristics and where it needs to go in the future. The study's dependence on Scopus data and its refusal to include data from other sources are two of its acknowledged drawbacks. It highlights the need for further research to address these limitations and recommends possible directions for future studies, such as incorporating diverse data and exploring various applications. This research contributes to the existing body of knowledge by providing a thorough bibliometric examination of the development of metaheuristic studies. It emphasizes the value of metaheuristic algorithms as optimization tools and their impact on resolving complex problems. Researchers, practitioners, and policymakers can all benefit from these findings, as they shed light on current and future paths in metaheuristics research.

1. Introduction

Large search areas, along with challenging issues, have given rise to the sophisticated optimization methods known as Meta-heuristic algorithms. These algorithms offer effective search strategies to minimize the size of the search space, making them well-suited for addressing challenging optimization problems across various domains. As the demand for efficient and effective problem-solving techniques continues to grow, Meta-heuristic research

has acquired significant attention in both academia and industry. Understanding the evolution of Meta-heuristic research and its current state is crucial for advancing the field and identifying future research directions.

Despite the increasing popularity of meta-heuristic algorithms, there is a need to comprehensively analyze the current state of the field to identify the main trends and advancements. Furthermore, as new challenges and applications arise, it is essential to assess the gaps and potential directions for future studies. Therefore, a bibliometric analysis is warranted to examine the performance and features of meta-heuristic research, providing valuable insights into research themes, prominent methodologies, and emerging areas within the field. The primary goal of this research study is to conduct an extensive bibliometric analysis of meta-heuristic research, focusing on identifying research trends and predicting future directions.

The following research questions are addressed in this study to achieve these goals.:

RQ1: What is the trend of research on metaheuristic in computer science to date?

RQ2: Which countries have a significant influence on the development of metaheuristic in computer science?

RQ3: What are the most influential publications on metaheuristic in computer science?

RQ4: What is the major phrase of empirical studies on metaheuristic in computer science?

RQ5: What insights and recommendations can be provided for future research directions in metaheuristic algorithms?

The paper is structured into four main sections. The Introduction (Section 1) sets the research context for meta-heuristic algorithms and presents the study's five research questions. Methods (Section 2) detail the bibliometric data collection and analysis techniques. Results (Section 3) present the empirical findings that answer the trend, country, publication, and topic-related questions (RQ1-RQ4). Finally, Discussions and Conclusion (Section 4) interprets these findings, addresses the study's overall goal, and provides insights for future research directions (RQ5).

2. Methods

According to Rehn et al., [1], bibliometrics has developed into a useful technique for evaluating scientific research by quantitatively examining research publications. Pritchard [2] states that it involves using statistical and quantitative techniques in literature and other types of communication. To identify trends and patterns in specific academic fields, bibliometric analysis is commonly employed to assess the quantity and quality of published papers [3]. As a method for reporting study trends and impact, it is gaining popularity [4]. Ahmi and Mohammad [4] state that the publication categorization, citations, authorship, publication impact, and country are the most often observed bibliometric markers. These bibliometric indicators are divided into three categories: structural, quality, and quantity indicators [5]. Quantitative indicators measure the output of researchers, whereas qualitative indicators evaluate their work. On the other hand, systematic signals evaluate the relationships between publications, authors, and the domain of study. Evaluation of growth, trends, and productivity can be conducted using the number of publications in a specific area of study. The number of citations or citations per year, the h-index or g-index, and impact measures such as the cite score, impact per publication (IPP), and impact factor (IF) can all be used to assess the performance and impact of a publication [6].

Examining structural indicators, which indicate involvement and connections within published resources, can be done using strategies such as co-authorship analysis, citation-based analysis, and co-word analysis. These techniques provide insights into a field's collaboration networks, influential references, and shared lexicon. Software tools such as R Studio (Bilioshiny) make it simple to perform bibliometric analyses, including co-authorship analysis, citation-based analysis, and co-word analysis. In conclusion, bibliometric analysis is a useful method for assessing research trends and impact in the field of metaheuristic algorithms. Researchers can gain insights into publishing productivity, performance, and engagement by assessing the quantity, quality, and structural factors that drive these aspects, which can inform future research orientations and decision-making processes.

2.1 Data Source and Strategy

As of May 2023, the Scopus database was utilized to conduct a bibliometric study. The search term "metaheuristic," which appears in the article title, was used to find relevant papers on computer science metaheuristic research written in any language. Since the article titles are the first thing readers would notice, we paid attention to them [7,8]; therefore, we focused on them. It identifies both the investigation's goal and the issue that is relevant to the topic of study. We restricted our explorations to papers published in 2015 and 2023, with the intention of identifying current trends in metaheuristic research. To avoid double counting or incorrect counting, we excluded errata and withdrawn papers.

2.2 Data Collection

Based on the article's title, the term "metaheuristic in computer science" is identified in the Scopus database using the phrase "metaheuristic in computer science." This study encompasses all document types retrieved from the Scopus database between 2015 and 2023, as of May 15, 2023. Consequently, the Scopus database's TITLE ("metaheuristic") search query is being used. The search returned 2200 results for metaheuristic-related literature. Since the search was conducted solely inside the article's title, we may conclude that all the materials discovered pertain to meta-heuristic, which is the focus of this investigation. After screening, no papers were eliminated. Thus, all 2200 documents qualified for inclusion in this bibliometric analysis. Figure 1 depicts the stage of this study's search approach.

2.3 Data Cleaning and Harmonization

This phase involves data cleansing. The quality of the input details will determine the quality of the final outcome. To detect duplicate and misspelled entries, for instance, various preprocessing approaches may need to be applied. Even though the great mass of bibliometric data is dependable, there might be several versions of the same projects in references that are stated, as well as various author names spelled in different ways. In addition, popular names can also be difficult because writers frequently shorten their names to only their last name and initials. Additionally, cited journals may appear in slightly different formats. Various editions of a book can result in different citations.

2.4 Data Analysis

We conducted performance evaluations in bibliometric studies to characterize advancements in publishing (RQ1), contributing nations (RQ2), publications (RQ3), sources (RQ4), keywords (RQ5), and future trends (RQ6) in research on "metaheuristic in computer science." [9]. The frequency and proportion of each publication were calculated using Microsoft Excel, and the corresponding graphics were also made using this program. In the meantime, we improved our inquiry by employing R Studio to conduct a science mapping analysis. Consider the free software program R Studio, which can collect citation data, bibliographical data, and keywords for network visualization of co-authorship and co-citation among writers. By utilizing the phrases co-occurrence review and document bibliographic coupling analysis, the same equipment was also employed to map the conceptual framework of "metaheuristic in computer science."

2.5 Tools

To accomplish the study's objectives and address the research questions we developed, we conducted a bibliometric analysis using R Studio, a simple application for the Bibliometric R package. Aria and Cuccurullo [10] developed this software with a focus on scientific mapping analysis. Figure 1 depicts the phases and analysis of this investigation. The research questions (RQs) presented in this paper's introduction must be addressed in order for the work to be complete, descriptive, and network analyses have been conducted.

Table 1 *Software used for analysis*

| Format	Software	Analysis/output
.xlsx	Bibliomagika 1.9	Trend of publication, Citation metric, Authorship Pattern, Most Prolific Authors, Core Journals, Top Cited Articles
.csv	R Studio	Co-occurrence network visualization map of the author keywords, Co-authorship network visualization map of the author, Co-authorship network visualization map of the country, Citation network visualization map of the journal .csv, comma-separated values; .ris,
.xlsx	Biiloimagika split 1.2	Cleaning data
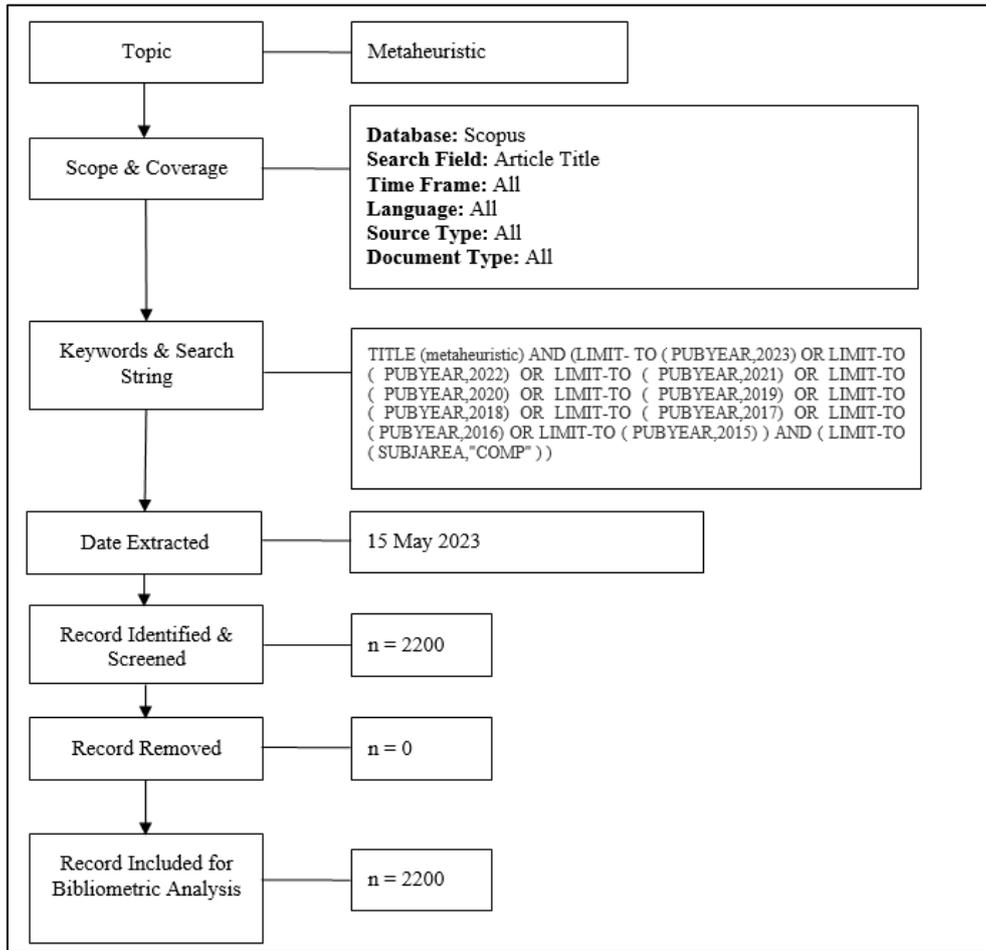
Fig. 1 *Flow diagram of the search strategy ([[11]; [12])*

3. Results

The Scopus database will be used to conduct in-depth analyses of bibliometric features, including publication year and growth rate, document and source type, language, country, field, topic, keywords, dynamic organization, authorship, and citation review. Most of the data are presented as frequency and percentage fluctuations.

3.1 Documents Profile

The categorization of a document is determined by its category, which may include, among other things, an article, an editorial, a review, a conference paper, a remark, and a book chapter. The categorization of published Metaheuristic materials across nine different document types is summarized in Table 2. Most publications (61%) were clearly categorized as articles, followed by conference papers (29%), in that order.

Table 2 *Document type*

	Total Publications (TP)	Percentage (%)
Article	1358	61.73%
Conference Paper	644	29.27%
Book Chapter	143	6.50%
Review	36	1.64%
Erratum	8	0.36%
Book	6	0.27%
Editorial	2	0.09%
Note	2	0.09%
Retracted	1	0.05%
Total	2200	100.00

By accessing data according to document source categories, this study also sought to determine the locations of Metaheuristic publications. Most of the sources, 1,410 (64%) of the total, were from journals, followed by conference proceedings (n = 449; 20%), with a difference of just 40%. Trade publications, which are often intended for a particular industry, trade, or kind of company and are typically published in the form of a magazine or periodical with topical matter, were the least common document category (n = 1; 0.05%). These trade articles are significant scientifically and are helpful in computer science, particularly in the context of metaheuristics, despite being rarely referenced. Table 3 shows the source type.

Table 3 *Source type*

Source Type	Total Publications (TP)	Percentage (%)
Journal	1410	64.09%
Conference Proceeding	446	20.27%
Book Series	311	14.14%
Book	32	1.45%
Trade Journal	1	0.05%
Total	2200	100.00

Based on Table 4, most publications in this research subject are written in English (2,178; 99%). Additionally, Spanish, Chinese, Turkish, and Portuguese are also encountered.

Table 4 *Languages*

Language	Total Publications (TP)*	Percentage (%)
English	2178	99.00%
Spanish	9	0.41%
Chinese	5	0.23%
Turkish	4	0.18%
Portuguese	3	0.14%
Russian	2	0.09%
French	1	0.05%
Total	2200	100.00

The published materials are then categorised in this study according to their topic matter, which is summarised in Table 7. Because computer science uses the keyword "Metaheuristic" so frequently, most research on metaheuristic originates from computer science (2200, 100%), engineering (1036, 47%), and mathematics (810, 36%). However, as shown in Table 5, other fields have also produced publications on metaheuristics, including choice sciences, materials science, decision sciences, and physics and astronomy.

Table 5 *Subject area*

Subject Area	Total Publications (TP)	Percentage (%)
Computer Science	2200	100.00%
Engineering	1036	47.09%
Mathematics	810	36.82%
Decision Sciences	284	12.91%
Materials Science	185	8.41%
Physics and Astronomy	141	6.41%
Energy	104	4.73%
Social Sciences	92	4.18%
Business, Management and Accounting	81	3.68%
Chemical Engineering	70	3.18%
Chemistry	33	1.50%
Medicine	33	1.50%
Environmental Science	31	1.41%

Subject Area	Total Publications (TP)	Percentage (%)
Neuroscience	29	1.32%
Biochemistry, Genetics and Molecular Biology	28	1.27%
Arts and Humanities	20	0.91%
Multidisciplinary	18	0.82%
Economics, Econometrics and Finance	15	0.68%
Earth and Planetary Sciences	12	0.55%
Agricultural and Biological Sciences	8	0.36%
Health Professions	1	0.05%

3.2 Publication Trends

Total Publication (TP): The highest total publication in the metaheuristic field was observed in 2021 and 2022, with 387 and 473 articles, respectively. Compared to prior years, these years experienced a marked rise in the number of publications. Total Citation (TC): The sum of all citations for works in the subject area of metaheuristics is represented by the entire citation score. Citation per Document (C/P): This measure indicates the average number of citations for each publication. From the available data, we can observe that the C/P values varied across the years. For example, in 2015 and 2016, the C/P values were 32.43 and 32.16, respectively. These values indicate that, on average, each document received around 32 citations. However, the C/P values decreased in subsequent years, indicating a lower average citation rate per document.

Citation per Year (C/CP): The average number of citations for each referenced article is represented by this measure. From the data provided in Table 6, we can observe that the C/CP values also varied across the years. For example, in 2015 and 2016, the C/CP values were 35.71 and 37.29, respectively. These values suggest that, on average, each cited publication received around 36 citations per year. Similar to C/P, the C/CP values decreased in subsequent years. h-index and g-index: The h-index and g-index provide insight into the productivity and impact of researchers in the metaheuristic area. The h-index is a measure of how many papers have h or more citations. The greatest number of publications with g^2 or higher citations is represented by the g-index. The h-index values ranged from 7 to 32, whereas the g-index rates varied over the years from 8 to 67, based on the currently accessible data. Figure 2 shows the citations and publications throughout the year.

Table 6 *Year of publication*

Year	TP	NCP	TC	C/P	C/CP	h	g
2015	120	5.45%	3892	32.43	35.71	30	61
2016	138	6.27%	4438	32.16	37.29	31	65
2017	154	7.00%	3276	21.27	24.09	29	54
2018	213	9.68%	4001	18.78	22.23	27	59
2019	232	10.55%	4110	17.72	20.05	28	56
2020	273	12.41%	5489	20.11	23.66	31	67
2021	387	17.59%	4714	12.18	15.31	32	58
2022	473	21.50%	2026	4.28	7.01	19	35
2023	210	9.55%	160	0.76	2.81	7	8
Total	2200						

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.
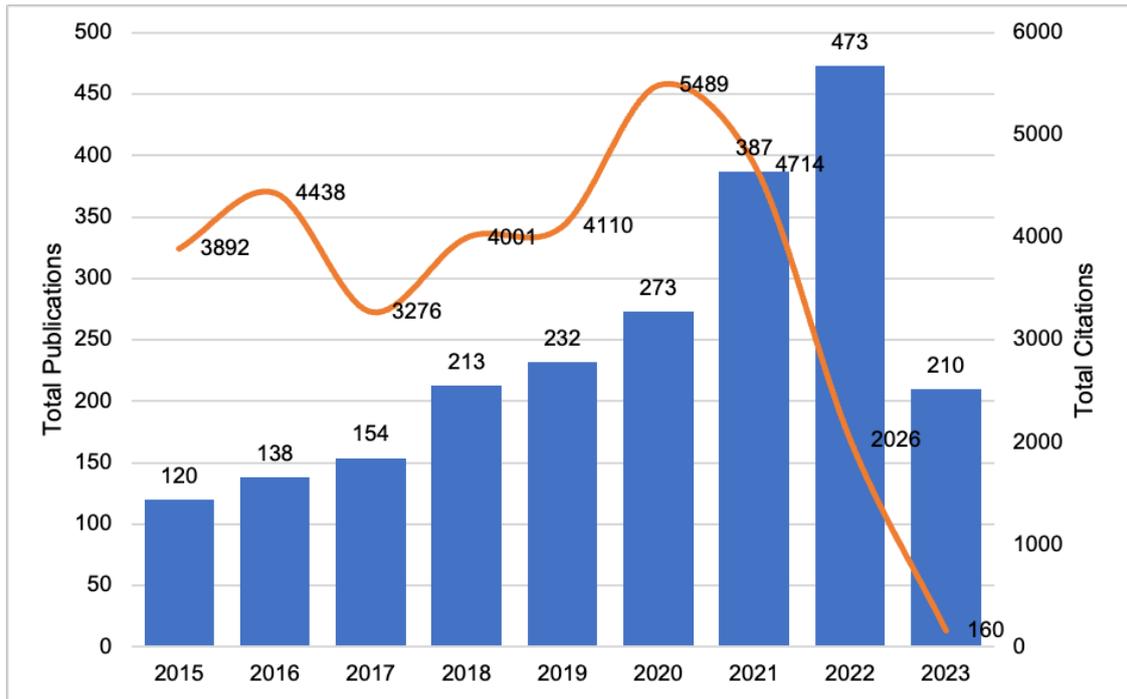
Fig. 2 *Citations and publications overall through year*

3.3 Publication by Year

The total number of different authors can be calculated by summing up the frequencies for each author count. Total different authors = 1 (frequency of author count 1) + 2 (frequency of author count 2) + 3 (frequency of author count 3) + … + 12 (frequency of author count 12).
Total different authors = 143 + 542 + 637 + 437 + 228 + 118 + 44 + 26 + 16 + 8 + 1
Total different authors = 3180
Number of single-author publications = 143 (frequency of author count 1)
Total number of publications = 2200 (sum of all frequencies)
Percentage of single-author publications = (Number of single-author publications / Total number of publications) * 100
Percentage of single-author publications = (143 / 2200) * 100
Percentage of single-author publications ≈ 6.50%

As a result, approximately 6.50% of papers on metaheuristics are the work of a single individual. based on the given data. Research works on metaheuristics often have two authors (24.64%) or three authors (28.95%). The greatest number of writers with papers in metaheuristic is 12.". Table 7 presents the number of author's per document.

Table 7 *Number of author(s) per document*

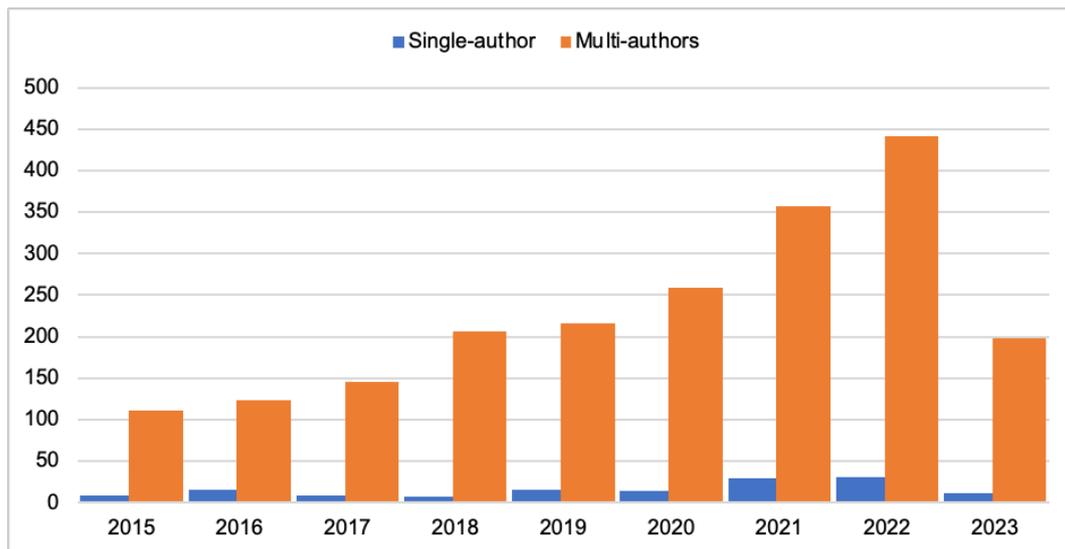| Author Count	Frequency
1	143
2	542
3	637
4	437
5	228
6	118
7	44
8	26
9	16
10	8
12	1
Total	2200

Fig. 4 *Total publications of single and multi-authors by year*

3.4 Geographical Distribution

The international geographic distribution of publications in the metaheuristics discipline. Table 8 gives the top 20 nations that provided content for the publication. India has the largest number of papers in the dataset (1,258), accounting for approximately 39.15% of all publications. This suggests that India has a sizable research output and a keen interest in the topic of metaheuristics. With 571 publications, China ranks second, after India, and accounts for approximately 17.77% of the total. The contribution from China demonstrates the nation's vibrant research scene and focus on metaheuristic approaches. With 468 publications, or approximately 14.54% of all publications, Iran ranks third in terms of the number of publications. This suggests that meta-heuristic studies are prominent in Iran's academic environment. A total of 395 publications from Mexico were included, accounting for approximately 12.29%.

Mexico's research output indicates its involvement and enthusiasm in the field of metaheuristics. With 312 publications, or 9.71% of the total, Turkey ranks fifth. Turkey's involvement and contribution to the subject are highlighted by the metaheuristic research conducted in the country. A total of 293 publications from Malaysia were included, accounting for approximately 9.12% of the total. Malaysia's research output demonstrates its involvement with and interest in metaheuristic approaches. Brazil accounts for approximately 8.72% of the total, with 280 articles. Brazil's involvement in metaheuristic research reflects its significant contributions to the field and active research activity. Overall, the regional distribution of publishing data in the metaheuristics area indicates that these nations have active research communities, demonstrating their substantial involvement and contributions to advancing knowledge and improvements in this field.

Table 8 *Top 20 nations provided content for the publications*

Country	TP	NCP	TC	C/P	C/CP	h	g
India	1258	14857	866	11.44607	17.15589	52	34
China	571	11073	465	19.39229	23.8129	49	21
Iran	468	13813	389	29.51496	35.509	54	18
Mexico	395	3050	277	7.721519	11.01083	20	19
Turkey	312	6021	237	19.29808	25.40506	39	15
Malaysia	293	4743	237	16.18771	20.01266	33	14
Brazil	280	3381	224	12.075	15.09375	23	15
Spain	259	3810	204	14.71042	18.67647	34	13
Egypt	243	5518	201	22.70782	27.45274	31	13
Saudi Arabia	205	1428	128	6.965854	11.15625	17	13
France	189	1092	139	5.777778	7.856115	17	12
Taiwan	183	1983	151	10.83607	13.13245	25	11
Vietnam	147	3041	124	20.68707	24.52419	31	8

Country	TP	NCP	TC	C/P	C/CP	h	g
United States	137	3908	115	28.52555	33.98261	25	9
United Kingdom	129	2042	109	15.82946	18.73394	24	9
Algeria	116	460	88	3.965517	5.227273	13	10
South Korea	115	1120	92	9.73913	12.17391	22	9
Australia	112	4021	97	35.90179	41.45361	25	7
Pakistan	109	1476	91	13.54128	16.21978	19	8

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

3.5 Publication by Source

With 79 articles published, this source title has the most publications overall. IEEE Access, a multidisciplinary, open-access publication, discusses a range of subjects, including metaheuristic research. There are 77 papers in this publishing series, which consists of the subseries Lecture Notes in Bioinformatics and Artificial Intelligence. It is a well-known venue for publishing computer science research, including work on metaheuristic algorithms and their uses. Sixty works in the field of intelligent systems and computing are included in the publication series Advances in Intelligent Systems and Computing, including research on metaheuristics. It addresses a broad variety of computational and AI-related topics. Table 9 lists the most active source titles.

With 54 papers, the Studies in Computational Intelligence series focuses on research in computational intelligence, including metaheuristic algorithms and optimization methods. This Swiss magazine of applied sciences has published 41 papers on a range of applied sciences, including the use of metaheuristic algorithms in diverse fields. 33 publications in the Lecture Notes in Networks and Systems series are devoted to network and system research, which may cover metaheuristic optimization and networking-related subjects. This Mathematics journal has 24 publications, and its topics include mathematical modelling and metaheuristic algorithm analysis. Twenty-two articles on soft computing, involving the application of metaheuristics to challenging problem-solving, were published in the Applied Soft Computing journal. This Sustainability (Switzerland): journal, with 18 publications, examines sustainable development and contains works that could use metaheuristic methods to address sustainability issues.

There are 18 articles in this series, Communications in Computer and Information Science, that address a variety of metaheuristic research subjects as well as other computer science and information science themes. These reference works are well-established venues for publishing research on metaheuristics and provide valuable forums for scholars to discuss their findings and advancements.

Table 9 *Most active source titles*

Source Title	TP	NCA	NCP	TC	C/P	C/CP	h-index	g-index
IEEE Access	79	324	79	1307	16.5443	16.5443	18	33
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	77	247	77	154	2	2	6	7
Advances in Intelligent Systems and Computing	60	221	60	198	3.3	3.3	8	10
Studies in Computational Intelligence	54	173	54	315	5.833333	5.833333	8	17
Applied Sciences (Switzerland)	41	185	41	444	10.82927	10.82927	13	20
Lecture Notes in Networks and Systems	33	111	33	33	1	1	3	4
Mathematics	24	123	24	96	4	4	7	9
Applied Soft Computing	22	69	22	382	17.36364	17.36364	8	19
Sustainability (Switzerland)	18	87	18	83	4.611111	4.611111	4	8
Communications in Computer and Information Science	18	56	18	64	3.555556	3.555556	5	7

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

3.6 Citation Metric

The citation metrics for the papers extracted as of May 2023 are shown in Table 10. As indicated, this dataset contains 1635 citations among the 2200 articles retrieved. This represents the overall number of citations made to the articles in other works. Years: The range of years considered in the analysis, denoting either the length of time the study spanned or the time from which the publications were chosen. In this scenario, we look at a period of nine years of data. Annual Citations: This measure determines the typical annual total of citations. The value of 8 in this data set indicates that the papers were cited an average of 8 times per year. The emphasis of this measure is the average number of citations per manuscript. This dataset has a very high average of 4013.25 citations per paper.

The statistic "citations per author" calculates the average number of citations that every single writer obtains. This dataset has a large average number of citations per author at 7486. This measure yields information on the typical number of writers per paper. According to this data set, there is an average of 3.40 authors per manuscript. The significance of an author's work is quantified by their h-index. The value h denotes the total number of papers with at least h citations. There are 73 publications in this dataset with at least 73 citations apiece, as indicated by the h-index of 73. Another indicator of an author's influence is the g-index. To match the g-index as a whole, the highest number of publications (g) needs to be referenced. The g-index for this data set is 139, which means that the bulk of citations comes from the top 139 papers.

Table 10 *Citations metrics*

Metrics	Data
Papers	2200
Number of Citations	1635
Years	9
Citations per Year	8
Citations per Paper	4013.25
Citations per Author	7486
Authors per Paper	3.40
h-index	73
g-index	139

3.7 Highly Cited Document

We present the top 20 most frequently cited papers in the metaheuristic research field in Table 11 to identify the most significant works. These articles have received significant attention and citations, indicating their impact and influence within the field. The most cited article is titled "A novel metaheuristic method for solving constrained engineering optimization problems: Crow search algorithm" by 13], which has accumulated 1356 citations. This research-based article presents an approach using metaheuristics to solve limited engineering optimization issues.

The second highest cited article, with 870 citations, is titled "Marine Predators Algorithm: A nature-inspired metaheuristic" by Faramarzi A., Heidarinejad M., Mirjalili S., and Gandomi A.H. [14]. The Marine Predators Algorithm, a metaheuristic algorithm inspired by natural phenomena, is introduced in this paper. These highly cited publications highlight significant contributions to the metaheuristic field and have garnered attention from researchers worldwide. The number of citations indicates their impact and influence on subsequent research and the development of new methodologies and algorithms in the field of metaheuristic optimization. Table 11 lists 20 most referenced articles of all time.

Table 11 *20 most referenced articles of all time*

No.	Authors	Title	Cites	Cites per Year
1	Askarzadeh A. [13] (2016)	A novel metaheuristic method for solving constrained engineering optimization problems: Crow search algorithm	1356	169.50
2	Faramarzi A.; Heidarinejad M.; Mirjalili S.; Gandomi A.H. [14] (2020)	Marine Predators Algorithm: A nature-inspired metaheuristic	870	217.50

No.	Authors	Title	Cites	Cites per Year
3	Dhiman G.; Kumar V. [15] (2017)	Spotted hyena optimizer: A novel bio-inspired based metaheuristic technique for engineering applications	626	89.43
4	Kaur S.; Awasthi L.K.; Sangal A.L.; Dhiman G. [16] (2020)	Tunicate Swarm Algorithm: A new bio-inspired based metaheuristic paradigm for global optimization	545	136.25
5	Wang G.-G. [17] (2018)	Moth search algorithm: a bio-inspired metaheuristic algorithm for global optimization problems	543	90.50
6	Yazdani M.; Jolai F. [18] (2016)	Lion Optimization Algorithm (LOA): A nature-inspired metaheuristic algorithm	422	52.75
7	Zheng Y.-J. [19] (2015)	Water wave optimization: A new nature-inspired metaheuristic	422	46.89
8	Salimi H. [20] (2015)	Stochastic Fractal Search: A powerful metaheuristic algorithm	383	42.56
9	Dokeroglu T.; Sevinc E.; Kucukyilmaz T.; Cosar A. [21] (2019)	A survey on new generation metaheuristic algorithms	380	76.00
10	Hussain K.; Mohd Salleh M.N.; Cheng S.; Shi Y. [22] (2019)	Metaheuristic research: a comprehensive survey	366	73.20
11	Hashim F.A.; Hussain K.; Houssein E.H.; Mabrouk M.S.; Al-Atabany W. [23] (2021)	Archimedes optimization algorithm: a new metaheuristic algorithm for solving optimization problems	345	115.00
12	Abdollahzadeh B.; Gharehchopogh F.S.; Mirjalili S. [24] (2021)	African vulture's optimization algorithm: A new nature-inspired metaheuristic algorithm for global optimization problems	329	109.67
13	Kalra M.; Singh S. [25] (2015)	A review of metaheuristic scheduling techniques in cloud computing	318	35.33
14	Ahmadianfar I.; Bozorg-Haddad O.; Chu X. [26] (2020)	Gradient-based optimizer: A new metaheuristic optimization algorithm	317	79.25
15	Ojha V.K.; Abraham A.; Snášel V. [27] (2017)	Metaheuristic design of feedforward neural networks: A review of two decades of research	308	44.00
16	Pierezan J.; Dos Santos Coelho L. [28] (2018)	Coyote Optimization Algorithm: A New Metaheuristic for Global Optimization Problems	303	50.50
17	Wang G.-G.; Deb S.; Dos Santos Coelho L. [29] (2018)	Earthworm optimization algorithm: A bio-inspired metaheuristic algorithm for global optimization problems	301	50.17
18	Shadravan S.; Naji H.R.; Bardsiri V.K. [30] (2019)	The Sailfish Optimizer: A novel nature-inspired metaheuristic algorithm for solving constrained engineering optimization problems	282	56.40
19	Abdollahzadeh B.; Soleimanian Gharehchopogh F.; Mirjalili S. [31] (2021)	Artificial gorilla troops optimizer: A new nature-inspired metaheuristic algorithm for global optimization problems	271	90.33
20	Wang G.-G.; Deb S.; Gao X.-Z.; Dos Santos Coelho L. [32] (2016)	A new metaheuristic optimization algorithm motivated by elephant herding behavior	254	31.75

3.8 Top Keywords

It's undeniable that the author's keywords are essential for spotting study patterns. Author keyword analysis, as outlined by [33], is crucial for tracking the progression of research subjects. The study presents the most admired

author phrases from 2015 to 2023. R Studio, a software package for generating and visualizing bibliometric networks, was then used to map all keywords (including author keywords and index keywords) provided for each text (see Fig. 5). Here, we look at how often two or more related keywords appear together. This criterion led to the discovery of 188 keywords. The measurement of the circles, the height of the text, and the thickness of the lines connecting them all show the relative relevance of the keywords to one another, which is a network visualization of all the keywords in R Studio [34]. Similar keywords, denoted by the identical colour, are commonly paired off. A cluster is represented by each of the colours in this diagram. In this representational map, four distinct groups are visible. Terms used by leading authors in the domain of metaheuristics research are shown in the table below, along with the total number of publications (TP) in which such keywords appear. The concepts and methods represented by these terms are essential to metaheuristic optimization research.

Optimization is the most popular keyword among authors, appearing 876 times in total. This emphasizes the importance placed on locating the best answers to problems across a wide range of contexts. The use of metaheuristic methodologies in optimization research is a central issue, and the word "metaheuristic" is the second most used keyword (554 publications). Metaheuristic algorithms (401 papers), genetic algorithms (378), particle swarm optimization (PSO) (361), heuristic algorithms (303), metaheuristics (295), and optimizations also feature prominently as author keywords (189 publications). These terms refer to the algorithms, methods, and approaches employed in metaheuristic optimization studies. The prevalence of these terms in scholarly works is indicative of their value in enhancing optimization approaches and problem-solving techniques, as well as their significance in the broader field of metaheuristics. Table 12 presents the top author's keywords.

Table 12 *Top author's keywords*

Author Keywords	Total Publications (TP)
Optimization	876
Metaheuristic	554
Meta Heuristic Algorithm	401
Genetic Algorithms	378
Particle Swarm Optimization (PSO)	361
Heuristic Algorithms	303
Metaheuristics	295
Optimizations	189
Metaheuristic Algorithms	187
Optimization Algorithms	185
Evolutionary Algorithms	171
Benchmarking	167
Meta-heuristic Approach	165
Meta Heuristics	162
Genetic Algorithm	158
Scheduling	153
Artificial Intelligence	152
Meta-heuristic Optimizations	152
Optimization Problems	144
Learning Algorithms	137
Metaheuristic Algorithms	133
Particle Swarm Optimization	132
Metaheuristic Optimization	129
Simulated Annealing	128
Ant Colony Optimization	119
Combinatorial Optimization	114

4. Discussions and Conclusions

In this discussion section, this study will interpret and examine the key findings of our bibliometric analysis on metaheuristic research. We will provide insights and recommendations based on our findings, addressing various content areas. From our bibliometric analysis, several key findings have emerged. Firstly, we observed that the metaheuristic research field has experienced significant growth in terms of publications over the years, with a

total of 2,200 publications from 2015 to 2023. The years 2021 and 2022 showed the most publications, indicating a growing interest in the field. Additionally, we identified the top productive institutions, with Universidad de Guadalajara, Duy Tan University, and Mansoura University being the most prolific contributors. Furthermore, we examined the collaboration network among countries and found that India, China, and Iran were the leading contributors in terms of the number of publications. These countries have made substantial contributions to the domain of metaheuristics, indicating the global nature of research collaboration in this area.

The emergence of highly cited articles such as "A novel metaheuristic method for solving constrained engineering optimization problems: Crow search algorithm" and "Marine Predators Algorithm: A nature-inspired metaheuristic" highlights the importance of innovative and nature-inspired approaches in solving complex optimization problems. These articles have garnered significant attention and citations, indicating their influence and impact on the metaheuristic research community. The prevalence of keywords such as "Optimization," "Metaheuristic," and "Genetic Algorithms" reflects the foundational concepts and techniques that researchers commonly employ in the field. These keywords highlight the focus on developing efficient optimization algorithms and exploring novel metaheuristic approaches for solving real-world problems.

The findings of our analysis have implications for practice in the field of metaheuristic research. The identified influential articles and productive institutions can assist as valuable references for researchers and practitioners seeking to gain insights into the latest advancements and established methodologies in metaheuristics. Practitioners can draw upon the findings to inform their decision-making processes when applying metaheuristic techniques to real-world problems, enhancing the efficiency and effectiveness of their optimization processes.

Based on our findings, we recommend several areas for upcoming research in the domain of metaheuristics. Firstly, further investigation into the application of metaheuristic algorithms in specific industries or domains could provide valuable insights and contribute to practical advancements. Additionally, exploring hybridization techniques that combine different metaheuristic algorithms or integrate metaheuristics with other optimization approaches could yield improved performance and efficiency in solving complex optimization problems. Furthermore, research could focus on the evolution of novel metaheuristic algorithms motivated by diverse natural phenomena, expanding the range of optimization techniques available to researchers and practitioners. Additionally, considering the ethical and societal implications of employing metaheuristic approaches in decision-making processes is an area that warrants attention and further exploration.

While our bibliometric analysis provides valuable insights into the metaheuristic research field, it is not without limitations. The analysis is established on the available literature up until 2023, and newer publications may have emerged since then. Additionally, our analysis focused on specific metrics and keywords, and other relevant factors may exist that were not considered in our study.

Future research could address these limitations by conducting more comprehensive and up-to-date bibliometric analyses. Incorporating additional metrics, such as Altimetric, could supply a broader understanding of the impact and reach of metaheuristic research beyond traditional citation-based metrics. Furthermore, considering interdisciplinary perspectives and collaborations with other fields, such as artificial intelligence or operations research, might help develop a more comprehensive grasp of the uses and possibilities of metaheuristic techniques.

The bibliometric study presented here concludes by providing a comprehensive overview of the metaheuristic research environment, highlighting key trends, influential articles, productive institutions, and collaboration networks. The findings of this study underscore the significance of bibliometric analysis in understanding the evolution of a research field, identifying influential contributions, and informing future research directions. As the field of metaheuristics continues to advance and address complex optimization problems, it is essential for researchers and practitioners to stay updated with the latest trends and insights. Bibliometric analysis serves as a valuable tool for mapping the intellectual structure of a research domain, identifying key contributors, and uncovering emerging areas of interest. We encourage future scholars interested in metaheuristic research or other domains to consider conducting bibliometric analyses to gain a comprehensive understanding of the research landscape. By leveraging bibliometric techniques, researchers can make informed decisions, identify research gaps, and drive innovation in their respective fields. In conclusion, bibliometric analysis offers a powerful approach to enhance our understanding of research trends, facilitate knowledge dissemination, and foster collaborations. As the field of metaheuristics continues to evolve, ongoing bibliometric analyses will be instrumental in shaping its trajectory and contributing to its continued growth and impact.

Acknowledgement

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

References

[1] Rehn, C., Kronman, U., & Wadskog, D. (2007). Bibliometric indicators—definitions and usage at Karolinska Institutet. *Karolinska Institutet*, *13*, 2012.

[2] Pritchard, A. (1969). Statistical bibliography or bibliometrics. *Journal of documentation*, *25*, 348.

[3] Sweileh, W. M., Al-Jabi, S. W., AbuTaha, A. S., Zyoud, S. E. H., Anayah, F. M., & Sawalha, A. F. (2017). Bibliometric analysis of worldwide scientific literature in mobile-health: 2006–2016. *BMC medical informatics and decision making*, *17*(1), 72.

[4] Aidi Ahmi, R. M. (2019). Bibliometric analysis of global scientific literature on web accessibility. *International Journal of Recent Technology and Engineering (IJRTE)*, *7*(6), 250-258.

[5] Durieux, V., & Gevenois, P. A. (2010). Bibliometric indicators: quality measurements of scientific publication. *Radiology*, *255*(2), 342-351.

[6] Ahmi, A., & Mohd Nasir, M. H. (2019). Examining the trend of the research on extensible business reporting language (XBRL): A bibliometric review. *International journal of innovation, creativity and change*, *5*(2), 1145-1167.

[7] Annesley, T. M. (2012). Now you be the judge. *Clinical chemistry*, *58*(11), 1520-1526.

[8] Jamali, H. R., & Nikzad, M. (2011). Article title type and its relation with the number of downloads and citations. *Scientometrics*, *88*(2), 653-661.

[9] Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of business research*, *133*, 285-296.

[10] Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of informetrics, 11(4), 959-975.

[11] Zakaria, R., Ahmi, A., Ahmad, A. H., Othman, Z., Azman, K. F., Ab Aziz, C. B., ... & Shafin, N. (2021). Visualising and mapping a decade of literature on honey research: a bibliometric analysis from 2011 to 2020. *Journal of Apicultural Research*, *60*(3), 359-368.

[12] Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International journal of surgery*, *8*(5), 336-341.

[13] Askarzadeh, A. (2016). A novel metaheuristic method for solving constrained engineering optimization problems: crow search algorithm. *Computers & structures*, *169*, 1-12.

[14] Faramarzi, A., Heidarinejad, M., Mirjalili, S., & Gandomi, A. H. (2020). Marine Predators Algorithm: A nature-inspired metaheuristic. *Expert systems with applications*, *152*, 113377.

[15] Dhiman, G., & Kumar, V. (2017). Spotted hyena optimizer: A novel bio-inspired based metaheuristic technique for engineering applications. *Advances in engineering software*, *114*, 48-70.

[16] Kaur, S., Awasthi, L. K., Sangal, A. L., & Dhiman, G. (2020). Tunicate Swarm Algorithm: A new bio-inspired based metaheuristic paradigm for global optimization. *Engineering Applications of Artificial Intelligence*, *90*, 103541.

[17] Wang, G. G. (2018). Moth search algorithm: a bio-inspired metaheuristic algorithm for global optimization problems. *Memetic Computing*, *10*(2), 151-164.

[18] Yazdani, M., & Jolai, F. (2016). Lion optimization algorithm (LOA): a nature-inspired metaheuristic algorithm. *Journal of computational design and engineering*, *3*(1), 24-36.

[19] Zheng, Y. J. (2015). Water wave optimization: a new nature-inspired metaheuristic. *Computers & Operations Research*, *55*, 1-11.

[20] Salimi, H. (2015). Stochastic fractal search: a powerful metaheuristic algorithm. *Knowledge-based systems*, *75*, 1-18.

[21] Dokeroglu, T., Sevinc, E., Kucukyilmaz, T., & Cosar, A. (2019). A survey on new generation metaheuristic algorithms. *Computers & Industrial Engineering*, *137*, 106040.

[22] Hussain, K., Mohd Salleh, M. N., Cheng, S., & Shi, Y. (2019). Metaheuristic research: a comprehensive survey. *Artificial intelligence review*, *52*(4), 2191-2233.

[23] Hashim, F. A., Hussain, K., Houssein, E. H., Mabrouk, M. S., & Al-Atabany, W. (2021). Archimedes optimization algorithm: a new metaheuristic algorithm for solving optimization problems. *Applied intelligence*, *51*(3), 1531-1551.

[24] Abdollahzadeh, B., Gharehchopogh, F. S., & Mirjalili, S. (2021). African vultures optimization algorithm: A new nature-inspired metaheuristic algorithm for global optimization problems. *Computers & Industrial Engineering*, *158*, 107408.

[25] Kalra, M., & Singh, S. (2015). A review of metaheuristic scheduling techniques in cloud computing. *Egyptian informatics journal*, *16*(3), 275-295.

[26] Ahmadianfar, I., Bozorg-Haddad, O., & Chu, X. (2020). Gradient-based optimizer: A new metaheuristic optimization algorithm. *Information Sciences*, *540*, 131-159.

[27] Ojha, V. K., Abraham, A., & Snášel, V. (2017). Metaheuristic design of feedforward neural networks: A review of two decades of research. *Engineering Applications of Artificial Intelligence*, *60*, 97-116.

[28] Pierezan, J., & Coelho, L. D. S. (2018, July). Coyote optimization algorithm: a new metaheuristic for global optimization problems. In *2018 IEEE congress on evolutionary computation (CEC)* (pp. 1-8). IEEE.

[29] Wang, G. G., Deb, S., & Coelho, L. D. S. (2018). Earthworm optimisation algorithm: a bio-inspired metaheuristic algorithm for global optimisation problems. *International journal of bio-inspired computation*, *12*(1), 1-22.

[30] Shadravan, S., Naji, H. R., & Bardsiri, V. K. (2019). The Sailfish Optimizer: A novel nature-inspired metaheuristic algorithm for solving constrained engineering optimization problems. *Engineering Applications of Artificial Intelligence*, *80*, 20-34.

[31] Abdollahzadeh, B., Soleimanian Gharehchopogh, F., & Mirjalili, S. (2021). Artificial gorilla troops optimizer: a new nature-inspired metaheuristic algorithm for global optimization problems. *International Journal of Intelligent Systems*, *36*(10), 5887-5958.

[32] Wang, G. G., Deb, S., Gao, X. Z., & Coelho, L. D. S. (2016). A new metaheuristic optimisation algorithm motivated by elephant herding behaviour. *International Journal of Bio-Inspired Computation*, *8*(6), 394-409.

[33] Wen, H., & Huang, Y. (2012). Trends and performance of oxidative stress research from 1991 to 2010. Scientometrics, 91, 51–63. https://doi.org/10.1007/s11192-011-0535-2

[34] Sweileh, W. M., Al-Jabi, S. W., AbuTaha, A. S., Zyoud, S. E. H., Anayah, F. M., & Sawalha, A. F. (2017). Bibliometric analysis of worldwide scientific literature in mobile-health: 2006–2016. *BMC medical informatics and decision making*, *17*(1), 72.