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Citation Distributions in Synthetic Biology Literature Output During 2005-2019

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Abstract
The study highlights the distribution citations in global Synthetic Biology research output during 2005-2019. The primary data for the analysis were retrieved from the Web of Science core collection database. This study illustrates various vital aspects like – year-wise distribution of citations, relative growth rate and doubling time of citations, citation per paper, citation pattern, distribution of cited and non-cited publications, and highly cited publications in Synthetic Biology. The results revealed that the publications on Synthetic Biology attracted a reasonably good number of citations during the period under evaluation. A total of 12012 publications received 329631citations with an average number of citations per publication value of 27.44. Around 90.27 percent of total publications was received at least one or more citations. There among 1169 (9.73%) publications did not have any citations. It was found that the relative growth rate of citations decreased steadily. At the same time, the value of doubling the time of citations was increased during this period.

Keywords: Synthetic Biology; Citation analysis; Citation pattern; Relative Growth Rate.

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1. Introduction

Citation rates reflect the impact of published works on the scientific community worldwide. Moreover, citations are vital aspects of assessing the quality of research work. Citations determine the quality and influence of the publications on the literature to follow. Citation data are increasingly used as the performance indicators in research policy and within the research system. Usually, citations are assumed to reflect the impact of research and its quality (Aksnes, 2019). A citation is defined as the acknowledgement that one document receives from another, and citation analysis is that area of bibliometrics that deals with studying the relationship between cited and citing papers (Smith, 1981). Significant advantages of citation analysis are its high reliability and unobtrusiveness (De Bellis, 2009). Citation analysis overcomes the problem of possible non-response bias associated with surveys. Citations indicate that a document has been read or referenced, which can be considered a measure of use. Citations have also been used to compare the scientific impact of publications (Rahm, 2005), monitor research systems, and evaluate research (Askenes, 2004). Hence, studying in detail in various branches of scientific disciplines is vital.

The present study attempts to carry out a detailed citation analysis of literature output related to Synthetic Biology (SB). The title "Synthetic Biology" appeared in the literature in the 1980s, when Barbara Hobom used it to describe genetically engineered bacteria using recombinant DNA technology (Hobom,1980; Benner and Sismour, 2005). According to the National Academy of Sciences, SB is "an emerging discipline that combines both scientific and engineering approaches to studying and manipulating biology" (NAS, 2013). SB has a broader scope because it attempts to recreate the emergent properties of living systems in artificial chemical methods, including inheritance, genetics, and evolution. Synthetic biology has many positive applications. SB's potential applications vary widely across scientific and engineering disciplines, from medicine to energy generation. Similarly, SB provides the tools for medical intervention at the molecular level, preventing the rather crude surgical or pharmaceutical instruments currently at our disposal. SB is an emerging technology that hopes to develop as a substitute for engineering further.

SB is a broad field that impacts numerous sectors of the economy, including food and agriculture (genetically engineered plants and animals, food additives, cell-based meats), energy and climate (bio-fuels, bioremediation, carbon technologies), manufacturing and chemicals (chemicals, plastics), and health and medicine (vaccines, drugs, medicines, protein therapeutics). There is a range of potential applications of SB which could monitor and respond to conditions of the human body. SB has wide application in developing and producing alternative routes for valuable compounds. One of the most crucial applications of SB research is bio-fuels (Khalil and Collins, 2010; Keshava et

al., 2018). The main focus areas of this study were to analyse the chronological wise distribution citations, relative growth rate and doubling time of citations, citation per paper, citation pattern, distribution of cited and non-cited publications, and highly cited publications.

2. Literature Review

The existing literature analysis reveals that so far, there are only a few partial scientometric studies have been carried out on Synthetic Biology literature. Oldham, Hall, and Burton (2012) examine the Synthetic Biology literature output using the 1,255 publication records obtained from the Web of Science database. Similarly, Hu and Rousseau (2015) analyse the Synthetic Biology literature publish during2000-2013.The authors report exponential growth publications in Synthetic Biology during this period. Later, Raimbault etal. (2016)explored the emergence of the Synthetic Biology domain using the data retrievedfrom the WOS database. They use the bibliographical details of 4,605 publications from2000-2015 as a sample for this study. This study mainly focuses on the mapping of textual and citation networks. Recently, Shapira et al. (2017) examine the emergence of the Synthetic Biologyliterature from 2000 to 2015. This study is based on the 8064 records obtained from theWOS database. This study shows a rapid increase in global SB research output during recent years. The authors report that the USA is the most productive country in SB research activities, followed by Germany and China.

3. Objectives of the Study

The study's primary purpose is to assess the distribution of citations received by the scientific literature output published in the Synthetic Biology discipline throughout 15 years (i.e., 2005 through 2019). The specific objectives are as follows:

1. To analyse the year-wise distribution of publications and citations;
2. To find out the relative growth rate and doubling time of citations;
3. To determine the year-wise value of citation per paper;
4. To know the citation pattern of publications;
5. To calculate the ratio of cited verses non-cited publications; and
6. To discover the bibliographic features of highly cited articles in Synthetic Biology during 2005-2019.

4. Data source and Methodology

The data for this study has been obtained from the Web of Science Core Collection database of Clarivate Analytics, Boston, USA, for 15 years, i.e., 2005-2019. The following search string developed and suggested by Shapira et al. (2017) have been used to the publication records pertaining to Synthetic Biology:

(((TS=("syntheticbiolog*"OR"syntheticdna"OR"syntheticgenom*"OR"synthetic *nucleotide"OR"syntheticpromoter"OR"syntheticgene*cluster") NOT TS=("photosynthe*")) OR (TS = ("synthetic mammalian gene*" AND "mammalian cell") NOT TS = "photosynthe*") OR (TS = "synthetic gene*" NOT TS = ("synthetic gener*" OR"photosynthe*")) OR(TS =("artificial gene* network" OR("artificialgene* circuit*"AND "biological system")) NOT TS = "gener*") OR (TS = ("artificial cell") NOT TS =("cell* telephone" OR "cell* phone" OR "cell* culture" OR "logic cell*" or "fuel cell*" or"battery cell*" or"load-cell*" or"geo-synthetic cell*" or"memory cell*"or"cellularnetwork"or"ramcell*"or"romcell*"or"maximumcell*" OR"electrochemicalcell*"OR "solar cell*")) OR (TS = ("synthetic cell") NOT TS = ("cell* telephone" OR "cell*phone" OR "cell* culture" OR "logic cell*" or "fuel cell*" or "battery cell*" or "load-cell*"or "geo-synthetic cell*" or "memory cell*" or "cellular network" or "ram cell*" or "romcell*"or"maximumcell*"OR"electrochemicalcell*"OR"solarcell*" OR"photosynthe*"))OR(TS=("artificialnucleicacid*"OR"artificial*nucleotide")) OR (TS=("biobrick"or "biobrick"or"bio-brick"))))

A total of 12012 publications were identified for further analysis. The collected data were organized, calculated, tabulated, analysed, and presented using simple arithmetic and statistical methods to provide an insights into the pattern of citation distribution in SB.

5. Results and Discussions

5.1 Year-wise distribution of Citations

Table 1 presents the year-wise distribution of citations on SB literature from 2005 to 2019. Table 1 indicates that the total 12012 publications together receivedwith 329631 citations from 2005 to 2019.

Table 1 Year-wise distribution of Citations on Synthetic Biology literature 2005-2019

Sl.no	Year	Publications	Citations	% of Citations
1	2005	202	13097	3.97
2	2006	243	13158	3.99
3	2007	257	14835	4.50
4	2008	324	17884	5.43
5	2009	407	23823	7.23
6	2010	511	26727	8.11
7	2011	585	26189	7.94

8	2012	793	31598	9.59
9	2013	838	32822	9.96
10	2014	976	30318	9.20
11	2015	1140	28037	8.51
12	2016	1365	26428	8.02
13	2017	1270	20655	6.27
14	2018	1567	16832	5.11
15	2019	1534	7228	2.19
Total		**12012**	**329631**	**100**

Table 1 show that the maximum of 32822 citations were recorded for the 838 publications in 2013, followed by 31598 citations in 2012. A minimum of 7228 citations were recorded in the last year of the study period, i.e., 2019. It inferred from the results that publications on SB attracted a reasonably good number of citations during the period under evaluation.

5.2 Relative Growth Rate (RGR) and doubling Time (Dt) of citations in SB Literature

The RGR and doubling Times (Dt) of citations in SB literature from 2005 to 2019 are calculated and presented in Table 2. It shows that the value of the relative growth rate of citations decreased steadily from 0.70 in 2006 to 0.02 in 2019. Simultaneously, the value of doubling time of citations increased from 1.00 in 2006 to 31.26 in 2019. The maximum 0.70 RGR was recorded in 2006, followed by 2007 with an RGR of 0.45. Similarly, the top 31.26 Dt was recorded in 2019, followed by 2018 with Dt 12.92.

The mean relative growth rate was 0.36 in the first seven years (i.e., 2006 to 2012), and it reduced to 0.10 in the last seven years, i.e., 2013 to 2019. The corresponding mean Dt of citations increased from 2.22 in the first seven years, i.e., 2006 to 2012, to 12.03 in the last seven-year period from 2013 to 2019. It is evident from these results that the growth of citations had a gradual reduction in the RGR and simultaneous increase of Dt.

Table 2 RGR and Dt for citations in SB literature during 2005 to 2019

Year	Citations	Cum. citations	Log1	Log2	RGR	Mean RGR	Dt	Mean Dt
2005	13097	13097		9.48				
2006	13158	26255	9.48	10.18	0.70		1.00	
2007	14835	41090	10.18	10.62	0.45		1.55	

2008	17884	58974	10.62	10.98	0.36		1.92	
2009	23823	82797	10.98	11.32	0.34	0.36	2.04	2.22
2010	26727	109524	11.32	11.60	0.28		2.48	
2011	26189	135713	11.60	11.82	0.21		3.23	
2012	31598	167311	11.82	12.03	0.21		3.31	
2013	32822	200133	12.03	12.21	0.18		3.87	
2014	30318	230451	12.21	12.35	0.14		4.91	
2015	28037	258488	12.35	12.46	0.11		6.04	
2016	26428	284916	12.46	12.56	0.10	0.10	7.12	12.03
2017	20655	305571	12.56	12.63	0.07		9.90	
2018	16832	322403	12.63	12.68	0.05		12.92	
2019	7228	329631	12.68	12.71	0.02		31.26	

Fig. 1 depicts the trend of RGR and Dt of citations from 2005 to 2019. It is clear from Figure 1 that the growth rate of citations was decreased, and the corresponding doubling time was increased throughout the period under evaluation. These results revealed that the actual growth trend of citations on SB from 2005 to 2019 did not follow either exponential or linear curves. The findings of this study clearly indicated that the citations to the literature published in SB have increased over stated period of evaluation.

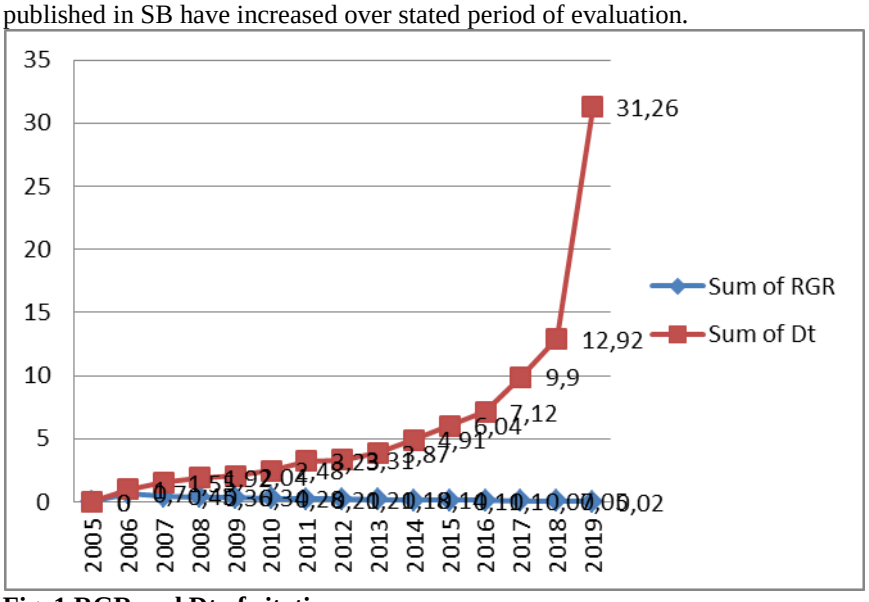

Fig. 1 RGR and Dt of citations

5.3 Average Citation per Publications (ACPP)

Table 3 shows the year-wise distribution of publications, total citations received, and the rate of citations per publication. It could see from Table 3 that the 12012 publications together received 329631 citations with an average of citations per publication (27.44) during the period under study. The rate of citation varied from 64.84 to 4.71. The highest rate CPP (64.84) was observed in 2005, followed by 2009 with CPP 58.53, 2007 with CPP 57.72, and CPP 55.20 in 2008. The lowest rate was observed in the year 2019 (CPP 4.71). Further, out of the total fifteen years, publications from 2005 to 2010 received a citation rate of more than 50, and ten out of fifteen years (i.e., Years from 2005 to 2014) recorded citation rates more than the average rate, i.e., 27.44.

Table 3 Citation Per Paper in the field of SB during 2005-2019

Sl.no	Year	Publications	Citations	% of Citations	Aaverage CPP (C/P)
1	2005	202	13097	3.97	64.84
2	2006	243	13158	3.99	54.15
3	2007	257	14835	4.50	57.72
4	2008	324	17884	5.43	55.20
5	2009	407	23823	7.23	58.53
6	2010	511	26727	8.11	52.30
7	2011	585	26189	7.94	44.77
8	2012	793	31598	9.59	39.85
9	2013	838	32822	9.96	39.17
10	2014	976	30318	9.20	31.06
11	2015	1140	28037	8.51	24.59
12	2016	1365	26428	8.02	19.36
13	2017	1270	20655	6.27	16.26
14	2018	1567	16832	5.11	10.74
15	2019	1534	7228	2.19	4.71
Total		**12012**	**329631**	**100.00**	**27.44**

Fig. 2 illustrates the number of citations per publication from 2005 to 2019. It is evident from the figure that the growth rate of citations per publication is not gradual over the years. Further, it was apparent that the citation rate per publication showed a decreasing trend from 2005 to 2019.

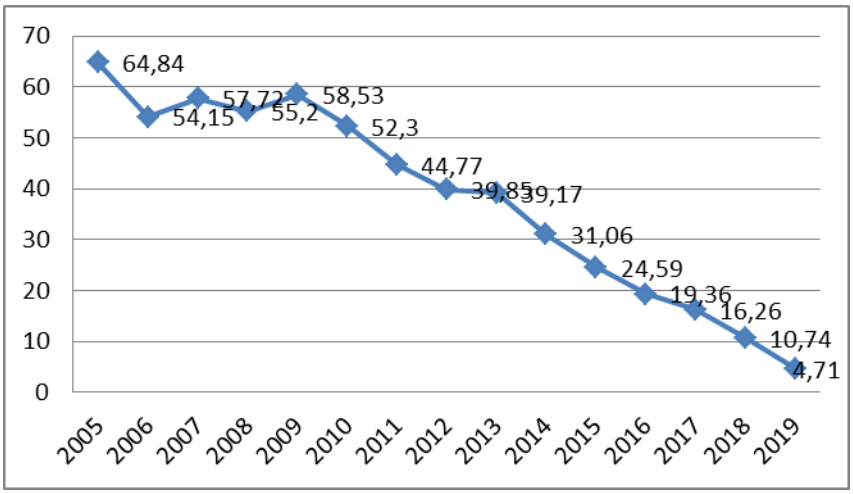

Fig. 2 Citation per publications during 2005 to 2019

5.4 Average Citation per Author (ACPA)

Table 4 shows the year-wise distribution of publications, citations, and the rate of citations per author. Table 4 displays the citation analysis derived from the 12012 publications contributed by 56820 authors which received 329631 citations with an average of citations per author (i.e., 5.80) during the period under study. The rate of citation varied from 0.90 to 14.61. The highest rate CPA (i.e., 14.61) was observed in 2009, followed by 2005 with 14.28. At the same time, the lowest rate was observed in the year 2019 (CPA 0.90). Further, out of the total fifteen years, publications from 2005 to 2011 received a citation per author rate of more than 10, and ten out of fifteen years (i.e., 2005 to 2014) recorded citations per author rate was more than the average rate, i.e., 5.80.

Table 4 Average Citation Per Author in the field of SB during 2005-2019

Sl.no	Year	Publications	Authors	Citations	% of Citations	Aaverage CPA
1	2005	202	917	13097	3.97	14.28
2	2006	243	1077	13158	3.99	12.22
3	2007	257	1111	14835	4.5	13.35
4	2008	324	1437	17884	5.43	12.45
5	2009	407	1631	23823	7.23	14.61
6	2010	511	2124	26727	8.11	12.58
7	2011	585	2486	26189	7.94	10.53

8	2012	793	3284	31598	9.59	9.62
9	2013	838	3785	32822	9.96	8.67
10	2014	976	4442	30318	9.2	6.83
11	2015	1140	5338	28037	8.51	5.25
12	2016	1365	6561	26428	8.02	4.03
13	2017	1270	6515	20655	6.27	3.17
14	2018	1567	8080	16832	5.11	2.08
15	2019	1534	8032	7228	2.19	0.90
Total		**12012**	**56820**	**329631**	**100**	**5.80**

5.5 Citation Pattern

Data of SB literature citation patterns were tabulated and presented in Table 5. It is evident from this table that, 1169 (9.73%) publications did not receive any citation and the remaining 90.27% received one or more citations. Among the cited publications, 40.43% of publications cited between 1 to 10 times, and the remaining 49.84% were cited more than ten times. The number of publications that received more than 100 citations was 617 (5.14%). The average rate of citations was 27.44. The number of publications cited more than the average rate was 2867.

Table 5 Citation Pattern of Synthetic Biology Literature 2005-2019

Citation pattern	Publications	% of Publications (N=12012)	Citations	% of Citations (N=329 631)
0	1169	9.73	0	0.00
1 to 10	4856	40.43	23085	7.00
11 to 20	2120	17.65	31816	9.65
21 to 30	1171	9.75	29389	8.92
31 to 40	695	5.79	24578	7.46
41 to 50	446	3.71	20158	6.12
51 to 60	317	2.64	17574	5.33
61 to 70	219	1.82	14375	4.36
71 to 80	157	1.31	11829	3.59
81 to 90	147	1.22	12561	3.81

91 to 100	98	0.82	9328	2.83
>100	617	5.14	134938	40.94
Total	**12012**	**100.00**	**329631**	**100**

5.6 Distribution of Cited and Non-cited publications

Table 6 provides the year-wise distribution of cited and non-cited publications along with the percentage share of yearly publications. Out of 12012 publications, 10843 (90.27%) were cited publications, i.e., publications with at least one or more citations. The reaming 1169 (9.73%) publications did not have any citations. Among the publications, 12 out of 15 years publications received more than 90 % of citations. The percentage share of cited publications was ranged between 81.68 to 96.89 percent during the period under study. It was evident that the highest percentage share (96.89 %) was recorded for the publications in 2007, followed by 95.99 5 in 2008 and years 2005, 2006, and 2009 with more than 93 percent. It is also observed that from the initial year 2005 to 2015, publications were cited fairly good percentage. It is interesting to note that 2018 and 2019 also received many citations in recent years. It inferred from the results that publications in SB are good quality studies that attract more scientists working in this field.

Table 6 Year-wise distribution of Cited V/S Non-cited publications

Sl.no	Year	Publications	Cited Publications	% of Publications	Non-cited Publications	% of Publications
1	2005	202	188	93.07	14	6.93
2	2006	243	227	93.42	16	6.58
3	2007	257	249	96.89	8	3.11
4	2008	324	311	95.99	13	4.01
5	2009	407	379	93.12	28	6.88
6	2010	511	473	92.56	38	7.44
7	2011	585	541	92.48	44	7.52
8	2012	793	727	91.68	66	8.32
9	2013	838	774	92.36	64	7.64
10	2014	976	894	91.60	82	8.40
11	2015	1140	1051	92.19	89	7.81
12	2016	1365	1226	89.82	139	10.18

13	2017	1270	1156	91.02	114	8.98
14	2018	1567	1394	88.96	173	11.04
15	2019	1534	1253	81.68	281	18.32
Total		**12012**	**10843**	**90.27**	**1169**	**9.73**

Concerning the non-cited publications, the maximum percentage–recorded in 2019were18.32%, and the minimum percentage in 2007was3.11%. It is inferred from the result that there was an increasing trend among the number of cited publications and concurrent decreasing movement among the number of non-cited publications on SB literature during the period under study.

Fig. 3 represents the trend of cited and non-cited publications. In almost all years, the number of cited publications is more than that of non-cited publications. Therefore, the cited publications are more numerous than the non-cited publications over all the years.

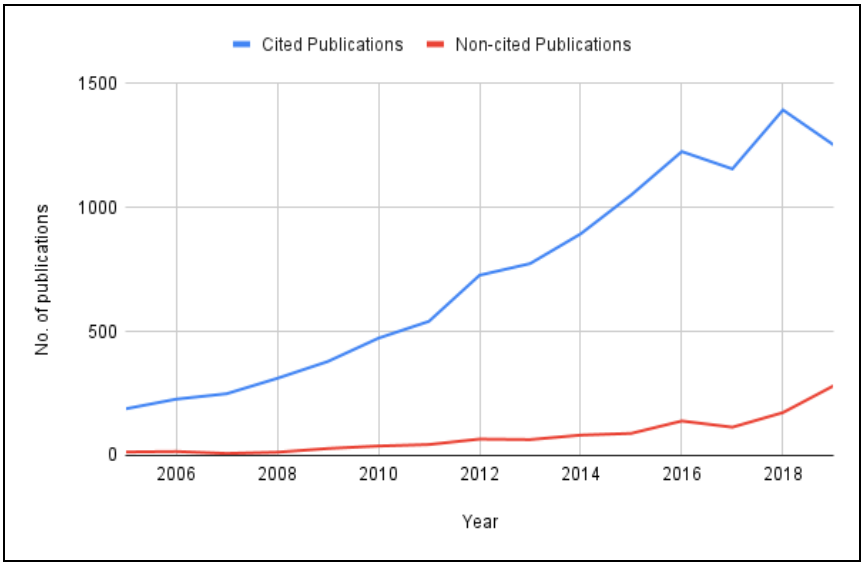

Fig. 3 Comparison of cited and non-cited publications

The "t" test was applied to assess the difference between cited and non-cited publications in Synthetic biology. The value obtained for t (28) = is 5.87605, p = < .00001. The result is significant at p < .05. The "t" –test also revealed a significant difference between cited and non-cited publications. Therefore statistically, it is evident that the cited publications are more than the non-cited publications over all the years.

5.7 Correlation between number of publications and cited publications

Pearson correlation coefficient was used to determine the relation between the number of publications and the number of cited publications. Table 7 shows the results of this test. It is seen that the coefficient value r=0.997. This means that there appears to be a very strong positive correlation between these two variables (r = .997, N = 15, p = 0.000). In other words, the large values publications are associated with many cited publications.

Table 7 Correlation between number of publications and cited publications

		NP	CP
NP	Pearson Correlation	1	.997**
	Sig. (2-tailed)		.000
	N	15	15
CP	Pearson Correlation	.997**	1
	Sig. (2-tailed)	.000	
	N	15	15

**. Correlation is significant at the 0.01 level (2-tailed).

5.8 Highly cited articles in SB

Table 8 shows the fourteen highly cited articles in Synthetic Biology with a TC2020 >700. These fourteen papers have received citations (since their publications till 15.08.2020) varying 700 to 4643 during this period. The cumulative citations received by these top-cited papers were 18187, with an average of 1299 citations per paper. Of these 14 articles, four were published in 2009. Of these fourteen papers, eight (eatured as "Articles," and the remaining six featured as "Reviews." Of these highly cited papers, only four involved in the international collaboration, and the remaining ten only took part in the domestic cooperation. The 90 authors of these highly cited papers originated from nineteen countries (including USA, Canada, Germany, UK, Czech Republic, France, Hungary, India, Israel, Netherlands, and Saudi Arabia). These authors are affiliated with 36 different institutions. These papers have appeared in ten journals, of which the journal of "*Science (IF=* 41.846)" has five highly cited documents followed by the journal of "*Nature (IF=* 42.779)" with two papers and the remaining seven papers appeared in seven journals.

Table 8 Highly cited publications in Synthetic Biology (>500 Citations)

Rank	Most cited publication	Journal (DT)	TC	TC / Year	NA	NI	NC
1	Mali et al., 2013	Science (Article)	4643	580.38	8	3	1
2	Pack et al., 2005	Nature reviews drug discovery (Review)	1855	115.94	4	2	1
3	Costanzo et al.,2010	Science (Article)	1380	125.45	15	10	3
4	Tibbitt and Anseth, 2009	Biotechnology and bioengineering (Article)	1341	111.75	2	1	1
5	Gibson et al., 2010	Science (Article)	1229	111.73	15	1	1
6	Li jwh and Vederas, 2009	Science (Review)	1176	98	2	1	1
7	Kypr et al., 2009	Nucleic acids research (Article)	926	77.17	4	1	1
8	Paddon et al., 2013	Nature (Article)	901	112.63	17	4	2
9	Kohanski et al., 2010	Nature reviews microbiology (Review)	882	80.18	3	1	1
10	Zhang and Seelig, 2011	Nature chemistry (Review)	880	88	2	2	1
11	Wang et al., 2009	Nature (Article)	846	70.5	7	4	1
12	Plotkin and Kudla, 2011	Nature reviews genetics (Review)	717	71.7	2	2	2
13	Kornmann et al., 2009	Science (Article)	711	59.25	7	3	2
14	Bath and Turberfield, 2007	Nature nanotechnology (Review)	700	50	2	1	1
	Total		18187		90	36	19

(DT= Document Type, TC=Total Citations, NA= No. of authors, NI= No. of institutions and NA= No. of countries)

Among these 33 highly cited papers, six received more than 1000 citations. The top most highly cited journal article/ paper is entitled- "*RNA-Guided human*

genome engineering Via Cas9", was written by Mali et al. in *Science* in 2013 and received4643 citations during this period. The second most cited paper is entitled -"*Design and development of polymers for gene delivery*," was by Packet al. in *Nature reviews drug discovery* in 2005, and had received 1855 citations. The third highly cited documententitled - "*The genetic landscape of a cell*," by Costanzo et al. in *Science* in 2010,and had 1380 citations. Tibbitt and Anseth (2009) published the fourth highly cited publication entitled - "*Hydrogels as extracellular matrix mimics for 3d cell culture*", in *Biotechnology and bioengineering* had 1341 citations. The fifth highly cited document entitled - "*Creation of a bacterial cell controlled by a chemically synthesised genome*," was by Gibson et al. in Science in 2010, and had received 1229 citations. The sixth document entitled - "*Drug discovery and natural products: end of an era or an endless frontier?*" was by Li jwh and Vederas in *Science* in 2009, and had received around 1176 citations during this period. The journal "Science" published four top articles out of the top six publications.

6. Conclusion

The present study examined the distribution of citations in Synthetic Biology literature published during 2005-2019. The results revealed that the publications on Synthetic Biology attracted a reasonably good number of citations during the period under evaluation. A total of 12012 publications received 329631 citations with an average number of citations per publication value of 27.44. A maximum (32822) citations were recorded for the 838 publications in 2013. At the same time, the lowest citations (7228) were recorded in the last year of the study period, i.e., 2019. the relative growth rate of citations decreased steadily from 0.70 in 2006 to 0.02 in 2019. Simultaneously, the value of doubling time of citations increased from 1.00 in 2006 to 31.26 in 2019. The highest rate CPP (64.84) was observed in 2005, while the lowest rate was followed in 2019 (CPP 4.71). The average of citations per author was observed as 5.80 during the period under study. Around 90.27 percent of total publications was received at least one or more citations. The remaining 1169 (9.73%) publications did not have any citations. 40.43% of cited publications received between 1 to 10 times. The number of publications that received more than 100 citations was 617 (5.14%). Out of 15 years of publication, just within 12 years more than 90 % publications were co-cited during the concerned years. The percentage co-cited publications was ranged between 81.68 to 96.89 percent during the period under study. The "t" –test between cited and non-cited publications revealed a significant difference. The results of this study will be helpful to a variety of stakeholders in Synthetic biology research.

References

Aksnes, D. W., Langfeldt, L., &Wouters, P. (2019). Citations, Citation Indicators, and Research Quality: An Overview of Basic Concepts and Theories. *SAGE Open*. https://doi.org/10.1177/2158244019829575

Aksnes, Dag W. and Gunnar Sivertsen. (2004). The effect of highly cited papers on national citation indicators. Scientometrics, 59 (2): 213-224.

Bath, J., &Turberfield, A. J. (2007). DNA nanomachines. *Nature nanotechnology*, *2*(5), 275-284. https://doi.org/10.1038/nnano.2007.104

Benner, S. A., &Sismour, A. M. (2005). Synthetic biology. *Nature reviews. Genetics*, *6*(7), 533–543. https://doi.org/10.1038/nrg1637

Costanzo, M., Baryshnikova, A., Bellay, J., Kim, Y., Spear, E. D., Sevier, C. S., ... & Boone, C. (2010). The genetic landscape of a cell. *science*, *327*(5964), 425-431. DOI: 10.1126/science.1180823

De Bellis, Nicola. (2009). Bibliometrics and citation analysis. Lanham, MD: Scarecrow Press.

Gibson, D. G., Young, L., Chuang, R. Y., Venter, J. C., Hutchison, C. A., & Smith, H. O. (2009). Enzymatic assembly of DNA molecules up to several hundred kilobases. *Nature methods*, *6*(5), 343-345.

Hobom, B. (1980). Surgery of genes at the doorstep of synthetic biology. *MedizinischeKlinik*, *75*(24), 14-21.

Hu, X., & Rousseau, R. (2015). From a word to a world: The current situation in theinterdisciplinaryfieldofsyntheticbiology.*PeerJ*,*3*:e728.doi:10.7717/peerj.728.

Keshava, R., Mitra, R., Gope, M. L., &Gope, R. (2018). Synthetic Biology: Overview and Applications. *Omics Technologies and Bio-Engineering*, 63-93. https://doi.org/10.1016/B978-0-12-804659-3.00004-X

Khalil, A. S., & Collins, J. J. (2010). Synthetic biology: applications come of age. *Nature Reviews Genetics*, *11*(5), 367-379. https://doi.org/10.1038/nrg2775

Kohanski, M. A., Dwyer, D. J., & Collins, J. J. (2010). How antibiotics kill bacteria: from targets to networks. *Nature Reviews Microbiology*, *8*(6), 423-435. https://doi.org/10.1038/nrmicro2333

Kornmann, B., Currie, E., Collins, S. R., Schuldiner, M., Nunnari, J., Weissman, J. S., & Walter, P. (2009). An ER-mitochondria tethering complex revealed by a synthetic biology screen. *science*, *325*(5939), 477-481. DOI: 10.1126/science.1175088

Kypr, J., Kejnovská, I., Renčiuk, D., &Vorlíčková, M. (2009). Circular dichroism and conformational polymorphism of DNA. *Nucleic acids research*, *37*(6), 1713-1725. https://doi.org/10.1093/nar/gkp026

Li, J. W. H., &Vederas, J. C. (2009). Drug discovery and natural products: end of an era or an endless frontier?. *Science*, *325*(5937), 161-165. DOI: 10.1126/science.1168243

Mali, P., Yang, L., Esvelt, K. M., Aach, J., Guell, M., DiCarlo, J. E., ... & Church, G. M. (2013). RNA-guided human genome engineering via Cas9. *Science*, *339*(6121), 823-826. DOI: 10.1126/science.1232033

National Academies of Science. (2013). Positioning synthetic biology to meet the challenges of the 21st century. Committee on Science, Technology, and Law, Policy and Global Affairs. NAENRC. Washington, DC: National Academies Press.

Oldham,P.,Hall,S.,&Burton,G.(2012).Synthetic biology:Mappingthescientificlandscape.*PLoSONE*,7:e34368.https://doi.org/10.1371/journal.pone.0161522

Pack, D. W., Hoffman, A. S., Pun, S., & Stayton, P. S. (2005). Design and development of polymers for gene delivery. *Nature reviews Drug discovery*, *4*(7), 581-593. https://doi.org/10.1038/nrd1775.

Paddon, C. J., Westfall, P. J., Pitera, D. J., Benjamin, K., Fisher, K., McPhee, D., ... & Newman, J. D. (2013). High-level semi-synthetic production of the potent antimalarial artemisinin. *Nature*, *496*(7446), 528-532. https://doi.org/10.1038/nature12051

Plotkin, J. B., & Kudla, G. (2011). Synonymous but not the same: the causes and consequences of codon bias. *Nature Reviews Genetics*, *12*(1), 32-42. https://doi.org/10.1038/nrg2899

Rahm, Erhard and Thor, Andreas. (2005). Citation analysis of database publications. SIGMOD Record, 34(4): 48-53.

RaimbaultB,CointetJP,JolyPB(2016)MappingtheEmergenceofSyntheticBiology.*Scientometrics*,*112*(3): 1439-1469.https://doi.org/10.1007/s11192-017-2452-5

Shapira,P.,Kwon, S.,&Youtie,J. (2017).Tracking the emergence of syntheticbiology. *Scientometrics*,*112*(3): 1439-1469.https://doi.org/10.1007/s11192-017-2452-5

Smith, L. C. (1981). Citation Analysis. Library Trends, 30(1), 83-106.

Tibbitt, M.W. and Anseth, K.S. (2009), Hydrogels as extracellular matrix mimics for 3D cell culture. Biotechnol. Bioeng., 103: 655-663. https://doi.org/10.1002/bit.22361.

Wang, H. H., Isaacs, F. J., Carr, P. A., Sun, Z. Z., Xu, G., Forest, C. R., & Church, G. M. (2009). Programming cells by multiplex genome engineering and accelerated evolution. *Nature*, *460*(7257), 894-898. https://doi.org/10.1038/nature08187

Zhang, D. Y., & Seelig, G. (2011). Dynamic DNA nanotechnology using strand-displacement reactions. *Nature chemistry*, *3*(2), 103-113. https://doi.org/10.1038/nchem.957