



Current research in biotechnology: Exploring the biotech forefront



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ABSTRACT

Biotechnology is an evolving research field that covers a broad range of topics. Here we aimed to evaluate the latest research literature, to identify prominent research themes, major contributors in terms of institutions, countries/regions, and journals. The Web of Science Core Collection online database was searched to retrieve biotechnology articles published since 2017. In total, 12,351 publications were identified and analyzed. Over 8500 institutions contributed to these biotechnology publications, with the top 5 most productive ones scattered over France, China, the United States of America, Spain, and Brazil. Over 140 countries/regions contributed to the biotechnology research literature, led by the United States of America, China, Germany, Brazil, and India. *Journal of Bioscience and Bioengineering* was the most productive journal in terms of number of publications. Metabolic engineering was among the most prevalent biotechnology study themes, and *Escherichia coli* and *Saccharomyces cerevisiae* were frequently used in biotechnology investigations, including the biosynthesis of useful biomolecules, such as myo-inositol (vitamin B8), monoterpenes, adipic acid, astaxanthin, and ethanol. Nanoparticles and nanotechnology were identified too as emerging biotechnology research themes of great significance. Biotechnology continues to evolve and will remain a major driver of societal innovation and development.

1. Introduction

Biotechnology research covers a broad range of topics. As defined in the scopes of the journals *Current Research in Biotechnology* and *Current Opinion in Biotechnology*, major themes of biotechnology research include genetic and molecular engineering; tissue, cell, and pathway engineering; plant and animal biotechnology; food biotechnology; energy biotechnology; environmental biotechnology; analytical biotechnology; systems biology; nanobiotechnology; chemical biotechnology; medicinal and pharmaceutical biotechnology. The term biotechnology is attributed to be coined by the agricultural economist-cum-engineer Karl Erkey from Hungary, exactly 100 years ago. Karl Erkey defined biotechnology as, translated into English, “all the lines of work by which products are produced from raw materials with the aid of living organisms” (Amarakoon et al., 2017; Bud, 1994). The Organization for Economic Co-operation and Development (OECD), an intergovernmental economic organization with 36 member countries, refined the definition of biotechnology as “application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services; new biotechnology involves the use of cellular and molecular processes to solve problems or make products” (Amarakoon et al., 2017). Starting in the mid-1980s, biotechnology became a very popular word in the title of research publications, appearing in papers concerning business, industry, biomedicine, chemical engineering, agricultural sciences, and even social sciences (Kennedy, 1991). In short, biotechnology signifies a new biological approach to a wide range of industries.

Biotechnology was suggested to have mainly 4 sectors, white, red, green, and blue, which represent industrial, pharmaceutical/medical, food and agriculture, and environment/marine, respectively (Barcelos et al., 2018). Two well-known examples of daily applications of biotechnology are the production of the multifunctional citric acid by fermentation with the aid of *Aspergillus niger*, and, to a lesser extent, *Yarrowia lipolytica* (Karaffa and Kubicek, 2003), as well as the use of *Y. lipolytica* as a model for bio-oil production (Beopoulos et al., 2009); and the production of non-nutritive sweeteners, steviol glucosides and mogrosides, from plants *Stevia rebaudiana* and *Siraitia grosvenorii*, respectively (Pawar et al., 2013). Meanwhile, genetically-modified (GM) foods represent another biotechnology-derived aspect that significantly affects our everyday life. A survey conducted in 2002 reported that the majority of consumers were negative about GM foods, as their moral and ethical concerns about GM food consumption outweighed the benefits of better taste and lower

price (Magnusson and Hursti, 2002). In 2015, however, GM crops were already grown on 180 million hectares of land in 28 countries, equivalent to 10% of total arable land worldwide (Taheri et al., 2017). While GM crops and GM foods will likely continue to flourish with the advancements in biotechnology, consumer surveys repeatedly indicate inferior consumer acceptance reflected in the lower willingness of purchasers to pay for GM foods than for non-GM foods (Colson and Rousu, 2013).

Red (medical and pharmaceutical) biotechnology has witnessed important recent developments and makes strong impact on human health and disease therapies. Biotechnology has been a frontline field driving both uncovering of molecular mechanisms of diseases and identification of new molecular biomarkers and drug targets (e.g., through the use of engineered biological models with knock-out, knock-down, or overexpression of relevant proteins), as well as the identification and subsequent pharmaceutical development of therapeutics (e.g., many antibiotics, other small-molecule natural product-derived drugs, and recombinant proteins such as antibodies and hormones) (Gartland et al., 2013).

Bibliometric analyses of biotechnology literature were so far occasionally published to reflect on the evolution of the field or evaluate the contributions and performances of specific countries. For a detailed list of such studies published until 2001, readers are referred to Table 1 of the work published in 2002 by Dalpé (Dalpé, 2002). In this latest addition of biotechnology literature analysis, we aimed to unveil the latest trends (since 2017) in biotechnology research. By analyzing the research literature, we identified the latest popular research themes, major contributors in terms of institutions, countries/regions, and journals.

2. Materials and methods

2.1. Literature search

In May 2019, a search was conducted through the Web of Science (WoS) Core Collection electronic database (Clarivate Analytics, Philadelphia, USA) to identify the latest biotechnology publications. The following search string was used: TOPIC = (“biotech*”). This search strategy yielded publications that mentioned the words biotech, biotechnology or their derivatives in the title, abstract, or keywords. In order to focus on contemporary biotechnology research trends, only articles published between 2017 and 2019 were included.

2.2. Data extraction and analysis

The bibliographic data of the included biotechnology publications were extracted, which included publication year, authorship, institutions, countries/regions of the institutions, journal title, WoS journal category, publication type, language, publication count, and citation count. The “Analyze” and “Create Citation Report” functions of the WoS platform were used for the initial analyses. The “full records and cited references” were exported and loaded into VOSviewer software (version 1.6.11, www.vosviewer.com) for further bibliometric analyses.

The VOSviewer software analyzes the terms used in titles and abstracts of the included publications, relates them to publication and citation data, and illustrates the results by a term map (van Eck and Waltman, 2009; Yeung et al., 2017; Yeung et al., 2019a). In a term map, the bubble size reflects how frequently a term is mentioned in the included publications (multiple mentioning in one publication counts as one only). The bubble color, on the other hand, reflects how frequently a publication mentioning the term is cited on average (citations per publication, CPP). Lastly, the distance between two bubbles reflects how frequently two terms are mentioned in the same publications. Only words that appear in at least 1% ($n = 124$) of the manuscripts are analyzed and visualized. The frequencies of author keywords and keywords added by WoS are also analyzed by VOSviewer.

3. Results and discussion

3.1. General landscape

The annual numbers of biotechnology publications indexed in WoS for years 2017–2019 (until May) were 5294, 5345, and 1712 respectively, summing up to a total of 12,351. These articles were predominantly published in English ($n = 12,045$; 97.5%). Original articles ($n = 9043$; 73.2%) were more prevalent than review papers ($n = 2308$; 18.7%), proceedings papers ($n = 569$; 4.6%), editorial materials (327; 2.6%), or meeting abstracts ($n = 126$; 1.0%) (Fig. 1). Among the top 25 most productive authors, 18 had a Chinese name, with the top 2 being “Wang Y” and “Zhang Y”. It is a known issue of WoS that some publications are recorded with initialized author names, which may confound the authors' publication counts by merging multiple authors into one, especially for initialized Chinese names (Yeung et al., 2019b). Therefore, no further analysis of authorship was performed.

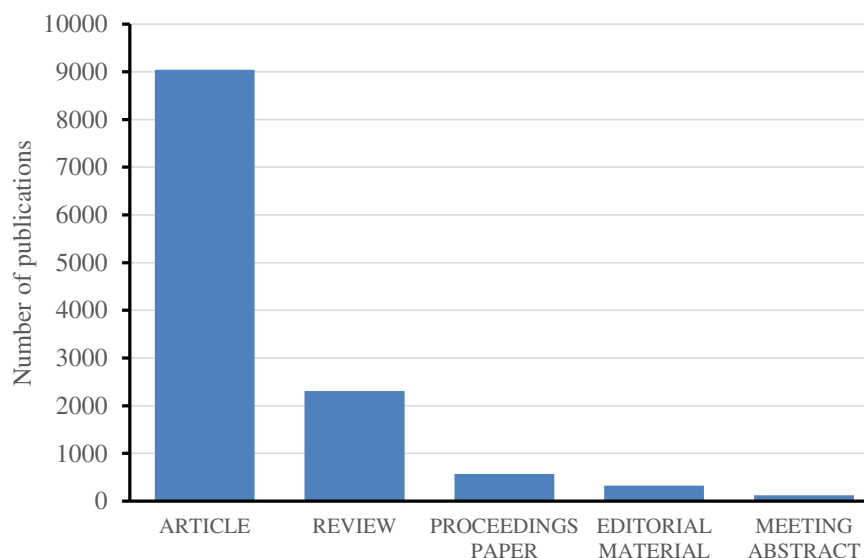


Fig. 1. Publication count of different document types.

Table 1

The top 5 most productive institutions, countries/regions, and journals.

Contributor	Publication count (% of total)	Citation per publication
Institution		
French National Center for Scientific Research (CNRS)	236 (1.9%)	3.6
Chinese Academy of Sciences	216 (1.7%)	3.6
University of California system	214 (1.7%)	4.6
Spanish National Research Council (CSIC)	204 (1.7%)	4.4
University of São Paulo	177 (1.4%)	2.6
Country/region		
The United States of America	2208 (17.9%)	3.9
China	1559 (12.6%)	3.3
Germany	1056 (8.6%)	3.6
Brazil	862 (7.0%)	2.0
India	756 (6.1%)	2.8
Journal		
Journal of Bioscience and Bioengineering	500 (4.0%)	1.8
Biotechnology and Bioengineering	224 (1.8%)	6.5
Applied Microbiology and Biotechnology	208 (1.7%)	2.9
Biotechnology Progress	181 (1.5%)	2.3
Scientific Reports	166 (1.3%)	3.1

3.2. Institutions and countries/regions

Over 8500 institutions contributed to these biotechnology publications. The top 5 most productive institutions were scattered over France, China, the United States of America, Spain, and Brazil (Table 1). These were followed by the Russian Academy of Sciences, Helmholtz Association of German Research Centres, French National Institute for Agricultural Research (INRA), the United States of America Department of Energy, and the Technical University of Denmark. Over 140 countries/regions contributed to biotechnology research, with the top 5 most productive ones being the United States of America, China, Germany, Brazil, and India. Together, these distributions highlight the latest (since 2017) worldwide research interest in biotechnology. These findings are also consistent with the report that countries like China, India, and Brazil are among the emerging science influencers that are currently publishing nearly 20 times more papers than they were in the early-1980s (Adams, 2013). A closer look into the most cited Brazilian publications revealed bioremediation as a common theme. Notable examples included an investigation of the gut microbiota as a potential tool to degrade insecticides (de Almeida et al., 2017), utilization of microorganisms for biosorption of the environmental

various models of consultancy, contract research, and public-private partnerships (Pronk et al., 2015). Hence, we expect an increasing contribution of biotechnology-linked research to be published by management journals in the near future. Along the same line, the highly interdisciplinary nature of biotechnology-linked research is also well reflected in the first four articles accepted for publication in *Current Research in Biotechnology*, which are coming from entirely different research spheres, in particular representing an expert opinion on safety of genome edited crops (Lassoued et al., 2019), research describing the development of whole-cell bacterial electrochemical urea sensor (Cabrera et al., 2019), study on the potential of dietary supplementation with black pepper to improve blood lipid levels, and the development of copper oxide-loaded polyacrylonitrile nanofiber membranes for antimicrobial breath mask applications (Kim et al., 2019).

3.4. Term map

The term map revealed that many of the publications investigated the production ($n = 3345$; CPP = 3.0) or synthesis ($n = 917$; CPP = 3.6) of valuable biomolecules, e.g., via bacteria ($n = 1328$; CPP = 3.0) (Fig. 2). Biotechnology was applied to study/modify genes ($n = 1831$; CPP = 2.6) and enzymes ($n = 1875$; CPP = 3.2), and to create optimized or synthetic metabolic networks and pathways for the production of biomolecules. Some of the more cited terms included biosensor ($n = 170$; CPP = 5.9), microbe ($n = 252$; CPP = 5.1); biofuel ($n = 236$; CPP = 4.8), polymer ($n = 335$; CPP = 4.8), metabolic engineering ($n = 238$; CPP = 4.8), and nanotechnology ($n = 194$; CPP = 4.4). The 25 most frequently mentioned terms are mostly words with more general meaning (e.g., production, application, analysis) and are listed in Table 3.

3.5. Keywords

Metabolic engineering was the second most prevalent author keyword, ranking in second place immediately after biotechnology, and the related term synthetic biology came in third place. Both author keywords and keywords added by WoS indicated that *Escherichia coli* and *Saccharomyces cerevisiae* were the most frequently used organisms in biotechnology investigations, including biosynthesis of valuable biomolecules (Tables 4 and 5). *E. coli* is a highly popular model organism used in a range of biotechnology applications, such as in metabolic engineering, where it can be modified to produce valuable compounds via synthetic metabolic networks (Erb et al.,

Table 3
The top 25 recurring terms from titles and abstracts.

Term	Publication count (% of total)	Citation per publication
Study	4509 (36.5%)	2.5
Biotechnology	3680 (29.8%)	3.2
Production	3345 (27.1%)	3.0
Application	2977 (24.1%)	3.8
Analysis	2907 (23.5%)	2.3
Activity	2647 (21.4%)	2.8
Process	2635 (21.3%)	2.8
Development	2577 (20.9%)	3.3
System	2462 (19.9%)	3.5
Use	2194 (17.8%)	3.0
Effect	2124 (17.2%)	2.5
Approach	2120 (17.2%)	3.4
Protein	2057 (16.7%)	3.0
Cell	2012 (16.3%)	3.1
Condition	2011 (16.3%)	2.6
Enzyme	1875 (15.2%)	3.2
Gene	1831 (14.8%)	2.6
Research	1758 (14.2%)	3.1
Review	1678 (13.6%)	5.4
Product	1656 (13.4%)	3.1
Property	1625 (13.2%)	3.5
Strain	1624 (13.1%)	2.6
Technology	1617 (13.1%)	3.4
Strategy	1592 (12.9%)	3.5
Concentration	1525 (12.3%)	2.4

Table 4
The top 25 recurring author keywords.

Keyword	Total publication count (% of total)	Citation per publication	2017 count	2018 count	2019 count (until May)
Biotechnology	810 (6.6%)	2.3	306	351	134
Metabolic engineering	184 (1.5%)	5.2	68	90	22
Synthetic biology	171 (1.4%)	3.9	50	87	28
Fermentation	131 (1.1%)	2.6	57	52	19
Microalgae	112 (0.9%)	2.9	23	65	23
<i>Escherichia coli</i>	98 (0.8%)	2.8	39	43	14
Cyanobacteria	93 (0.8%)	3.1	34	45	13
Bioremediation	91 (0.7%)	3.8	30	42	13
<i>Saccharomyces cerevisiae</i>	91 (0.7%)	3.0	44	38	7
Biocatalysis	90 (0.7%)	4.8	39	35	14
Nanoparticles	81 (0.7%)	3.6	27	32	17
Immobilization	80 (0.6%)	4.8	30	36	10
Innovation	80 (0.6%)	1.5	30	41	9
Gene expression	76 (0.6%)	2.4	33	35	6
Yeast	76 (0.6%)	2.7	31	26	16
Genome editing	75 (0.6%)	3.1	21	36	15
Bacteria	72 (0.6%)	2.7	18	37	14
Biomass	71 (0.6%)	2.5	31	32	8
Enzymes	70 (0.6%)	2.9	32	26	9
Nanotechnology	70 (0.6%)	3.1	32	26	11
Genetic engineering	65 (0.5%)	2.0	19	34	12
Biodegradation	60 (0.5%)	3.8	13	32	10
Lipase	59 (0.5%)	2.5	6	22	10
Protein engineering	59 (0.5%)	2.4	20	24	14
Industrial biotechnology	56 (0.5%)	2.6	16	31	7

2017), such as myo-inositol (inositol) (You et al., 2017) and monoterpenes (Korman et al., 2017); and in genetic engineering, where the recently developed CRISPR and its associated genome-editing techniques yielded many follow-up studies that apply to diverse species (Burstein et al., 2017; Pawluk et al., 2018; Komor et al., 2017). Similarly, engineered *S. cerevisiae* is, for example, deployed to produce adipic acid, a useful monomer in nylon synthesis (Kruyer and Peralta-Yahya, 2017); astaxanthin, a keto-carotenoid which is a food colorant and potent antioxidant (Zhou et al., 2019); and also biofuels, such as ethanol, converted from xylose in agricultural residues and energy crops (Kwak and Jin, 2017; Jansen et al., 2017). Similarly, biotechnology applications can also be used for scaled-

Table 5
The top 25 recurring keywords added by Web of Science (Keywords Plus).

Keyword	Publication count (% of total)	Citation per publication
<i>Escherichia coli</i>	735 (6.0%)	3.9
Expression	716 (5.8%)	2.3
Biotechnology	597 (4.8%)	1.8
Identification	517 (4.2%)	2.1
Growth	497 (4.0%)	2.2
Purification	490 (4.0%)	1.9
Protein	360 (2.9%)	2.2
<i>Saccharomyces cerevisiae</i>	340 (2.8%)	4.1
<i>In vitro</i>	326 (2.6%)	3.6
Biosynthesis	312 (2.5%)	2.9
Gene-expression	312 (2.5%)	3.6
Gene	300 (2.4%)	2.6
Bacteria	267 (2.2%)	2.7
Optimization	266 (2.2%)	2.0
Fermentation	265 (2.1%)	2.5
Diversity	256 (2.1%)	2.1
Proteins	255 (2.1%)	2.3
System	234 (1.9%)	2.9
Performance	225 (1.8%)	1.7
Cells	224 (1.8%)	2.6
Nanoparticles	224 (1.8%)	3.3
Enzymes	216 (1.7%)	2.8
Evolution	214 (1.7%)	3.1
Degradation	212 (1.7%)	2.5
Acid	202 (1.6%)	2.9

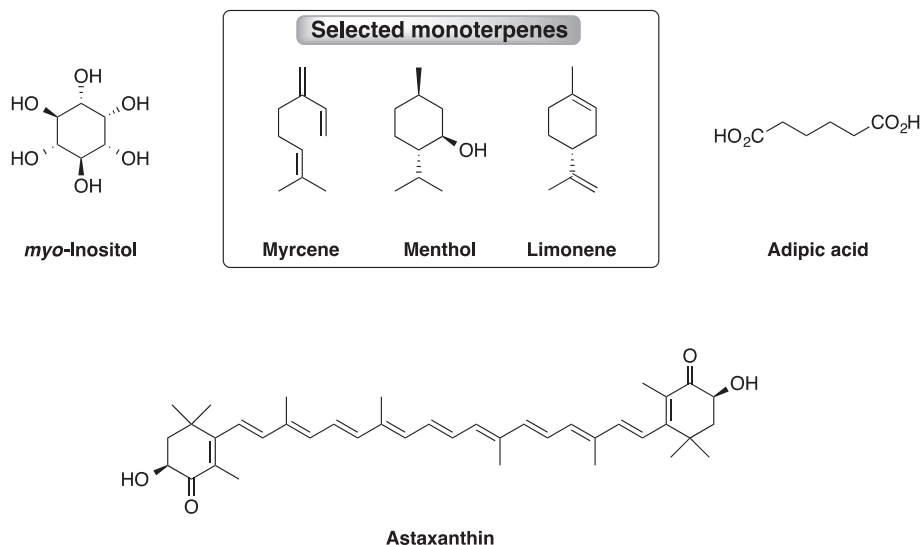


Fig. 3. Structures of selected natural products with biotechnological relevance.

up production of natural products that become successful drugs (Atanasov et al., 2015) or have other biomedical applications (Brahmi et al., 2018; Cătană et al., 2018; Eid et al., 2017; Ververidis et al., 2007). Biocatalysis was another popular topic, which relates to optimization of existing enzymes, including their immobilization for improving their stability and multiple usages, to fit into predefined parameters for producing pharmaceuticals and commodity chemicals (Sheldon and Woodley, 2017). Biocatalysis is also a central theme in environmental and medical bioremediation research (Karigar and Rao, 2011; Mathieu et al., 2009). The chemical structures of selected chemicals with biotechnological relevance are presented in Fig. 3.

Both author keywords and keywords added by WoS indicated nanoparticles and nanotechnology to be trending research themes in the recent (since 2017) biotechnology literature. For instance, some relevant recent works from this area focused on the synthesis of nanofibers that could be applied in tissue engineering, drug delivery systems, and wound dressings (Haider et al., 2018). Important application-area of nanotechnology is also the use of engineered nanoparticle-mediated delivery of genes and biotherapeutic agents (Singh et al., 2017). Metal nanoparticles were also studied as additives to improve the combustion performance and stability of diesel engines (Saxena et al., 2017).

4. Conclusion

We conducted a bibliometric analysis of the biotechnology research literature since 2017. Over 12,000 publications were identified and analyzed. Over 8500 institutions contributed to biotechnology publications during this period. The top 5 most productive institutions were scattered over France, China, the United States of America, Spain, and Brazil. Over 140 countries/regions contributed to biotechnology research, with the top 5 most productive ones being the United States of America, China, Germany, Brazil, and India. *Journal of Bioscience and Bioengineering* was the most productive journal in terms of numbers of publications, and *E. coli* and *S. cerevisiae* were frequently involved in the biotechnology investigations. The traditionally important theme of metabolic engineering was also among the most important biotechnology research topics of the analyzed time period (2017–2019), and nanoparticles/nanotechnology are contemporary trending biotechnology research themes. It is expected that genetic and metabolic engineering will continue to thrive to further improve the efficacy of biosynthesis of useful chemicals and bioremediation of environmental pollutants. When the 25 most frequent keywords for 2017, 2018, and 2019 were examined separately, we found that purification, genomics, fungi, laccase, and biofilm were on the list in 2017, but

were replaced by protein engineering, thermostability, biofuels, innovative biotechnologies, and drug delivery in 2019. Biotechnology research as a whole will continue to make strong impact on the environment, medicine, agriculture, food, and other diverse industrial areas. With more advanced technology on protein engineering, biofuels, and drug delivery, it is expected that biotechnology will particularly create a greener environment, and benefit human health.

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Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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