Berita Biologi
Jurnal ilmu-ilmu hayati

Berita Biologi 25(2): 379–401 (2026)
https://ejournal.brin.go.id/berita_biologi ISSN 2077 7019
DOI: 10.55981/berita_biologi.2026.5553

P-ISSN 0126-1754
E-ISSN 2337-8751

ARTICLE

MAPPING THE DEVELOPMENT OF BIOTECHNOLOGY RESEARCH IN INDONESIA BASED ON BIBLIOMETRIC ANALYSIS

[*Pemetaan Perkembangan Penelitian Bioteknologi di Indonesia Berdasarkan Analisis Bibliometrik*]

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ABSTRACT

This study employs a systematic review and meta-analysis approach, following the PRISMA framework, to analyze biotechnology research in Indonesia. The data were collected from the Scopus database. The literature research was conducted for publication over a 30-year period (1994-2023). The initial search identified 1,344 articles. Subsequently, a screening process was conducted using inclusion and exclusion criteria, including publication year, author relevance, research type, English language, and accessibility. After the screening and eligibility assessment stages, 49 articles were selected for final analysis. Based on research results, Bogor Agricultural University (IPB) is the university that conducts the most research in biotechnology, followed by Gadjah Mada University (UGM), the University of Indonesia (UI), and Airlangga University (UNAIR). Furthermore, over the past 10 years, the number of biotechnology research projects in Indonesia has increased, with health and agriculture as the most dominant topics. In addition to health and agriculture, biotechnology research in Indonesia also addresses sectors such as plantations, industry, maritime affairs, food, and the environment, as evidenced by studies focusing on applications unique to these fields. This indicates the increasingly broad application of biotechnology across these areas. Overall, these findings indicate that biotechnology research in Indonesia continues to grow but still requires strengthening in collaboration, funding, and infrastructure to support more optimal innovation in the future.

Keywords: Biotechnology, Indonesia, bibliometric, metanalysis

Submitted: 1 July 2024; **Revision:** 11 May 2026; **Accepted:** 12 May 2026
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ABSTRAK

Studi ini menggunakan pendekatan tinjauan sistematis dan meta-analisis, mengikuti kerangka kerja PRISMA, untuk menganalisis penelitian bioteknologi di Indonesia. Data tersebut dikumpulkan dari database Scopus. Penelitian terhadap literatur dilakukan untuk publikasi selama periode 30 tahun (1994-2023). Pencarian awal mengidentifikasi 1.344 artikel. Selanjutnya, proses penyaringan dilakukan dengan menggunakan kriteria inklusi dan eksklusi, termasuk tahun publikasi, relevansi penulis, jenis penelitian, bahasa Inggris, dan aksesibilitas. Setelah tahap penyaringan dan penilaian kelayakan, 49 artikel dipilih untuk analisis akhir. Berdasarkan hasil penelitian, Institut Pertanian Bogor (IPB) merupakan perguruan tinggi yang paling banyak melakukan penelitian di bidang bioteknologi, disusul oleh Universitas Gadjah Mada (UGM), Universitas Indonesia (UI), dan Universitas Airlangga (UNAIR). Selain itu, selama 10 tahun terakhir, jumlah proyek penelitian bioteknologi di Indonesia telah meningkat, dengan kesehatan dan pertanian sebagai topik yang paling dominan. Selain kesehatan dan pertanian, penelitian bioteknologi di Indonesia juga membahas sektor-sektor seperti perkebunan, industri, urusan maritim, pangan, dan lingkungan, sebagaimana dibuktikan oleh studi yang berfokus pada aplikasi unik untuk bidang ini. Ini menunjukkan penerapan bioteknologi yang semakin luas di berbagai bidang ini. Secara keseluruhan, temuan ini menunjukkan bahwa penelitian bioteknologi di Indonesia terus berkembang namun masih membutuhkan penguatan kolaborasi, pendanaan, dan infrastruktur untuk mendukung inovasi yang lebih optimal di masa depan.

***Kata kunci**: Bioteknologi, Indonesia, bibliometrik, metanalysis*

INTRODUCTION

Global population growth, rising food demand, climate and environmental change, and healthcare are current global challenges that are driving the development of knowledge and technology to address these issues (van Dijk *et al*., 2021). One of the fields of science experiencing rapid growth today is biotechnology. Biotechnology is a branch of biology that utilises biological systems and living organisms—whether in the form of cells, tissues, or molecular components—to produce goods and service. Globally, biotechnology has advanced rapidly since the late 20th century (Wai *et al*., 2019). Conventional biotechnology, well known and widely used by the public, includes processes such as fermentation, cuttings, and grafting. Modern or molecular biotechnology is widely utilised to develop new varieties and advancements (Chibueze *et al*., 2016). Techniques such as tissue culture, genetic engineering, DNA analysis, cloning, bioinformatics, and nanobiotechnology are increasingly strengthening and expanding the application of biotechnology—particularly molecular biotechnology—across various sectors (Bayda *et al*., 2019). In agriculture, biotechnology is used to produce superior crops that are higher in nutrition, more resilient, and more productive. In healthcare, biotechnology can produce vaccines, serums, and cell-based therapies. In the environmental and marine sectors, it can be utilised for waste treatment, conservation, and the exploration of potential microorganisms (Trincone, 2011).

Figure 1. Total Indonesian resident (*Jumlah penduduk Indonesia*) Source (*Sumber*): (BPS, 2023).

In November 2022, the world population reached 8 billion, while Indonesia ranked fourth in terms of population size, with 275,773,800 people (BPS, 2023). This large population will pose significant challenges regarding food supply, health, energy, clean water, and environmental sustainability. These conditions make biotechnology a strategic field for supporting food security, public health, environmental conservation, and sustainable development (Fedoroff, 2015; Schneider *et al*., 2011; van Dijk *et al*., 2021).

Indonesia, a country with vast land and seas, plays a crucial role in the development of biotechnology due to its diverse wealth of germplasm, including plants, animals, and microorganisms (Siregar & Arifin, 2010). Despite its significant potential, biotechnology development in Indonesia still faces various challenges. Research capacity, availability of laboratory infrastructure, research funding, down streaming of research results, regulations, intellectual property protection, and public acceptance of biotechnology products remain key issues (Chasanah, 2008; Siregar and Arifin, 2010; Aranda and Fahrudin, 2024). Compared with developed countries, biotechnology development in Indonesia has been slower, particularly in the development of research-based commercial products . Indonesia remains a market for various biotechnology products from abroad across health, food, agriculture, and industry. This situation indicates a gap between the vast potential of biological resources and the national capacity to independently develop, produce, and utilise biotechnology products.

The period from 1994 to 2023 is crucial for assessing the direction of biotechnology in Indonesia. These years saw major changes in molecular biology, DNA technology, tissue culture, genetic engineering, and biotechnology in medicine, agriculture, the marine environment, and the environment. The era also reflects shifting research policies, growth in scientific publications, development of research institutions, increased academic partnerships, and changing demand for biotechnology products. Reviewing these three decades clarifies dominant research areas, publication trends, institutional roles, research themes, and future opportunities for biotechnology in Indonesia.

Based on this description, this article aims to examine the development of biotechnology in Indonesia from 1994 to 2023 through a literature review. This study is expected to provide an overview of the dynamics of biotechnology research in Indonesia, the most developed application areas, the research gaps that remain to be addressed, and the strategic direction of national biotechnology development. By understanding these developments, Indonesia can formulate strategies to strengthen biotechnology research and innovation that better align with the richness of its biological resources, societal needs, and the challenges of sustainable development.

Literature Review Development Biotechnology
Biotechnology Classic

The term biotechnology was introduced in 1919 by a Hungarian engineer named KarK Erkey (Virma, 2011). The term introduced refers to the definition that biotechnology is the application of engineering principles and biological sciences to create new products from raw materials derived from biology, for example vaccines or food. Even so, in essence the practice of biotechnology has been carried out by long before. That in prehistoric times (<600 - ± 400 BC) people have used this concept to store game meat during the hunting season as preparation for future bad conditions and use yeast for wine and bread making. The concept of smoking/drying meat to make it last longer and using yeast for fermentation are ancient biotechnology practices that are still used today.

The development of biotechnology has accelerated since the discovery of genetics by Gregor Mendel in 1956 which was able to cross various color variants of peas. This discovery is the gateway to the advancement of biotechnology. Mendel's discovery broke the mystery that traits and genetics could be transferred from individual to individual of the same kind by producing offspring that were different from the parents (intermediates). Mendel's work only began to be recognized by experts in 1900. This important discovery was sunk because at that time the heyday of Darwin's theory with his theory of evolution. Apart from Mendel, other discoveries related to biotechnology were the discoveries of Robert Brown, namely the discovery of the nucleus in cells and Federich Misher discovered nuclein, a type of nucleic acid from white blood cells until the late 1800s, namely in 1893, Robert Kock succeeded in creating the microbial culture technique (Dahm, 2005).

The development of biotechnology continued to grow until the end of the second world war, namely in 1953. Several important discoveries that became the basis for the development of biotechnology were the discovery of the term's gene, genotype, phenotype by Wilhelm Johannsen (1857-1927). Then in 1926 TH Morgan conducted research and found that there was a role for chromosomes in inheritance through research on Drosophila which was later given the name, 'The theory of the Gene'. In its development in 1928 a phenomenal discovery, namely the accidental discovery by Alexander Fleming discovered an antibiotic with the name penicillin and Griffith in the same year discovered the process of genetic transformation and transfer (Priest *et al*., 2018).

Modern or molecular biotechnology

Modern biotechnology began with the discovery of the structure of DNA in 1953 by WD Jadson FCH Krick which was later named the double helix model of DNA (Klug, 2004). This model can explain various phenomena related to DNA replication, and its role in inheritance. Later, Jacob and Monad had given the concept of the Operon in 1961, while Kohler and Milestein, in 1975, came up with the concept of cytoplasmic hybridization and produced the first monoclonal antibodies, which have revolutionized diagnostics. In the 1600s, microbes began to be used to mine uranium in Canada. This is a form of biotechnology that utilizes microbial metabolism to produce uranium. In 1972 a researcher named Paul Berg managed to make recombinant DNA with ecoRI and 1973, Boher Cohen and Chang engineered *E. coli* bacteria with a recombinant plasmid (Cohen, 2013).

Modern biotechnology uses molecular concepts in its applications. The development of modern or molecular biotechnology is characterized using genes and their properties to produce products that are beneficial to living things. The use of these genetic materials marked the birth of molecular biotechnology (Antonius, 1998). The development of molecular biotechnology can be seen in Table 1.

Table 1. Development biotechnology modern (*Pengembangan bioteknologi modern*).

Year (*Tahun*)	**Expert** (*Ahli*)	**Invention** (*Penemuan*)
1970		Enzyme somatic phase restriction isolated for the first time (*Pembatasan fase somatik enzim terisolasi untuk pertama kalinya*)
1972	Khorana and friends	Succeed synthesize in a manner chemical all tRNA genes (*Berhasil mensintesis dengan cara kimia semua gen tRNA*)
1973	Boyer and Cohen	Expose recombinant DNA technology (*Mengekspos teknologi DNA rekombinan*)
1975	Kohler and Milstein	Describe production somatics monoclonal (*Menjelaskan produksi somatik monoklonal*)
1976		Development of somatic techniques for determining DNA sequences (*Pengembangan teknik somatik untuk menentukan urutan DNA*)
1978	Genentech	Produce human insulin in *E. coli* (*Menghasilkan insulin manusia dalam E. coli*)
1980		Microorganisms resulting from genetic manipulation can be patented (*Mikroorganisme yang dihasilkan dari manipulasi genetik dapat dipatenkan*)
1981		For the first time, automated DNA synthesizers were sold commercially (*Untuk pertama kalinya, synthesizer DNA otomatis dijual secara komersial*)
1982		For First time vaccine animal results recombinant DNA technology Approved use in Europe (*Untuk pertama kalinya*

Year (*Tahun*)	Expert (*Ahli*)	Invention (*Penemuan*)
		vaksin hasil hewan teknologi DNA rekombinan Penggunaan yang disetujui di Eropa)
1983		Genetically engineered Ti plasmids are used for plant transformation (*Plasmid Ti yang direkayasa secara genetik digunakan untuk transformasi tanaman*)
1988		Polymerase Chain Reaction method published (*Metode Reaksi Berantai Polimerase diterbitkan*)
1990		Test somatic cell gene therapy in humans Approved (*Uji terapi gen sel somatik pada manusia Disetujui*)
1995		Sequence complete gene pool of the bacterium Hemophilus influenzae, organism First aside from the virus, it worked be read (*Urutan kumpulan gen lengkap bakteri Hemophilus influenzae, organisme Pertama selain virus, itu bekerja dibaca*)
1996		Read the complete sequence of yeast (*Saccharomyces cerevisiae*), which is the longest genome, 12 million base pairs of DNA (*Baca urutan lengkap ragi (Saccharomyces cerevisiae), yang merupakan genom terpanjang, 12 juta pasangan basa DNA*)
1997	Researcher Scotland	Successfully cloned Dolly the sheep with DNA from adult sheep cells (*Berhasil mengkloning domba Dolly dengan DNA dari sel domba dewasa*)
2000		Transgenic rice "Golden Rice", engineered to produce vitamin A, hope for the third world to reduce myopia and blindness (*Beras transgenik "Beras Emas", direkayasa untuk menghasilkan vitamin A, berharap dunia ketiga mengurangi miopia dan kebutaan*)
2005	Researcher from Harvard University	Succeeded in turning skin cells into embryonic stem cells (embryonic stem cells), through the fusion of skin cells with these stem cells (*Berhasil mengubah sel kulit menjadi sel punca embrionik (sel punca embrionik), melalui fusi sel kulit dengan sel punca ini*)
2007	Taiwanese researcher	Developing Eucalyptus trees with genetic engineering that can absorb three times more CO_2 than conventional varieties. This tree also produces more cellulose and less lignin (*mengembangkan pohon Eucalyptus dengan rekayasa genetika yang dapat menyerap* CO_2 *tiga kali lebih banyak daripada varietas konvensional. Pohon ini juga menghasilkan lebih banyak selulosa dan lebih sedikit lignin*)
2010	J. Craig Venter Michael Riehle	Produced the world's first synthetic bacterial cell, which was named Synthia (JCV1-syn1.0). This cell is controlled by a synthetic genome capable of self-replication. Has developed mosquitoes through genetic engineering, which cannot be infected by plasmodium malaria (*Menghasilkan sel bakteri sintetis pertama di dunia, yang diberi nama Synthia (JCV1-syn1.0). Sel ini dikendalikan oleh genom sintetis yang mampu mereplikasi diri. Telah mengembangkan nyamuk melalui rekayasa genetika, yang tidak dapat terinfeksi oleh malaria plasmodium*)
2012	Jennifer Doudna	Developed the CRISPR-Cas9 technique to edit genomes with high precision, efficiency and flexibility (*Mengembangkan teknik CRISPR-Cas9 untuk mengedit genom dengan presisi, efisiensi, dan fleksibilitas tinggi*)
2015	consortium	Genome map most complete man has published (*Peta genom pria terlengkap yang pernah diterbitkan*)

Biotechnology Nano

Nanobiotechnology developed after nanoparticles were discovered and successfully made. The science of nano biotechnology is a combination of biotechnology and nanotechnology. Nanotechnology is a field of applied science based on the discovery of nano-sized materials in various fields such as nanoparticles, nanotubes, nanofibers, nanomembranes and others (Shahcheraghi *et al*., 2022). The nano-approach in biotechnology was developed to overcome the limitations of biotechnology in applying it at the cellular level or smaller than that, such as genes and DNA. Various researches have been conducted on biotechnology using nanotechnology such as in agriculture (Ndlovu *et al*., 2020), mining (Zahed *et al*., 2021)), health (Rottenberg *et al*., 2021; Goracci *et al*., 2020; Roopngam, 2019), bioremediation {Formatting Citation}, and food (Tang, 2021; Razavi *et al*., 2020). Nano biotechnology is a current and future trend of biotechnology research, As an example of the application of nanobiotechnology can be seen in Figure 2, namely on the left, graphene-based material is combined with pectinase enzymes which can form nano-biocatalysts that can increase the stability and efficiency of biological reactions. On the right, graphene with nano membranes is used to purify clean water, while the bottom shows that nanobiotechnology can also be used for nanocarriers in medicine and therapy.

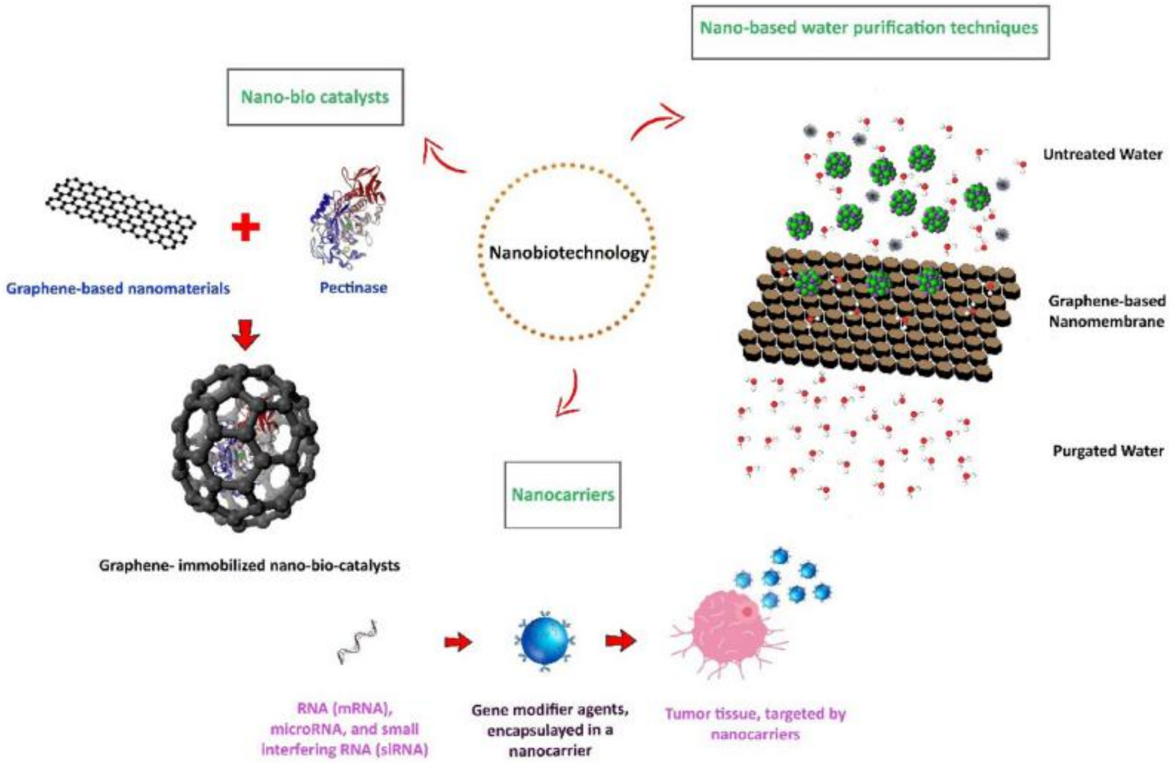

Figure 2. Application of nano biotechnology in several field (*Penerapan bioteknologi nano di beberapa bidang*) (Shahcheraghi *et al*., 2022).

This article discusses the development of biotechnology research in Indonesia based on scientific publications from 1994 to 2023. The analysis includes various research conducted by Indonesian universities, as well as the results of collaborations with foreign universities. This study not only focuses on certain branches of biotechnology, such as modern biotechnology, but also includes all research related to or intersecting with the field of biotechnology in general.

RESEACH METHODS

This research is a systematic literature review conducted in accordance with the PRISMA 2020 framework. Prisma was chosen because it provides a more transparent and scientific reporting framework that explains the processes of identification, selection, assessment, and eligibility for determining which articles to analyse. Data were collected from various Scopus-indexed journals published by Indonesians from 1994 to 2023. The keywords used include general and specific terms related to Indonesian biotechnology, such as Indonesian biotechnology, agricultural biotechnology in Indonesia, health biotechnology in Indonesia, marine biotechnology in Indonesia, food biotechnology in Indonesia, environmental biotechnology in Indonesia, industrial biotechnology in Indonesia, plantation biotechnology in Indonesia, and livestock biotechnology in Indonesia. The articles found were then selected based on inclusion and exclusion criteria. Of the initial 1,344 articles, 49 met the final criteria for analysis. The final articles were classified by field of study, author's institution, publication period, and publisher. This process resulted in a systematic overview of the development, distribution, and direction of biotechnology research in Indonesia over the past three decades.

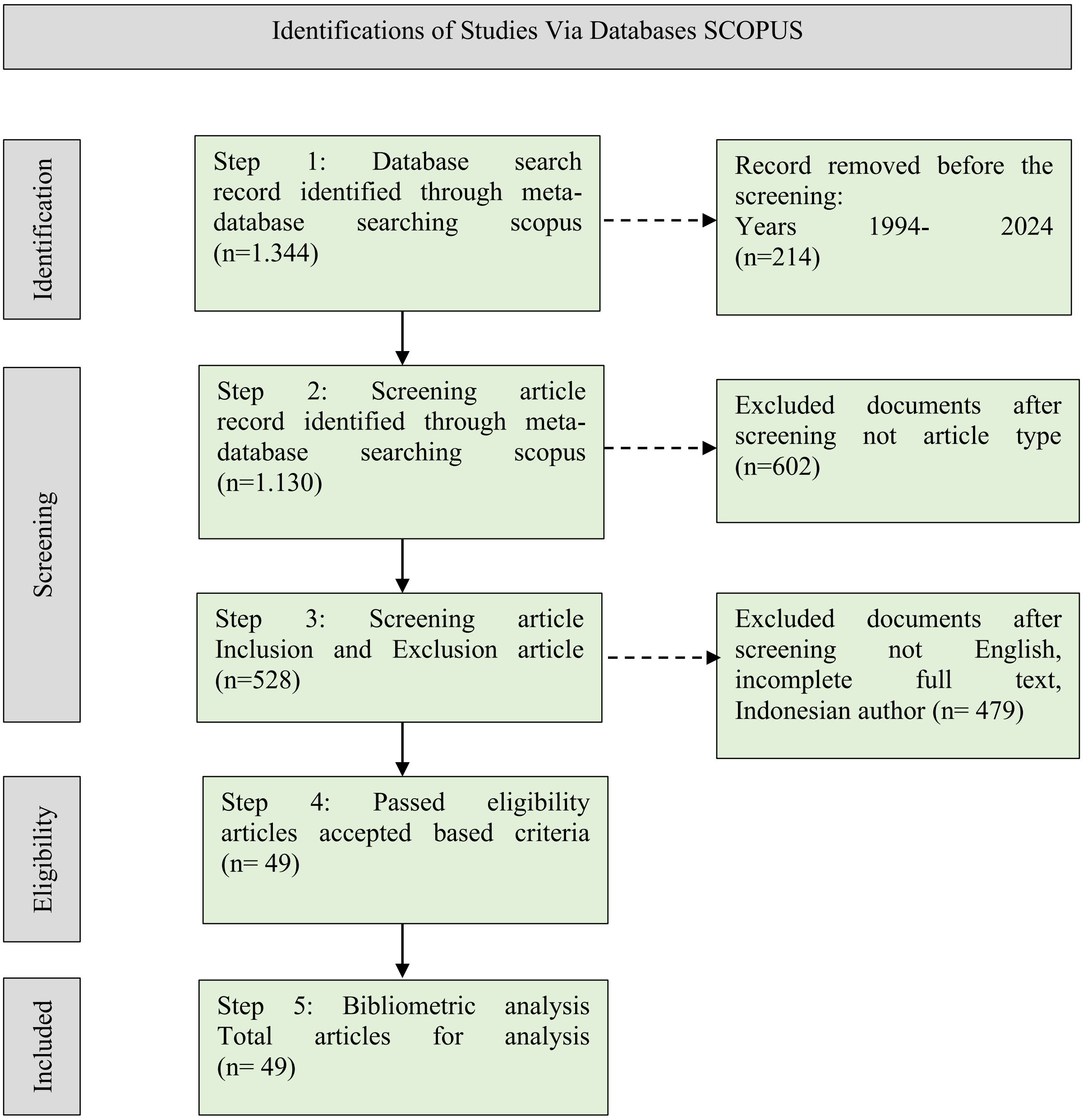

Figure 3. Prisma Diagram of Research (*Diagram Penelitian Prisma*).

RESULTS AND DISCUSSION

From the search results that have been carried out, 1344 articles were obtained, then the researcher identified these articles, which included several things such as whether the researcher was from Indonesia, year of publication, type of article, articles that could be accessed, and suitability with the field of study, so that 49 articles were obtained. with the characteristics that the researcher has made. Based on the analysis, not all universities conduct biotechnology research, and some of it has occurred in the last 10 years. Furthermore, much of the research conducted is published by Spinner, Sage, and Emerald.

Not all universities that offer science and applied science programs conduct and publish research in biotechnology in journals published by Emerald, Sage, and Springer. Some of the universities recorded from the results of this study are as follows:

Table 2. Universities with Research and Publications in the field of biotechnology (*Perguruan Tinggi dengan Penelitian dan Publikasi di bidang bioteknologi*).

No	University (*Universitas*)	Amount (*Jumlah*)	Percentage (*Persentase*)
1.	Bogor Agricultural Institute	13	26.53%
2.	Gajah Mada University	12	24.5%
3.	University of Indonesia, University Airlangga	5	20.4%
4.	Brin/LIPI	3	6.12%
5.	University Padjadjaran, University Jember	2	7.6%
6.	UB, USU, Atmaja, UNP, UNILA, UNDIP, Sam Ratulangi University, UNHAS, Mulawarman, Tanjung temple, Medan Area, Islam Lamongan, BPPT	1	18.36%
Amount (*Jumlah*)		49	100%

Based on the Table 2, the universities that have published the most research on biotechnology from 1994 to 2023 are IPB and UGM. Bogor Agricultural Institute (IPB) is a campus that focuses on the development of agriculture and biology. Many expert researchers in agriculture and biotechnology come from IPB. Meanwhile, Gadjah Mada University (UGM) is the 2nd-best campus in Indonesia, offering a wide range of disciplines. From the campus perspective, almost all campuses conducting biotechnology research are located on the island of Java. There are several reasons why biotechnology research in Indonesia is not well developed, including the fact that biotechnology research facilities require sophisticated laboratories, inexpensive equipment, and qualified human resources. Many large campuses on the island of Java have these facilities or also have access to the required facilities, both from state facilities (BRIN) and from private companies. In addition, government research funds are sufficient to conduct research, but research on biotechnology will be much more difficult to carry out with the same funding as research on other themes. Biotechnology research requires expensive tools and materials; errors or failures often result in repetition of research and so on.

The government should provide more space for biotechnology research, so it has the same opportunities as other research to develop. Biotechnology research is a profitable field and provides significant economic benefits for the country and society. Very few biotechnology products result from Indonesian research, even though, from a human and natural resource standpoint, they are abundant and offer great opportunities for various discoveries in this field.

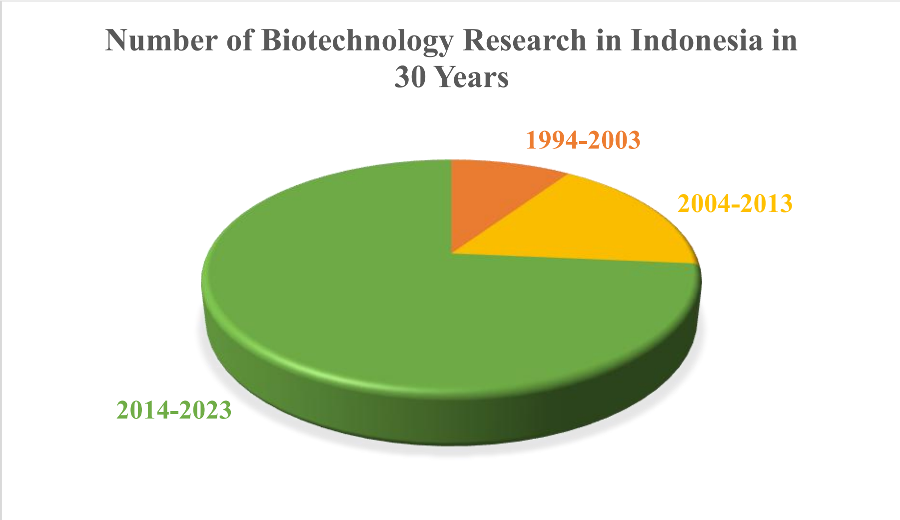

Figure 4. Development Research Biotechnology from 1994-2023 (*Pengembangan Riset Bioteknologi dari tahun 1994-2023*).

Figure 4 shows a steady increase in biotechnology research in Indonesia from 1994 to 2023. Between 1994 and 2003, 5 articles were published in Scopus-indexed journals. This number rose from 9 in 2004 to 23 in 2013, and from 23 in 2014 to 2023. Notably, the analysis only covers journals from three accessible publishers, so the actual number of published research articles may be higher if national and other international journals are included.

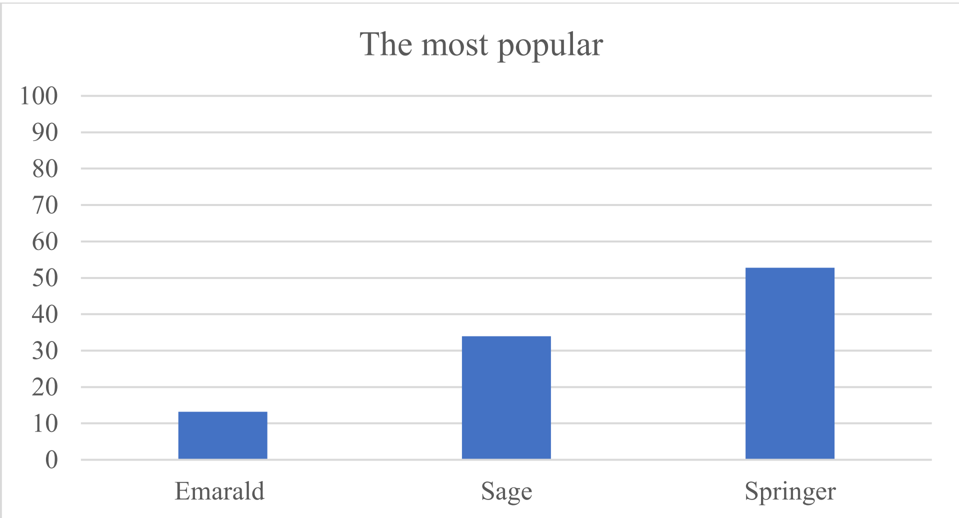

Figure 5. The Most Popular Publisher of Biotechnology Researcher in Indonesia (*Penerbit Terpopuler Peneliti Bioteknologi di Indonesia*).

Based on Figure 5, biotechnology researchers in Indonesia publish more of their research results in Springer Publishers (52.8%), followed by Sage Publishers (33.96%) and Emerald Publishers (13.21%). Some of the targeted journals are: Nutrition and Food Science, Natural Product Communications, International Journal of Medical Research, Science Progress, Drug Target Insight, Bioinformatics and Biology Insights, Cancer Informatics, Reproductive Sciences, Sage Open Medicine, Applied Microbiology and Biotechnology, Journal of Crop Science and Biotechnology, J. Crop Sci. Biotech, Marine Biotec, Food Science. Biotechnol, Molecular Biotech, Biotechnology and Bioprocess Engineering, World J Microbiol Biotechnol, and Transgenic Res. The journals are Scopus-indexed, with quartiles ranging from Q1 to Q4. Publishing in Scopus-indexed journals is not easy because selection is very strict and highly competitive. Restrict results that meet the above criteria are considered original and interesting to read.

The results show that biotechnology research in Indonesia covers various fields, including agriculture, plantations, animal husbandry, marine, industry, health, food, and the environment. The research percentage data is shown in the image below.

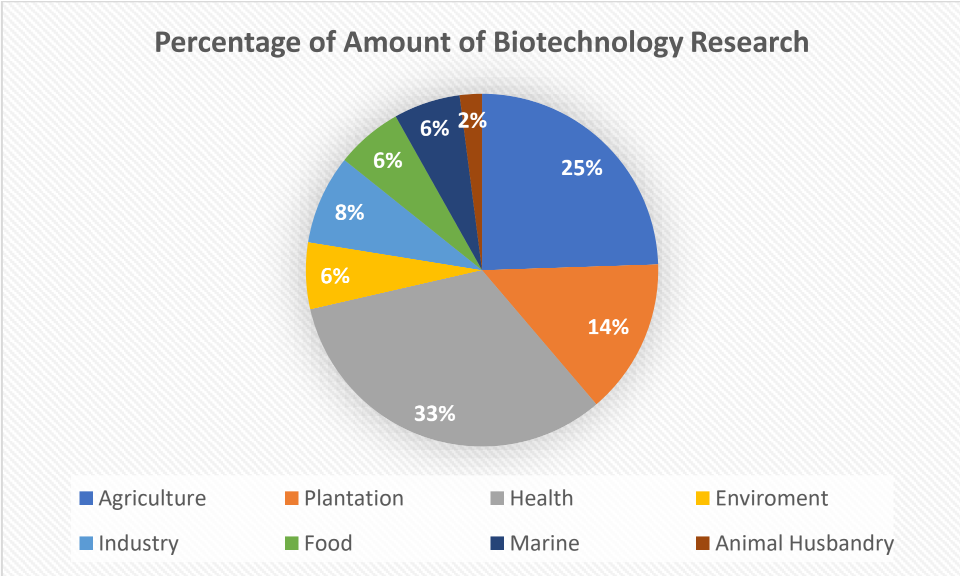

Figure 6. Percentage Publication Biotechnology in Various Field (*Persentase Publikasi Bioteknologi di Berbagai Bidang*).

Based on Figure 6, it shows that the fields that are mostly carried out in biotechnology research are health with a percentage of 33% (n=16) and agriculture 25% (n=12). The fields of agriculture and health are the fields most closely related to biotechnology research. Applications of biotechnology in the health sector include the use of markers for disease detection, the use of secondary metabolites for treatment and even the latest discovery is gene editing to prevent human genetic diseases in the future (Nelson et al., 2022); (Sheng et al., 2022); (Braga et al., 2022); (Shaffer, 2019); (Kawai et al., 2018) although this is still being debated regarding ethics, this research continues to develop (Meyer, 2022). The field of biotechnology agriculture is also growing rapidly, many biotechnology agricultural products have been sold freely after receiving recommendations from experts in the form of GMOs ((Pinstrup-andersen & Policy, 1999;) and (Viju et al., 2017). GMOs in agriculture can be rice with insulin hormone, donkey, potato, seedless watermelon and others ((Barragán-Ocaña et al., 2019) (Charlebois et al., 2019)). GMOs are still being debated by experts regarding their safety for both humans who consume them directly and for other living things in nature(Xue & Tisdell, 2000). There is concern that it will break off and interfere with and attach to other genes that could endanger health or become mutations for other organisms(Laxman & Ansari, 2011).

Overall, the research results indicate that biotechnology research in Indonesia during the 1994–2023 period remains dominated by the health and agriculture sectors, as both are directly related to basic human needs, such as food security and healthcare. This dominance is supported by high market demand, government policy priorities, and the large allocation of research funding in national strategic research programs. Indonesia's abundant potential for biological resources and germplasm has not been optimally utilised for biotechnology development in other sectors, such as the environment, energy, and industry. This situation indicates the need for increased support in the form of research facilities, industry collaboration, human resource development, and sustainable funding to expand biotechnology exploration and innovation more evenly across various national development sectors.

Biotechnology Research in Agriculture Sector

Agriculture is one of the vital areas in the life of a country, staple food needs are obtained from agriculture. Countries that consume rice as a source of carbohydrates need rice farming for survival, European people who consume bread need wheat farming and so on. Indonesia is a country with the largest population in Southeast Asia, which produces quite a lot of agriculture, however production is not sufficient to meet needs, so the government through the Ministry of Trade imports rice from neighboring countries with a value of 183.80 in 2021 and an increase of 9.9% in 2022. with a value of 202.04 Million USD (BPS, 2023). Some of the things that become obstacles to agriculture in Indonesia are the number of harvests that are not optimal caused by pests, types of rice that are less superior, long harvest times, natural disasters and dense quantities. Some of these conditions can be overcome by the study of biotechnology in agriculture. Some research on biotechnology can be seen in Table 3.

Table 3. Research Biotechnology in Indonesia in the Agriculture Sector (*Riset Bioteknologi di Indonesia di Sektor Pertanian*).

Author and Year (*Penulis dan Tahun*)	**University** (*Universitas*)	**Title** (*Judul*)
(Surodjo *et al*., 2008)	Airlangga University, University of Queensland	Biotransformation of Mefenamic Acid by Cell Suspension Cultures of Solanum mammosum
(Jadid *et al*., 2022)	Institute Technology 10 November, Surabaya, Islamic University of Lamongan, Indonesia	Genetic diversity and growth responses of Indonesian tomato (*Solanum lycopersicum* L.) genotypes under lead stress
(Jadid *et al*., 2021)	Institute Technology Ten November, University Airlangga,	In Silico Analysis of Partial Fatty Acid Desaturase 2 cDNA From Reutealis trisperm (Blanco).
(Dewi *et al*., 2020)	IPB	Angiotensin -Converting Enzyme (ACE) Inhibitory Activities of Protein Hydrolysates from Indonesian Sea Cucumbers
(Arisandi *et al*., 2020)	University Of Jember	Effect of ethylene inhibitor, type of auxin, and type of sugar on another culture of local East Java aromatic rice varieties
(Estiati *et al*., 2018)	LIPI	Overexpression of RF2a in Transgenic Rice Plants Cultivar IR64 Enhances Tolerance to Rice Tungro Virus
(Anhar *et al*., 2021)	UNP	Molecular characterization of *Trichoderma* strains from West Sumatra, Indonesia and their beneficial effects on rice seedling growth
(Fitri *et al*., 2021)	University Of Jember	Genetic and phytochemical analysis of Indonesian black rice cultivars,
(Ikasari & Mitchell, 1994)	University quesland	Protease production by *Rhizopus oligosporus* in solid-state fermentation L.
(Rosana *et al*., 1999)	IPB	Characterization of Transposon-Generated Protease Mutant of *Xanthomonas campestris* pathovar glycine 8ra Enzyme Activity, Cloning, and Mapping of Flanking DNA
(Koehorst-van Putten *et al*., 2012)	LIPI	Field testing and exploitation of genetically modified cassava with low-amylose or amylose-free starch in Indonesia
(Rumengan *et al*., 2021)	University Sam Ratu Langi	Ascidian-associated photosymbionts from Manado, Indonesia: secondary metabolites, bioactivity simulation, and biosynthetic insight

Data in Table 3 shows that biotechnology research in Indonesia from 1994 to 2023 focused on staple food commodities and economically valuable crops. For example, research by (Arisandi *et al*., 2020; Estiati *et al*., 2018; Fitri *et al*., 2021) related to rice. Extensive research also focused on *Solanum mammosum* and *Solanum lycopersicum* L. (Jadid *et al*., 2022; Surodjo *et al*., 2008). Research focused on developing superior seeds aligns with Indonesia's biotechnology research priorities and national needs, namely, strengthening staple food production through genetic improvement, tissue culture, and the use of beneficial microorganisms.

In addition to rice, the development of agricultural biotechnology in Indonesia is evident in other commodities such as tomatoes (*S. mamosum*), castor bean, cassava, black rice, and enzyme-producing microorganisms. This pattern emphasises that Indonesian agricultural biotechnology is not only focused on increasing productivity, but also on exploring genetic diversity, developing functional foods, providing industrial raw materials, and utilising local biological resources. However, the number of identified publications remains relatively limited, underscoring the need for increased research on local food commodities, horticultural crops, plantation crops, soil microorganisms, and modern breeding technologies. With Indonesia's rich germplasm, agricultural biotechnology has the potential to become a crucial foundation for reducing dependence on imports, strengthening food security, increasing the added value of local commodities, and supporting the development of the national bioindustry.

Biotechnology Research in the Health Sector

Biotechnology research in the health sector has made significant progress over the past three decades. Health biotechnology research focuses on the diagnosis, prevention, and treatment of various diseases caused by genetic factors, bacteria, and viruses. Furthermore, biotechnology is also utilised in the development of biomarkers to detect disease and identify infectious agents, such as the SARS and H1N1 viruses. Based on reference searches, biotechnology research in the health sector was the most dominant area of research conducted by Indonesian researchers during 1994-2023. The research topics are shown in Table 4.

Table 4. Research Biotechnology in Indonesia in the Health Sector (*Riset Bioteknologi di Indonesia di Bidang Kesehatan*).

Author and Year (*Penulis dan Tahun*)	**University** (*Universitas*)	**Title** (*Judul*)
(Kusuma *et al*., 2022)	Gadjah Mada University	Effect of fermented cassava tuber on the gene expression of PI3K/ Akt signaling and AMPK pathway in STZ-NA-induced diabetic rats
(Widodo *et al*., 2019)	Gadjah Mada University	Antidiabetic effect of fermented milk using intestinal probiotics
(Andriani *et al*., 2021)	Gadjah Mada University	Genotypic and Phenotypic Analyzes of Antibiotic Resistance in Indonesian Indigenous Lactobacillus Probiotics
(Istiqomah *et al*., 2020)		Anticancer Effects of Polyisoprenoid from *Nypa fruticans* Leaves by Controlling Expression of p53, EGFR, PI3K, AKT1, and mTOR Genes in Colon Cancer (WiDr) Cells
(Ramadhan & Phuwapraisirisan, 2015)	University, Mulawarman University,	Arylalkanones from Horsfieldia macrobotrys are Effective Antidiabetic Agents Achieved by α-Glucosidase Inhibition and Radical Scavenging,
(Fadaeinasab *et al*., 2015)	University of Malaya, Universitas Airlangga	Anti-malarial Activity of Isoquinoline Alkaloids from the Stem Bark of Actinodaphne macrophylla
(Gunadi *et al*., 2021)	Gadjah Mada University	Effect of semaphorin 3C gene variants in multifactorial Hirschsprung disease
(Tambunan *et al*., 2017)	University of Indonesia	Modification of S-Adenosyl-l-Homocysteine as an Inhibitor of Nonstructural Protein 5 Methyltransferase Dengue Virus Through Molecular Docking and Molecular Dynamics Simulation
(Maksum *et al*., 2017)	UNPAD	Bioinformatics Study of m.9053G>A Mutation at the ATP6 Gene in Relation to Type 2 Diabetes Mellitus and Cataract Diseases

Author and Year (*Penulis dan Tahun*)	**University** (*Universitas*)	**Title** (*Judul*)
(Destiarani *et al*., 2020)	UNPAD	Molecular Dynamics Simulation of T10609C and C10676G Mutations of Mitochondrial ND4L Gene Associated with Proton Translocation in Type 2 Diabetes Mellitus and Cataract Patients
(Purwosunu *et al*., 2009)	Showa University University of Indonesia, University of Bologna, Bologna, Italy (AF).	Expression of Angiogenesis-Related Genes in the Cellular Component of the Blood of Preeclamptic Women
(Auerkari *et al*., 2014)	UI, University of Leicester, Leicester and Loughborough University, UK	Gene promoter polymorphism of RUNX2 and risk of osteoporosis in postmenopausal Indonesian women
(Pawestri *et al*., 2018)	National Institute of Health Research Development, Ministry of Health, Jakarta, Republic of Indonesia	Detection of neuraminidase inhibitorresistant influenza A (H1N1) pdm 09 viruses obtained from influenza surveillance in Indonesia
(Putri *et al*., 2022)	Airlangga University, Brawijaya University,	Alveolar Repair Using Cancellous Bone and Beta Tricalcium Phosphate Seeded with Adipose-Derived Stem Cells
(Wargasetia *et al*., 2021)	Maranatha Christian University, The University of Brawijaya ,	Bioinformatics Study of Sea Cucumber Peptides as Antibreast Cancer Through Inhibiting the Activity of Overexpressed Protein (EGFR, PI3K, AKT1, and CDK4)
(Helianti *et al*., 2008)	BPPT	Cloning, sequencing, and expression of a b-1,4-endoxylanase gene from Indonesian *Bacillus licheniformis* strain I5 in Escherichia coli

Table 4 shows that health biotechnology research in Indonesia during the period 1994–2023 shows a strong tendency towards the use of molecular approaches, bioinformatics, bioactive metabolites, probiotics, and cell-based therapies to address degenerative diseases, infections, cancer, and genetic disorders. The most prominent themes relate to diabetes (Destiarani *et al*., 2020; Kusuma *et al*., 2022), cancer (Istiqomah *et al*., 2020; Wargasetia *et al*., 2021), infectious diseases (Pawestri *et al*., 2018), antimicrobial resistance (Andriani *et al*., 2021), and diseases based on genetic variation. Overall, the distribution of biotechnology research themes in the health sector, as shown in Table 4, confirms that Indonesian health biotechnology has evolved from natural material exploration and fermentation to research based on genomics, bioinformatics, protein engineering, molecular detection, and regenerative therapies. However, the dominance of research at the laboratory and computational stages indicates that the main challenges still lie in clinical validation, product standardisation, biological safety, down streaming, and integration of research results into the healthcare system. Therefore, strengthening Indonesian health biotechnology should be directed toward translational research that links molecular discoveries to the development of diagnostics, drugs, vaccines, therapeutic probiotics, biomaterials, and cell-based therapies.

Biotechnology Research in the Industry Sector

In the industry sector, several biotechnology studies related to remediation include research conducted by Rahayu, 2019 relating to the use of multisymbiotic organisms to remediate Lapindo mud. Lapindo Mud is a mining tragedy that occurred in 2006 and has not stopped until now. The gas mine failed during excavation and emitted hot mudflow which has now covered 19 villages with an area of 1,143.2 hectares. The results of the research show that this biological consortium in the form of plants, mycorrhiza and bacterium can be an alternative model for managing Lapindo mud in the future (Rahayu, 2020). Other biotechnology research in the industrial sector is related to palm oil. Palm oil is the main commodity especially on the islands of Sumatra and Kalimantan. Indonesia has a very large area of oil palm land of 14.99 million Ha in 2022 (BPS, 2023) and is the largest supplier of palm oil in the world after Malaysia. The potential for oil palm research is very important to increase the production and quality of oil palm, biotechnology is one of the right ways to produce quality seeds such as pest resistance, produce dense fruit, produce fruit with good quantity and quality of oil and so on (Ayu *et al.*, 2016; Elvitriana *et al.*, 2018). Research on bio composite from coconut shell and biodiesel is also an interesting theme for research by biotechnology researchers in Indonesia(Tanjung *et al*., 2020; Machsun *et al*., 2010).

Table 5. Research Biotechnology in Indonesia in the Industry Sector (*Riset Bioteknologi di Indonesia di Sektor Industri*).

Author and Year (*Penulis dan Tahun*)	**University** (*Universitas*)	**Title** (*Judul*)
(Rahayu, 2020)	UNS	Bioremediation model of oil-contaminated soil in Lapindo mud using multisymbiotic organisms
(Elvitriana *et al*., 2018)	USU	Production of Lipid Biomass in Locally Isolated Microalga Cultivated in Palm Oil Mill Effluent (POME)
(Tanjung *et al*., 2020)	University of Medan Area, Curtin University, Prasetya Mulya University, University of Malaysia Perlis,	Enzymatic degradation of coconut shell powder– reinforced polylactic acid biocomposites
(Ayu *et al*., 2016)	IPB-UNRI	Effect of Tocopherols, Tocotrienols, β-Carotene, and Chlorophyll on the Photo-oxidative Stability of Red Palm Oil 3
(Machsun *et al*., 2010)	UI	Membrane Microreactor in Biocatalytic Transesterification of Triolein for Biodiesel Production

Biotechnology research in Indonesia's industrial sector demonstrates that it is focused not only on the production of biological materials but also on addressing environmental issues arising from industrial activity. However, the number of studies remains very limited, underscoring the need for government support and attention to this research topic. This will allow biotechnology research to move toward down streaming, production scale, standardisation, and integration with the national industry, forming the basis for a bioindustry that can support economic and environmental sustainability.

Biotechnology Research in the Plantation Sector

Plantation products are one of Indonesia's main commodities. Some biotechnology research in the field of plantations is related to tea, coffee and cocoa. For example, research is related to a simple kit for detecting polyphenols in green tea using biological agents (Hidayat *et al*., 2020). In addition, research conducted by (Table 6; Lukman *et al.*, 2014; Ali *et al.*, 2019) is related to cocoa by identifying and constructing bacterial genes that cause dieback. on chocolate and aceh brown lineage using a single nucleotide polymorphym (SNP).

Table 6. Research Biotechnology in Indonesia in the Plantation Sector (*Penelitian Bioteknologi di Indonesia di Sektor Perkebunan*).

Author and Year (*Penulis dan Tahun*)	**University** (*Universitas*)	**Title** (*Judul*)
(Rudiyansyah *et al*., 2019)	Tanjungpura University, Heinrich-Heine-Universität Düsseldorf, Peking University,	Arugosins OQ, New Fungal Metabolites from the Fungus *Xylariaceae sp.* Isolated from Leaves of *Lansium domesticum* (Meliaceae)
(Masanto *et al*., 2019)	Gadjah Mada University	Genetic diversity of *Phytophthora palmivora* isolates from Indonesia and Japan using rep-PCR and microsatellite markers

Author and Year (*Penulis dan Tahun*)	University (*Universitas*)	Title (*Judul*)
(Hidayat *et al*., 2020)	UNAIR	Simple and Sensitive Paper-based Colorimetric Biosensor for Determining Total Polyphenol Content of the Green Tea Beverages
(Kurniawan *et al*., 2017)	IPB	Metabolomic approach for understanding phenolic compounds and melanoidin roles on antioxidant activity of Indonesian robusta and arabica coffee extracts
(Lukman *et al*., 2014)	Malikusaleh university and IPB	Genetic Identity, Ancestry and Parentage in Farmer Selections of Cacao from Aceh, Indonesia Revealed by Single Nucleotide Polymorphism (SNP) Markers
(Ali *et al*., 2019)	UNHAS	Draft genome sequence of the fastidious pathogen *Ceratobasidium theobromae,* which causes vascular-streak death in Theobroma cacao

Overall, these studies demonstrate that plantation biotechnology in Indonesia is developing in three main directions: product quality and bioactive compound testing, secondary metabolite exploration, and molecular analysis to support breeding and disease control. However, the limited number of publications indicates that plantation biotechnology research needs to be strengthened in downstream stages, field validation, the development of disease-resistant varieties, the utilisation of endophytic microorganisms, and rapid detection technologies. Given Indonesia's position as a significant producer of tropical plantation commodities, strengthening plantation biotechnology can serve as a basis for increasing productivity, export quality, product added value, and the sustainability of the national agro-industry.

Biotechnology Research in the Marine Sector

Indonesia's coastal area is 14,600,000 Km^2 with a beach length of 108,000 Km, the potential has not been fully utilized. Some activities that use the sea and beaches as state divisions are fisheries, tourism, mining and transportation. Applications of biotechnology in the marine sector include the utilization of a bacterial consortium to decompose oil spills in the sea by using the *Alcanivorax borkumensis* bacteria which can convert hydrocarbon into fatty acids. In addition, several studies have been conducted to clone the chitin gene from *Aromonas cavie* which is stable at high temperatures and purify the chitin gene from *Bacillus licheniformis* (Table 7; Malik *et al.*, 2003; Toharisman *et al.*, 2005; Ekowati *et al.*, 2006). In 2023 , BRIN researchers tested the potential of polysaccharide degrading genes from brown algae in Indonesia as anti-biological agents and vitamins beneficial to health (Ethica *et al*., 2023).

Table 7. Research Biotechnology in Indonesia in the Marine Sector (*Riset Bioteknologi di Indonesia di Sektor Kelautan*).

Author and Year (*Penulis dan Tahun*)	University (*Universitas*)	Title (*Judul*)
(Ekowati *et al*., 2006)	IPB	Biochemical Characteristics of Chitosanase from the Indonesian *Bacillus licheniformis* MB-2
(Antoro *et al*., 2006)	National Sea Farming Development Center, Lampung 35454, Indonesia	Study of Genetic Diversity of Orange-Spotted Grouper, *Epinephelus coioides*, from Thailand and Indonesia Using Microsatellite Markers
(Malik *et al*., 2003)	UI	Cloning, DNA Sequence, and Expression of *Aeromonas caviae* WS7b Chitinase Gene
(Ethica *et al*., 2023)	BRIN	Biotechnologically potential genes in a polysaccharide-degrading epibiont of the Indonesian brown algae *Hydroclathrus sp*.
(Toharisman *et al*., 2005)	IPB	Purification and characterization of a thermostable chitinase from *Bacillus licheniformis* Mb-2

Overall, research patterns in the marine sector indicate that Indonesian marine biotechnology is still at the stage of genetic resource exploration and molecular characterisation, but has great potential for development in oil spill bioremediation, chitin-based waste processing, genetically engineered aquaculture, the enzyme industry, functional foods, marine pharmaceuticals, and the coastal bioeconomy. The low number of publications in this field compared to health and agriculture indicates that Indonesia's marine potential has not yet been fully translated into a strong national biotechnology research base.

Biotechnology Research in the Agriculture and the Environment Sector

Biotechnology research in the livestock sector has not shown good progress. In the last 30 years, only one study has been identified as biotechnology research in the livestock sector, namely one on the diversity and relationships of local goats on the island of Java, as revealed by analysis of the cytochrome b gene. The results showed a close kinship relationship between sheep in Java, which fall into the Haplo B class, except for Garut sheep and Priangan sheep, which fall into the Haplo A category (Ibrahim *et al*., 2023). This limited publication highlights a research gap that needs to be addressed to ensure that livestock biotechnology not only documents genetic diversity but also serves as a strategic instrument to improve seed quality, productivity, livestock health, and animal food security in Indonesia. In the environmental sector, biotechnology research was conducted in 2021 using a systematic literature review on rapid extraction and purification of environmental DNA, molecular cloning, and molecular diversity (Santosa, 2001).

Table 8. Research Biotechnology in Indonesia in the Agriculture and the Environment Sector (*Penelitian Bioteknologi di Indonesia di Sektor Pertanian dan Lingkungan*).

Author and Year (*Penulis dan Tahun*)	**University** (*Universitas*)	**Title** (*Judul*)
(Ibrahim *et al*., 2023)	Gadjah Mada University	Genetic diversity and relationship among Indonesian local sheep breeds on Java Island based on mitochondrial cytochrome b gene sequences
(Santosa, 2001)	IPB	Rapid Extraction and Purification of Environmental DNA for Molecular Cloning Applications and Molecular Diversity Studies

The findings in Table 8 confirm that the livestock and environmental sector is a research area that is still weak but has great potential. Both need to be further developed through more applicable research, such as mapping the genomes of local livestock, identifying disease-resistance genes, genetic conservation, environmental metagenomics, exploring pollutant-degrading microbes, and developing bioremediation technologies based on local microorganisms. Strengthening these two areas is crucial to ensure that Indonesia's biotechnology development is not solely focused on health and agriculture, but also encompasses livestock and environmental resource management as part of sustainable development.

Biotechnology Research in the Food Sector

Food biotechnology research in Indonesia shows that traditional fermented foods have great potential for the development of modern food biotechnology, although the number of publications remains limited and concentrated in the period 2013–2016 (Table 9). Several studies have focused on the identification of microorganisms in tape, on food safety based on pathogenic bacteria, and on bacteriocin production by microbes isolated from shrimp paste. Molecular studies of yeast in tape indicate that the traditional fermentation process can be scientifically understood and standardised through a biotechnological approach, while the isolation of bacteriocin-producing bacteria from shrimp paste demonstrates that Indonesian fermented foods have the potential to serve as a source of natural antimicrobial compounds, probiotics, and functional microbes. Furthermore, research on pathogenic bacteria in food indicates that biotechnology also plays a crucial role in food safety systems through the detection and control of harmful microorganisms. However, the development of food biotechnology research in Indonesia is still not commensurate with the richness of local foods and the diversity of traditional fermented products, such as tempeh, tape, shrimp paste, dadih, and oncom. Therefore, it is necessary to strengthen research by identifying local microbes, characterising their genes, developing functional foods, and down streaming fermented products, so that the potential of traditional Indonesian foods can be translated into biotechnological innovations with high scientific and economic value.

Table 9. Research Biotechnology in Indonesia in the Food Sector (*Penelitian Bioteknologi di Indonesia di Sektor Pangan*).

Author and Year (*Penulis dan Tahun*)	**University** (*Universitas*)	**Title** (*Judul*)
(Kobayashi *et al*., 2016)	Undip and researchers Japan	Production of bacteriocin by Virgibacillus salexigens isolated from " terasi ": a traditionally fermented shrimp paste in Indonesia
(Nurjanah *et al*., 2014)	IPB	Stability and Growth Characteristics of GFPuv - Labeled *Cronobacter sakazakii* Isolated from Foods
(Soka & Irene, 2013)	Atmajaya	Molecular Analysis of Yeasts from Indonesian Cassava and Glutinous Rice Tapé

CONCLUSION

Based on the analysis that has been carried out, Bogor Agricultural University (IPB) is the university that conducts the most research in biotechnology, followed by Gadjah Mada University (UGM), the University of Indonesia (UI), and Airlangga University (UNAIR). Furthermore, over the past 10 years, the number of biotechnology research projects in Indonesia has increased, with health and agriculture as the most dominant topics.

ACKNOWLEDGMENT

We would like to thank Indonesian Education Scholarship (BPI), Center for Higher Education Funding and Assessment (PPAPT), and Indonesian Endowment Fund for Education (LPDP) who have funded the author in research.

AUTHOR CONTRIBUTIONS

TI: collecting research data, drafting the article, final revision of the manuscript; TH: Creating research concept, final revision of manuscript; AR: Create research concepts, draft articles, revise manuscripts.

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