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Research Article

Emergence of Bioplastic as a Sustainable Polymer in the Indian Food Packaging Industry: A Scientometric Analysis

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ABSTRACT

The use of bioplastics as a potential remedy for the problems caused by plastic pollution is gaining the attention of researchers and policy makers globally. Bioplastics are regarded as sustainable and valuable in several industries, particularly food packaging sector. In this context, the paper aims to evaluate the literature on bio-plastics research in India at the institutional level to determine correlations through a scientometric analysis. In doing so, a total of 1705 publications were extracted from the Web of Science database for the period between 2000 and 2021.The study results showed that sustainable plastics had gained the attention of the research community, with an upturn in publication from 2010 onwards. Furthermore, the study constructed a thematic map which indicates rising research trends in bioplastics are moving towards technologies for the food packaging sector. The study findings highlight the future research trend on bioplastics and provide meaningful information for sustainable food packaging in India.

Keywords: Bibliometric, Bioplastic, Co-citation, Collaboration analysis, VOS viewer.

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INTRODUCTION

With the rapid development of technology and the growth of the world's population, plastics have found widespread use in business and everyday life. Prof. Guilio Natta optimistically characterized the 1960s as "the age of plastics," a description still holds today (Fagnani *et al*., 2021). Plastic is the most commonly used material in the 21st century, especially for packaging. The global production of plastics is 381 million tons/year, and its demand is continuously rising, and about half of the all plastic used is single-use plastic (SUP) (Paletta *et al*., 2019). The packaging sector uses about 42 percent of the total produced plastic worldwide (Geyer *et al*., 2017). The Indian packaging sector consumes 59 per cent of the total plastics produced in India (PlastIndia, 2020). Packaging products have a much less 'in use' lifetime, from 5 minutes to six months (Geyer *et al*., 2017). Therefore, the packaging sector is a significant contributor to 'single-use plastic' waste and accounts for approximately half of the total global waste. The food and beverage industry holds a significant share of the packaging sector (Phelan *et al*., 2022).

In 2015, 6300 Mt of plastic waste was produced, of which approximately 9% was recycled, 12% was incinerated, and 79% was disposed to landfills or natural environments (Jambeck *et al*., 2015). By 2050, more than 12,000 metric tons of plastic garbage will be dumped in landfills if the same manufacturing and waste management pattern is continued (Geyer *et al*., 2017).

Rising environmental concerns and global commitment to sustainable development have put pressure to abandon fossil-based plastics from the planet. Many countries have implemented full or partial bans on single-use plastic (SUP). According to the United Nations, 127 nations have passed laws regulating plastic bags, 27 countries have prohibited specific SUPs, materials, or manufacturing levels, and 63 countries have mandated expanded producer responsibility for SUPs by 2018 (UNEP, 2018). China, which produces and consumes the most plastic in the world, has declared a ban on non-degradable SUPs in key cities by the end of 2020 and across the country by 2025 (UNEP, 2018). The present government in India has shown total commitment to fighting against the nuisance of SUP to achieve sustainable development. Altogether 29 States and Union Territories have initiated and banned SUP. However, this ban is ineffective in many states due to inadequate enforcement. Plastic Waste Management Amendment Rule 2021 has made it mandatory to phase out the manufacturing, selling, importing, stocking and distributing SUP (21 items have been identified for a ban) from July 1, 2022. These items have low utility and high littering potential nationwide (PIB, 2022).

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The global trend to ban single-use plastics has motivated policy makers and researchers to develop alternative sustainable plastics which could be produced from renewable resources. Bioplastic has emerged as one such viable alternative to fossil fuel-based plastics. However, its contribution is still meagre in the plastic industry mainly due to its complex structure and inadequate understanding of its degradation (Ahmed *et al*., 2018).

More than 35 countries have given the green signal to degradable plastics by incentivizing the development, import, or use of oxo-biodegradable, biodegradable, and compostable SUPs. In the last two decades, many forms of biodegradable polymers have been promoted as a potentially game-changing solution for resolving the problems associated with the non-biodegradability of plastic (UNEP, 2018). In the last few years, India has also promoted biodegradable plastic products by exempting the thickness limit for plastics designated as compostable and biodegradable (MoEFCC, 2016).

Since India is following the path of *Atma Nirbhar Bharat* (self-reliant India) and promoting sustainable development by banning Single Used Plastic since July 2022, it is relevant to explore the status of research and development in the field of bioplastics in India. Studies using bibliometric analysis for bioplastic research around the world are quite negligible. Garrido *et al*., (2021) used the bibliometric analysis in the context of national policies worldwide and focused on trends in publications by country, authors and collaboration networks. Rana *et al*., (2022) elaborated on key publications or scientific productions, the most productive researchers in terms of publications and citations, latest hotspots (keywords), the countries with the most active research, collaborations between the countries, highly cited journals, highly contributing organizations, and co-cited references with their cluster analysis of bioplastic research. Sagapova & Cudlínová (2022) stated that bioplastic research is mainly focused on biology, chemistry and biotechnology research to develop a bioplastic product. There are very few studies on bioplastic research based on bibliometric analysis, particularly in the Indian context. The bibliometric technique is an effective instrument for assessing the developments and trends in research in a particular area of interest (Lu *et al*., 2018; Ma *et al*., 2018). Therefore, in this paper, an attempt is made, based on bibliometric analysis, to analyse the research and development trend in India in the field of bioplastics. The remaining sections of this paper are organized as follows:

The second section critically analysed the literature on plastic pollution in India and the emergence of bioplastics as an alternative in the food packaging sector. This section also focuses on the role of R&D institutions and policy frameworks in achieving the vision of a circular bioeconomy. The third section provides the aims and objectives of the study. The fourth section deals with the methodology adopted for the study. The fifth section provides key features of data and a detailed bibliometric analysis and emerging research trends in bioplastics in India. The sixth section gives the conclusion and policy implications of the study.

LITERATURE REVIEW

Plastic Pollution- Indian Scenario

Marine plastic contamination of ecosystems and organisms is widespread worldwide (Thompson, Moore, Saal, & Swan, 2009). Although scientists discovered plastic pollution in the ocean in the 1970s, it received widespread media coverage and public attention only recently (Law, 2016). Marine microplastic has entered the biological systems of all organisms, ranging from herbivores and secondary consumers to the predators of higher trophic levels, including microorganisms, planktons, benthic invertebrates, fish, deep ocean biota, and larger mammals (Amelia *et al*., 2021). The amount and the quality of the food supply for people and other aquatic species are reduced due to these consequences (Wong *et al*., 2020). The hazardous pollutants like persistent organic pollutants (POP) and heavy metals are carried by microplastic and enter the environment through the food chain (Wang, Ge, & Yu, 2020; Zhang *et al*., 2020). As per one estimate tens of thousands of individual animals, representing at least 558 species and 50 per cent of all seabird species, have been contaminated by entanglement and ingestion of microplastic (Gall & Thompson, 2015).

As per the latest data, India generates approximately 34,6,780 tons of plastic waste, which has almost doubled since 2015-16 (CPCB, 2021). The Ministry of Petroleum and Natural Gas estimates that per capita annual plastic consumption will be 20 kgs by 2022 (TERI, 2018). Plastic consumption by the packaging sector is around 59% of total plastic; out of it, approximately 70% of plastic used in packaging is used for single-use. India can recycle 60% of total plastic waste, which is more than twice the global average (FICCI, 2020).

Plastic waste generation in developed nations is significantly higher than in developing nations, but their mismanaged plastic waste generation is much lower compared to low-middle income nations because of the effective waste management system. Mismanaged plastic is at a higher risk of entering the oceans. India's mismanaged plastic waste generation is 12.99 million tonnes which is the highest in the world, and two rivers (Ulhas and Ganges) are on the list of the top 10 polluting rivers in the world (Meijer *et al*., 2021). India has taken action to resolve the plastic waste problem by introducing a nationwide ban on single use plastic since July 1, 2022. This ban will create opportunities for alternative materials that can substitute conventional plastic. Bioplastic has shown significant potential to capture the market of petroleum-based SUP.

Bioplastic- A sustainable Polymer

Sustainability comes from the French verb 'soutenir', which means to uphold (Brown, Hanson, Liverman, & Merideth, 1987). By limiting resource extraction, the forestry industry, and subsequently ecologists, ensured that humankind did not exceed nature's ability to restore itself (Geissdoerfer *et al.*, 2017). The early applications of the word sustainable in the polymer sector indicated processes like sustainable polymer, recycling or sustainable polymer processing. Later the term was used to identify sustainable polymers (Schneiderman & Hillmyer, 2017). However, the subcommittee on polymer nomenclature of the International Union of Pure and Applied Chemistry has not (yet) defined 'sustainable polymer'. The closest equivalent to sustainable polymer is 'green polymer', which is a polymer that follows the green chemistry concept (Vert *et al.*, 2012). As a result, the term 'sustainably produced polymer' has remained imprecise and susceptible to interpretation.

An economy based on sustainable material is a knowledge-based economy where sustainable material must be able to cope with the following challenges: (1) Dependency on oil-based resources; (2) total energy consumption; (3) Carbon footprint/environmental concerns; (4) Food supply security; (5) Contamination caused upon disposal. Bioplastic has emerged as a sustainable material that can fulfil the characteristics of less energy consumption during production, less carbon footprint, no contamination after disposal and moving away from fossil-based resources (Leadbitter, 2002).

Bioplastic as an Alternative

Frequently, "bioplastic" and "biodegradable" are used interchangeably. However, not all bioplastics are biodegradable; only some are biodegradable (Di Bartolo *et al.*, 2021). Bioplastic is a family of plastic different from conventional plastics in terms of biodegradability and the use of raw materials. This means the term 'bio' in biopolymer and bioplastics use is customized to denote one or both of the following characteristics (i) based on biomass resources; (ii) biodegradable (Gioia *et al.*, 2021). The term "bio-based" refers to a polymer that is either wholly or partially derived from biomass, including organic waste and any renewable organic material. The term "biodegradable" refers to a material's ability to decompose through the activity of microbes into natural components like carbon dioxide, water, and biomass. In a more precise sense, biodegradable plastic is a substance that satisfies official biodegradability requirements, where a specified level of disintegration must be scientifically observed within a specific timeframe and under specific circumstances. Similarly, compostable plastic must adhere to strict criteria as it biodegrades in industrial composting facilities (Di Bartolo *et al.*, 2021). The nature of the plastic could be represented in four quadrants (Figure 1). The details are discussed below.

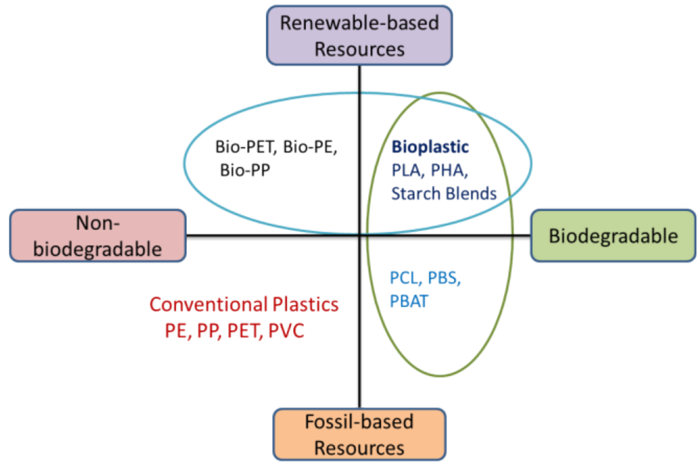


Figure 1: Four Quadrants of Plastics (Pathak, Sneha, & Mathew, 2014).

Table 1: List of Bioplastic and their origin and biodegradability

Polymer	Bio-based	Biodegradable
PLA	Yes	Yes
Starch blends (Thermoplastic starch)	Yes	Yes
PHA	Yes	Yes
PBS	Yes/No	Yes
PU	Yes/No	Yes/No
PCL	No	Yes
PVA	No	Yes
PBAT	No	Yes
PEF	Yes	No
Bio-PP	Yes	No
Bio-PTT	Yes	No
Bio-PET	Yes	No
Bio-PE	Yes	No
Bio-PAs	Yes	No

Source: (Bartolo *et al.*, 2021)

Classification of bioplastics

Bioplastics can be classified into three broader categories based on their biodegradability and biomass resources. These are: **Biobased and Non-biodegradable Bioplastics, Biobased and Biodegradable Bioplastics and Non-biobased and Biodegradable Bioplastic (Table.1).** Recently, polymers have been synthesized fully or partially from biomass to produce bioplastics which are non-biodegradable such as Bio-PE (Bio-polyethylene), Bio-PET (bio-polyethene terephthalate), Bio-PTT (bio-polytrimethylene terephthalate) and Bio-PP (Bio-polypropylene) (Garrido *et al.*, 2021; Moshood *et al.*, 2022).

Biobased and Biodegradable Bioplastics are biodegradable and obtained from biomass resources. They are categorized into two groups: (i) Natural polymers such as starch, cellulose and lignin; (ii) Polymers obtained from biomass such as PLA (polylactic acid), PHA (Polyhydroxyalkanoates) (Wellenreuther *et al*., 2022). The **non-biobased and biodegradable bioplastic** uses fossil-based resources but is biodegradable in nature. For instance, PBAT (Polybutylene adipate-co-terephthalate), PCL (polycaprolactone), and PVA (Polyvinyl alcohol) (Garrido *et al*., 2021; Moshood *et al*., 2022).

Growth of the Bioplastic Industry

In 2007, the production of newly developed biobased polymers was just 0.36 million tonnes globally, and it was expected that by 2019 the production will rise to 2.11 metric tons and 2.43 million tons by 2024 (Thompson *et al*., 2009). Biobased plastics have a 90% technical substitution capability for petrochemical plastics (European Bioplastics, 2018). About 55.5 percent (more than 1 million tonnes) of the world's total bioplastics manufacturing capacity is based on biodegradable polymers such as PLA, PHA and starch blends. India's bioplastics market is anticipated to increase at a CAGR of 23.91 per cent, from US$208.475 million in 2019 to US$754.648 million in 2025. One of the key elements expected to propel the Indian bioplastics market to a new peak during the projected period is rising environmental consciousness and the ban on single-use plastic from July 1, 2022 (Research and Market, 2020).

Policies related to Bioplastic in India

In September 2007, the Department of Biotechnology (DBT), Government of India, released the first National Biotechnology Development Strategy (2015-2020). The strategy was to start four critical missions in healthcare, food and nutrition, clean energy, and education. The National Biotechnology Development Strategy focused on producing biomaterials, bioplastics, value-added biomass, and goods made from natural resources. After the 2019 pandemic, India adopted another National Strategy for 2020-2025 to tap the biotechnology sector's potential to achieve a bio-economy with the inclusion of value-added products, i.e. 'Bioplastics'.

The Plastic Waste Management Rule, 2016 was amended by Ministry of Environment, Forest & Climate Change (MoEF&CC) on July 6, 2022, to include some new terms for the first time, such as biodegradable plastics, end-of-life disposal, plastic packaging waste, waste processor, pre- and post-consumer plastic packaging waste. These amendments defined the responsibility of the Producer, Importer, Brand Owners and Plastic Waste Processors. The degree of degradability and disintegration of plastic material was defined, and the standards for compostable (IS/ISO 17088:2021) and Biodegradable plastics (IS 17899 T: 2022) were notified by the Bureau of Indian Standards. This landmark policy change related to biodegradable plastics in India as it set the standards for the labelling of bioplastics and ensured its quality as per BIS and CIPET. To promote the development of sustainable plastics, several government laboratories, research institutions, and government and private universities are engaged in conducting research (Table 1).

OBJECTIVES

The primary objective of the study is to find out the emerging pattern of research in the area of bioplastics in India. The focus is to explore the trends in publications, research areas, citations, collaboration, influential journals, and influential authors contributing to bioplastic research between 2000 and 2021. There are two research questions: (1) What are the current trends of bioplastic research in India reflected in terms of the publications, citation and collaboration patterns; which are the influential journals and Institutions, and who are the prominent contributing authors in India's bioplastic research? (2), What are the emerging issues in bioplastic research and where is the gap in research?

METHODOLOGY

This study is based on a scientometric analysis of research papers on bioplastics related to the Indian food packaging industry. Bibliometric analysis is widely used for investigating and evaluating vast scientific data. It enables us to explore the subtleties of a field's evolutionary history while illuminating its frontiers (Donthu *et al*., 2021). This method is used to explore the growth of a research field, areas and topics of the research, and to identify the weakest and most vital points of the research. This type of research facilitates evidence-based policymaking for the use of bioplastic in the food packaging sector. In this study, we adopted four steps for conducting bibliometric analysis, as suggested by Donthu (Donthu *et al*., 2021). These steps are explained further in the following paragraphs.

Step 1: Define the bibliometric study's aims and scope: This study's aims and objectives are already explained in the research objective section.

Step 2: Choose a technique for bibliometric analysis: To perform the bibliometric analysis, the choice of techniques is crucial for meeting the aims and scope of the study. Since the aim of the study is to explore the emerging trends of research on bioplastics, particularly in the food packaging sector, a combination of 'co-citation analysis' for the history, 'bibliographic coupling' for the present, 'co-word analysis' for the future and 'co-authorship analysis' for social interaction were adopted. The 'co-word analysis' with 'co-citation' and 'bibliographic analysis', along with publication and citation trends, was used descriptively.

The software used for this study's techniques mentioned above is *biblioshiny* of *bibliometrix R* and *VOSviewer*. This software can visualize raw data downloaded from the 'Web of Science'. It is free Java-based software primarily designed for bibliometric network

Table 1: **Research and Development Institutes in Bioplastics in India**

Institutions	Technologies	TRL	Application	References
CSIR-National Institute of Interdisciplinary Science and Technology	Alternative to SUPs	TRL-7	Food Packaging	(NITI Aayog, 2022)
	Bio-based and biodegradable resin	TRL-5	Food Packaging	(NITI Aayog, 2022)
CIPET: School for Advanced Research in Petrochemicals (SARP)-LARPM	Bio-derived polyutheranes	TRL-5	Agricultural	(NITI Aayog, 2022)
IIT Guwahati and the Indian Institute of Science	Bio-derived PUs from castor oil,	TRL-5	Food Packaging	(NITI Aayog, 2022)
	Bio-derived PUs from jojoba oil	TRL 2-3	Food Packaging	(NITI Aayog, 2022)
IIT Bombay	Starch-based bioplastic	TRL-4	Food Packaging	(NITI Aayog, 2022)
Indian Plywood Industries Research and Training Institute (IPIRTI)	Recycled plastic to produce mat boards and plastic-bonded plywood	TRL-4	Household sectors	(NITI Aayog, 2022)
K J Somaiya College of Engineering	Cellulose from paddy straw	TRL-4	Food Packaging	(NITI Aayog, 2022)
	Biodegradable plates from rice pulp	TRL-2	Food Packaging	(NITI Aayog, 2022)
Indian Association for the Cultivation of Science	Biodegradable polymers	TRL(2-3)	Food Packaging	(NITI Aayog, 2022)
	Synthetic polyesters	TRL(2-3)	Agriculture	(NITI Aayog, 2022)
	Foldable polyurethanes	TRL(2-3)	Medical sciences	(NITI Aayog, 2022)
Indian CSIR-Central Salt and Marine Research Institute	Biodegradable films from seaweed	TRL-4	Food Packaging	(NITI Aayog, 2022)
Indian Institute of Food Processing Technology	Biodegradable products using mango seed shells	TRL-4	Food Packaging	(Muthu, 2019).
University of Calcutta	Biopolymer from recycled plastic waste	TRL-3	Medical sciences	(Sarkar et al., 2014).
	Biopolymers from PET waste	TRL-4	Medical sciences	(Ghosal et al., 2020)
ICAR – Centre Institute for Research on Cotton Technology	Biopolymers from recycled plastic waste	TRL-3	Medical sciences	(Bagde & Nadanathangam, 2019)
Tezpur University	Biodegradable films from pumpkin seeds and peels	TRL-5	Food Packaging	(Lalnunthari et al., 2019)
Anna University	PU from Mahua oil	TRL-3	Food Packaging	(K., Indumathi, & Rajarajeswari, 2019)
National Institute of Ocean Technology	Biopolymer using seaweed	TRL-5	Food Packaging	(NITI Aayog, 2022)
IIT Guwahati (CoE SusPol)	PLA, PHB, PCL and its copolymer	TRL (4-6)	Food Packaging	(NITI Aayog, 2022)

Source: Compiled by authors from different sources

analysis and visualization. It may build maps of keywords based on co-occurrence networks or maps of publications, authors, or journals based on co-citation networks (Selvavinayagam, 2018)

Step 3: Collect the Data for bibliometric analysis: To conduct a scientometric analysis, we have extracted peer-reviewed journals from the 'Web of Science' database (https://www.webofscience.com) retrieved on June 28, 2022. This database has the most extensive abstract and citation index, including an enormous range of subjects and peer-reviewed journals. The quality of the database is maintained through specific criteria that should be included in the journals.

The search criteria were based on strings appearing in Title/Abstract/Keywords. The major keywords used for the search were: TS= ((bioplastic) OR (bio-plastic) OR (biodegradable plastic) OR (bio-degradable plastic) OR (biobased biodegradable plastic) OR (bio-based biodegradable plastic) OR (bio-based bio-degradable plastic) OR (biopolymer) OR (sustainable food packaging) AND (food packaging)) to generate sufficient Data on Global South concerning India. From these criteria, a total of 5967 articles were received. Our search criteria were limited to the English language only.

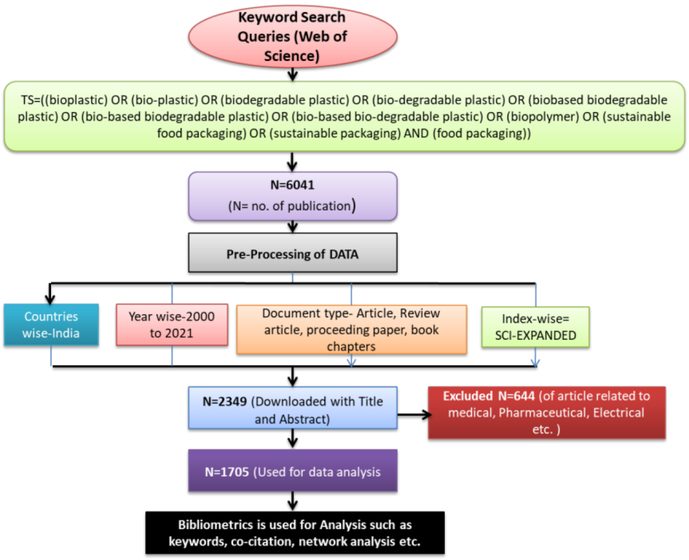


Figure 2: Schematic representation of research strategy (Source: Created by Author).

The further filtering of Data was done countries-wise (India), period-wise (2000-2021), document type-wise (article, review article, proceeding papers and book chapters), and data index-wise (SCI-expanded only). Since the data before 2001 were negligible in number, they were excluded from the analysis. After applying these filters, we received the total number of publications 2349 and downloaded them for analysis. Further scrutiny of Data was done by reading the title and abstract to access the document's relevance; whenever necessary, a full text was also examined to determine whether the article is related to bioplastic research in food packaging. In this process, some articles (N=644) related to pharmaceutical, electrical and biomedical fields were excluded. The remaining (N=1705) articles were used to conduct the bibliometric analysis for the study.

Step 4: Run the bibliometric analysis and report the findings- the analysis details are reported in the following sections.

Key features of Data and Analyses:

The vital information on bioplastic research in India is presented in Table 2. A total of 1705 articles from 'Web of Science' published in 546 sources by 4699 authors were used for further analysis. The annual growth of publication by year was 8.49%, and the average citation per document was 31.29, with a complete citation of 80296 for the 1705 publications. There were 4699 multi-authored, and only 24 were single-authored documents. While single-authored documents numbered 24, the number of co-authors per document number was 4.26, and the percentages of collaboration with international co-authorship were 26.1. These trends indicate that research on bioplastics in India has a rich collaboration network. The types of documents used for bibliometrics analysis included articles (1399), proceeding papers (30), reviews (275) and Book Chapters (1).

Table 2: **Key information on Indian bioplastic research from 2000 to 2021.**

Description	Results
MAIN INFORMATION ABOUT THE DATA	
Timespan	2000-2021
Sources	546
Documents	1705
Annual Growth Rate %	8.49
Average citations per doc	31.29
References	80296
DOCUMENT CONTENTS	
Keywords Plus	4522
Author's Keywords	4314
AUTHORS	
Authors	4699
Authors of single-authored docs	23
AUTHORS COLLABORATION	
Single-authored docs	24
Co-Authors per Doc	4.24
International co-authorships %	26.1
DOCUMENT TYPES	
Article	1399
Proceedings paper	30
Review	275
Book chapter	1

Publication Trends

The most often employed scientometric indicators in evaluating research are the number of publications, citations, and the *h*-index (Hostiuc & Negoi, 2016). Publication output shows how a study topic progresses (Guo *et al*., 2019), and the citations show the prominence (Hostiuc & Negoi, 2016), scientific influence, and relevance of the publication, author, institution, and nation of the study being evaluated. Citations track where other researchers are concentrating their attention (Johnston, Piatti, & Torgler, 2013), and when used properly, they can assist in giving an objective assessment of the research. A researcher's prominence and overall contributions to research are gauged by the h-index (Hirsch, 2005). If the h-index of a scientist's Np publications have at least h citations each and the remaining (Np-h) papers have h citations each, then the scientist has an index of h (Hirsch, 2005). A researcher with an *h*-index of 10 has produced ten or more publications, and at least ten of those articles have received at least ten citations. A higher *h*-index means a researcher is "more visible" (Masic & Begic, 2016).

The year-wise production of research articles and citations from 2000-2021 is shown in Figure 3. Significant growth in the

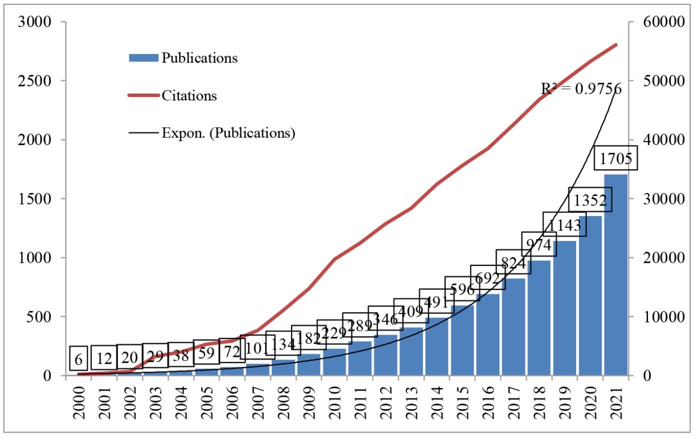


Figure 3: Publication and Citation trends output for the period 2000-2021

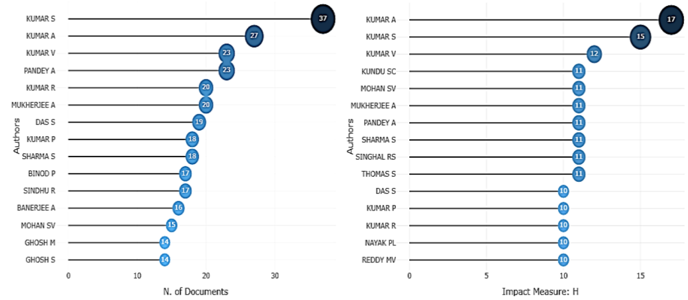
publication can be observed from 2010 onwards, and since 2016, the growth of publication has been robust in bioplastic research. The total number of citations per year has increased constantly over time which is represented by a red line in Figure 3.

There is no significant variation observed in the citation pattern over the year, and it has been growing steadily since 2000. More than 50 % of publications were produced after 2010 in the field of biopolymers related to the food packaging sector. Figure 3 shows the positive growth of bioplastic research in the Indian food packaging sector in recent times and the maturity level of the research field.

Significant Authors and Institutions

The analysis has shown that 4708 authors have produced 1705 documents in the field of bioplastic with their application in the food packaging sector in India. It depicted that 2.8 authors per document are contributing. From the dataset, Kumar A has the highest *h*-index (17) with 27 publications and 719 citations. Figure 4 (a) shows the top 12 single authors' contributions in the field of bioplastic research. These authors are Kumar S (N=37), Kumar A (N=27), Kumar V (N=23), Pandey A (N=22) and Kumar R (N=20). They have contributed the highest number of publications among 4708 authors with a share of (2.1%), (1.6%), (1.4%), (1.3%) and (1.3%), respectively, of a total of 1705 publications. Interestingly, the authors' *h*-index shows the cumulative impact of an author's scholarly output and performance. In contrast, Kumar A (h=17), Kumar S (h=15), Kumar V. (h=12), Kundu SC (h=11), Mohan SV (h=11) and Mukherjee A (h=11) has higher citations per publication compared to the top 12 single authors contribution in the bioplastic research in Figure 4(b).

Figure 5 shows the productivity of authors between 2000 to 2021, when they started research in the field of bioplastic, and where it is going. Only four authors, namely Kumar, A., Kumar R., Banerjee, A. and Ghosh, S., started contributing to the field of bioplastic output before 2005. They have sustained a more extended period; however, their contribution is less than the authors who started



4 (a) 4 (b)

Figure 4: Top 12 single authors with their contribution (a) and impact measure by *h*-index (b).

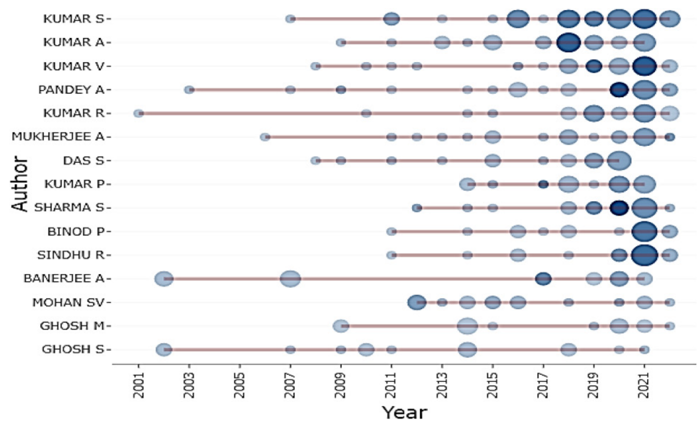


Figure 5: Productivity of authors over time.

later. Much of the research on bioplastics is concentrated in the last five years, from 2017-2021, representing almost 60% of all publications, which indicates that research on bioplastics is evolving. The size of the circle shows the contribution and impact of their research in the field of bioplastics. The remaining authors started their research after 2005, and their impact on the research is significant, as shown in Figure 5.

Hot Research Areas and Highly Cited Papers

The major area of research in bioplastics is confined to Chemistry (N=503), Polymer science (N=470), Engineering (N=322), Material Science (N=310), Biotechnology Applied and Microbiology (N=232). It indicates that bioplastic research by the Indian scientific community is coming significantly from the contribution of researchers in chemistry and polymer science. Table (5) shows the top 13 highly cited papers from 2000-2021, and these top 13 most cited articles contribute 24.36% of total citations from the whole database for the study period. Only two articles published after 2010 were in the list of 13 highly cited papers. The highly cited paper list is dominated by articles published in 2003-2010. It could be happened because of increased research in the field of bioplastics.

Table 5: Most Cited Papers (2000-2021).

Publications	Authors	Year	Citations
An overview of the recent developments in polylactide (PLA) research.	Nampoothiri, KM; Nair, NR; John, RP	2010	1665
Hierarchically porous carbon derived from polymers and biomass: effect of interconnected pores on energy applications.	Dutta, S; Bhaumik, A; Wu, KCW	2014	1041
Pretreatments of Natural Fibers and their Application as Reinforcing Material in Polymer Composites-A Review.	Kalia, S; Kaith, BS; Kaur, I	2009	889
Photochemical Green Synthesis of Calcium-Alginate-Stabilized Ag and Au Nanoparticles and Their Catalytic Application to 4-Nitrophenol Reduction.	Saha, S; Pal, A; Kundu, S; Basu, S; Pal, T	2010	819
Biodegradable films and composite coatings: past, present and future.	Tharanathan, RN	2003	806
Chitosan modifications and applications: Opportunities galore.	Mourya, VK; Inamdar, NN	2008	746
Polyhydroxyalkanoates: An overview.	Reddy, CSK; Ghai, R; Rashmi; Kalia, VC	2003	744
Mechanistic implications of plastic degradation.	Singh, B; Sharma, N	2008	666
Chitin - The undisputed biomolecule of great potential.	Tharanathan, RN; Kittur, FS	2003	654
Polyethene and biodegradable mulches for agricultural applications: a review.	Kasirajan, S; Ngouajio, M	2012	592
Recent advances in microbial polyhydroxyalkanoates.	Khanna, S; Srivastava, AK	2005	506
Thermolysis of waste plastics to liquid fuel A suitable method for plastic waste management and manufacture of value-added products-A world perspective.	Panda, AK; Singh, RK; Mishra, DK	2010	446

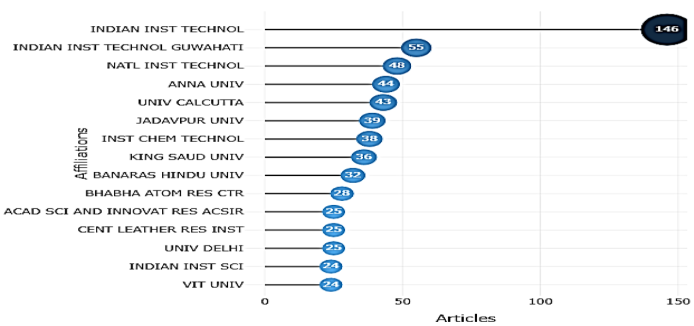


Figure 6: Top 15 most relevant institutions.

From the analysis of 1393 institutional affiliations doing research on bioplastics in India, universities were found to be the most productive, followed by government R&D institutions such as the Council of Scientific and Industrial Research (CSIR). The 15 most productive institutions are given in Figure 6.

Using the Bibliometrix package and biblioshiny, a thematic diagram was constructed to illustrate the four quadrants of the research structure relating to bioplastics. The thematic map helps to analyse topic profiling, considering the tremendous publication growth over the last five years. The leading thematic clusters are presented in Figure 7. The most central and prominent theme is the motor theme that reflects food packaging, nanoparticles and gelatine. The themes are well-developed (high density) and have high strength (degree of centrality).

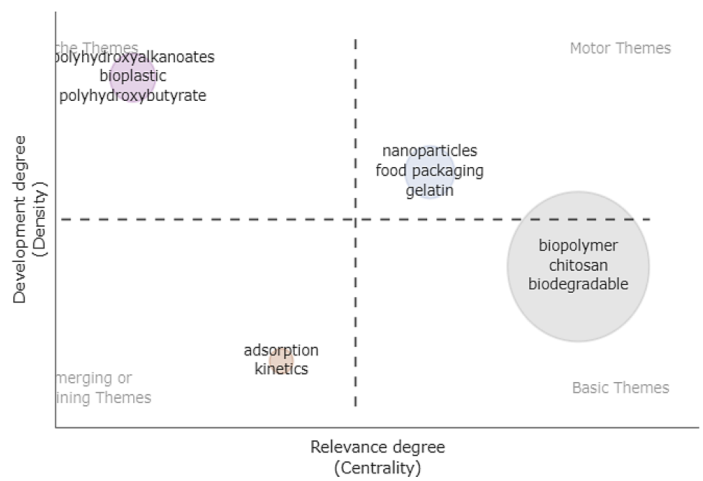


Figure 7: Thematic areas (Number of 1000 words).

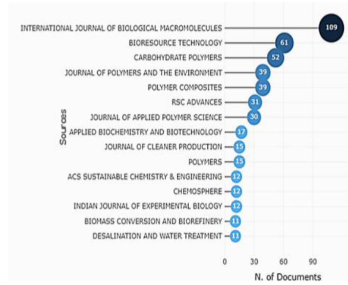
Relevant journals in bioplastic research in India

In bibliometric analysis, subject categories and journal articles explain how research breadth varies for various topics(Leydesdorff & Rafols, 2009) . A total of 547 journals published the 1705 documents analysed in this study. Figure 8(a) shows the top 15 productive journals accounting for 28% of total publications by the Indian research community in bioplastic research related to food packaging. The most influential journals related to the topic are the *International Journal of Biological Macromolecules*

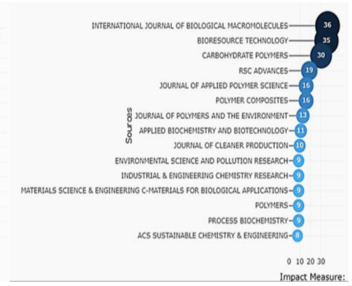
(N=109), *Bioresource Technology* (N=61), *Carbohydrate Polymers* (N=52), *Journal of Polymers and The Environment* (N=39) and *Polymer Composites* (N=39). These top 5 journals have received the maximum publication share with a high *h*-index since 2000. The *International Journal of Biological Macromolecules* deals with all-natural macromolecules and their molecular structure related to chemical and biological activities; therefore, it has received more number of publications than any other journal. *Carbohydrate Polymers* is the second important journal covering the areas such as bioenergy, bioplastics, biomaterial, biorefining, food, health, nanotechnology and packaging materials.

The *h*-index value is the number of papers (*h*) published in a journal that has been cited at least h times. Figure 8(b) shows the same thing; for example, the *h*-index of the *International Journal of Biological Macromolecules* is 36, meaning the journal has published 36 publications that have been cited at least 36 times. The *h*-index of journals like *Bioresource Technology* (35), *Carbohydrate Polymers* (30) and *RSC Advances* (19) have the highest in the top 15 journal list, and these are the most productive and impactful journals in the field of bioplastic research.

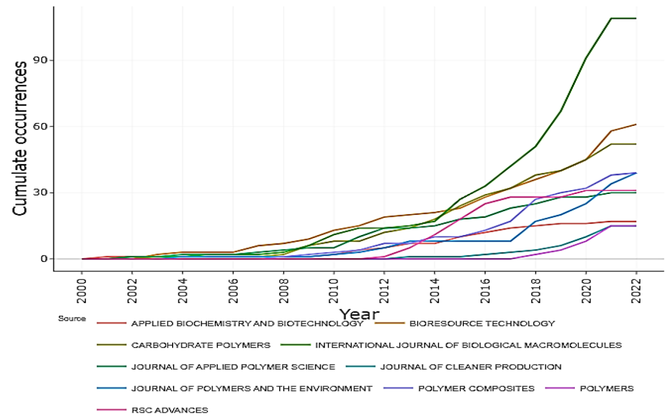
The cumulative journal occurrence shows the journal occurrence in a specified period of 2001-2021 in Figure 8(c). Figure 8(c) shows constant cumulative growth among the top 10 journals, though the *International Journal of Biological Macromolecules* has grown exponentially from 2014 onwards. Because of increased bioplastic research in the Indian community at the fundamental molecular level, the journal received the highest publication in a given time. This shows that the Indian research community is more interested in basic bioplastics research than the application part of the research.



8(a)



8(b)



8 (c)

Figure 8: (a) Top 15 journals with number of publications, (b) Top 15 journals with Impact measure, (c) Top 10 Journals Cumulative Occurrence.

Co-occurrence of authors' keywords

Co-occurrence analysis may be used to pinpoint current issues and directions so that researchers can track the development of scientific programmes and research (Gao *et al*., 2017). These keywords represent the academic community's concentration on the topic during the past two decades, and different researchers have used them to determine the best course of study in a particular area (Simões *et al*., 2021). The number of times the labels' size and circles show keywords is given in Figure 12. A link made up of lines connects keywords that have appeared together.

The cumulative strength of a keyword's linkages with other keywords is the link strength of the keyword co-occurrence (van Eck & Waltman, 2013). The terms with lower total link strength values have a more significant chance of appearing together than those with greater total link strength values. The distance between two keywords represents the topic's similarity and relative strengths (Guo *et al*., 2019). The co-occurrence of the author's keywords was examined using a *VOS viewer*, as seen in Figures 12 and 13. The magnitude of a term reflects how

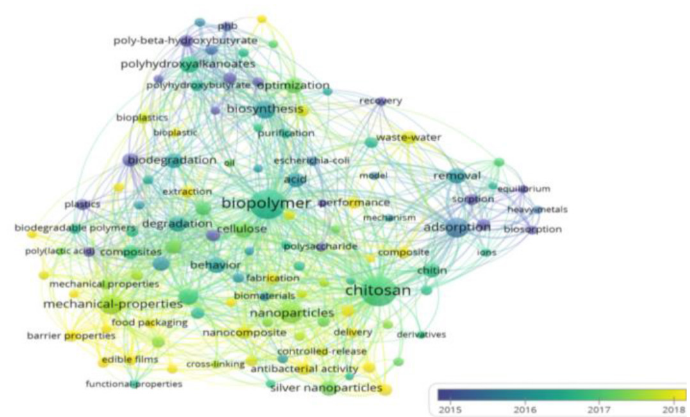


Figure 12: Keyword Co-occurrence with more than 20 times.

many publications it appears in, while the distance between two keywords approximates their relationship. The comprehensive counting approach identified 586 terms. Only 129 keywords match the criterion since a keyword must appear five times. The temporal changes in keyword frequencies also highlight the importance of different aspects of bioplastics research in India.

The keywords used from 2015 to 2016 were 'biopolymer', Polyhydroxy butyrate', and 'Polylactic acid', in blue. From 2017 onwards, emerging keywords in the research areas were 'bio plastics', 'food packaging', 'biodegradation' and others that can

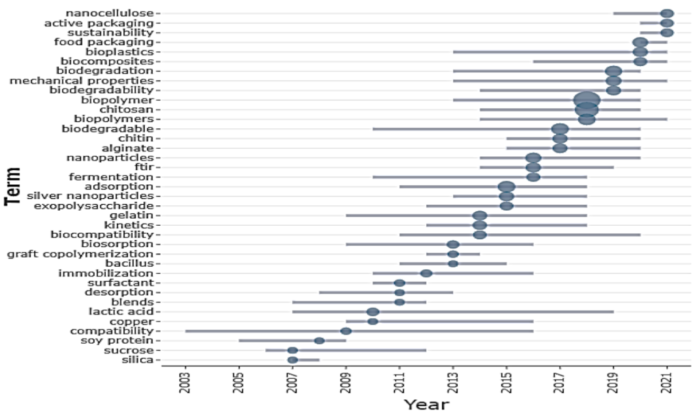


Figure 13: Topic based on author keywords.

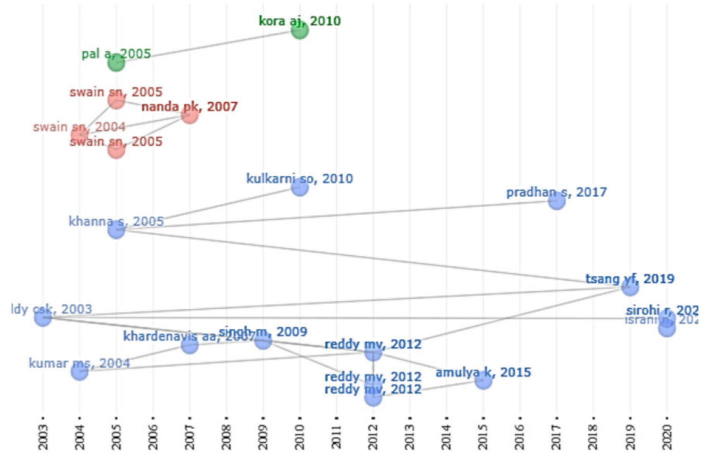


Figure 14: Co-citation network and linkages based on the author's first author-name.

be seen in yellow (Figure 12). Figure 13 shows the evolution of authors' keywords in the research field of bioplastic in India since 2001. Before 2015, bioplastic research was focused on the molecular level structure to develop biobased products, and bioplastic research has used keywords such as 'biodegradable', 'biopolymers', 'mechanical properties, and 'biodegradability' since 2016. From 2019 onwards, the authors' keywords are 'bioplastic', 'antimicrobial activities', 'nanocellulose', 'food packaging', 'active packaging' and 'sustainability'. These emerging keywords illustrate that bioplastic research in India has matured and is moving towards sustainable polymers for the food packaging industry.

Co-citation analysis

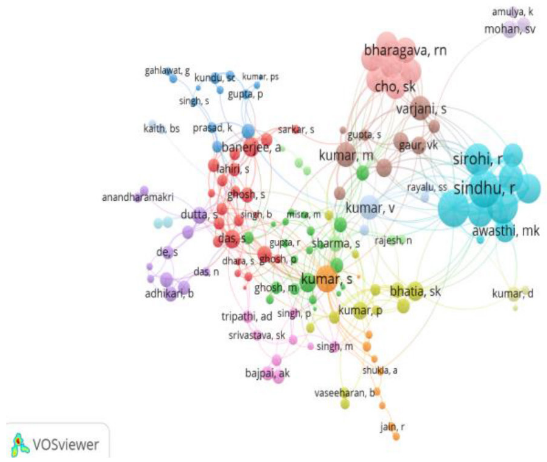
Based on how frequently two items are cited together, Co-citation analysis is intended to establish the link between them. Co-citation analysis offers big data on a subject in a particular field of study from the most cited sources, authors, and references, which may help assess the most influential publications on a particular subject (Mao, Chen, Wang, Hou, & Xiang, 2020). For this study, the co-citation of the cited authors has been conducted using *biblioshiny* from 2000 to 2021, depicted in figure (14).

From this figure (14), we can see the emergence of three significant and prominent co-citation clusters between 2000 and 2021. The first cluster of co-citation of authors was limited to the period between 2004 and 2007, presented in red. The second cluster emerged between 2005 and 2010. The third cluster developed between 2010 and 2021, the most significant cluster with 14 authors. The emergence of these clusters shows the shifting focus of research from basic to application dimensions of bioplastics.

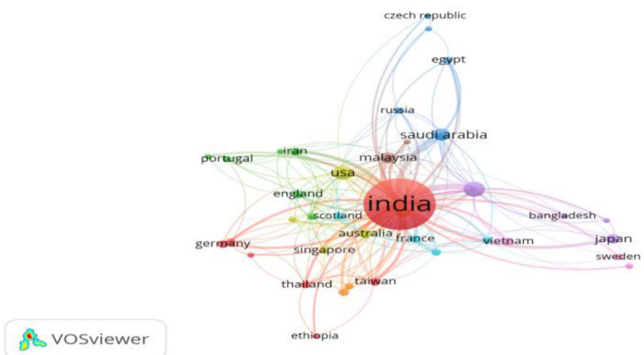
Collaborating Network Analysis

Collaboration network analysis may provide valuable information for individuals, institutions, and countries looking for partners or organizations to collaborate to advance their field of study and achieve the goal of scientific cooperation (Mao *et al.*, 2020). This study shows the practices of scholarly exchanges at multiple levels among authors, institutions and countries (Han *et al.*, 2014). In this study, the complete counting approach in VOSviewer was used to analyse the co-authorship of authors and countries. For analysing authors' collaboration network, a minimum document number per author was fixed with at least five publications, and 144 authors were observed. The total strength of the co-authorship ties for the 144 authors was computed. From 144 authors in the networks, 10 clusters of authors were identified. We observed that only two clusters have the most substantial connection based on the total link strength. These authors are: Sirohi, R., Sindhu, R., Awasthi, M K., and Bhargava, RN., Cho, SK. They are well connected among themselves and with others too. The relationship among 10 clusters are shown in the figure 15 (a).

For the co-authorship analysis of countries, 71 countries are collaborating with India, with the maximum number of countries per document being 25. When we reduced the minimum of five documents in a country and citations per document to zero, only 38 countries had more than five co-authored publications with Indian authors. The authors from 38 countries collaborating with Indian authors were grouped into eight clusters; the largest cluster comprised seven authors, and the smallest was two. The grouping of clusters is based on each country's shared co-occurrence rate. The authors categorized into the same coloured cluster in Figure 15(b) suggests they are highly related. As the size of a country's circle increases with the increasing number of research articles, the connecting lines become thicker as the scale of collaboration among authors increases (Deng, Wang, Chen, & Wang, 2020). The strength of the link between two objects, which connects them, represents how cooperative they are with one another. The above figures show that India and Thailand have the highest link strength (16) among all the countries. The next collaborating link strength was found with Saudi Arabia (13) and the USA (11). This analysis shows that India is emerging as one of the research hubs in the bioplastic fields.



(a)



(b)

Figure 15: (a) Collaboration network analysis of authors in bioplastic research in India between 2000 and 2021. (b) Collaboration network analysis of countries in bioplastic research in India between 2000 to 2021.

CONCLUSION

Growing concern about environmental sustainability and protecting marine and animal life has resulted in implementation of policies restricting the production and use of plastics and promoting research on bioplastics or biodegradable plastics. This study provides an extensive scientific mapping of Indian research on bioplastic as a sustainable material, particularly in the food packaging sector from 2000-2021. The study is based on 1705 research articles from the *Web of Science*, written by 4699 authors. An in-depth analysis indicates that research on bioplastics had witnessed steady growth since 2017 when the number of publications and research impact (Figure 3) have increased substantially . The Indian Institute of Technology cluster is the most influential institution in R&D, and IIT Guwahati is emerging as one of the most significant contributors to bioplastic research. The authors' keyword occurrence and 'co-word analysis' show that sustainability, bioplastic, biodegradation, active packaging, nanocellulose, antimicrobial activity, and food packaging are emerging issues in bioplastic research in India. The emerging new keywords are a good sign of transitioning plastic food packaging to more sustainable plastic packaging and align with the goal of sustainable development. The collaboration network of Indian authors with other countries is 71, including India. There are 36 countries with more than five co-authored publications with Indian authors. This study shows that bioplastic is emerging as a sustainable material in the food packaging sector in India and suggests that more research should be focused on the application part of bioplastic in the food packaging sector. The study also indicates that there is very little research on the socio-economic dimension of bioplastics and its application in the food packaging sector. The study may be helpful to academicians, entrepreneurs, and policymakers interested in finding the emerging areas of research in bioplastics, its sustainability and the safe and hygienic use food packaging sector.

LIMITATIONS

This study is focused on bioplastic research in India related to the food packaging sector. Our bibliometric analysis is based on the articles published in journals included in the 'Web of Science' between 2000-2021 and hence a possibility of overlooking some important articles published outside the web of science journals. The study is limited to only visualizing the research trends and did not focus on analysing every article to demonstrate the paper's scientific quality. Since the analysis is solely focused on the research publications of researchers in India, it may not indicate the global research productivity in bioplastics.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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