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Research Article

CiteSpace Visualisation and Analysis of Research Trends and Hotspots in Degradable Plastics

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Abstract

Degradable plastics refer to adding some additives to promote their degradation or using renewable natural substances as raw materials; their light quality, good comprehensive performance, easy processing, and many other advantages have been favoured by society. Through the research method of bibliolatry, retrieval in 2013-2023 Web of Science database about biodegradable plastics research related literature information, using CiteSpace measurement analysis software visual analysis in the relevant literature keywords, publications, high cited frequency, cooperation and common word clustering information change trend, analyze the research situation in the field of biodegradable plastics in recent years, summarizes the biodegradable plastic research status, progress and research hotspot. The results of the analysis show that degradable plastic materials are an emerging research field, and the number of publications has increased rapidly since 2020. The 2019-2022 accounted for about 81% of the total in the research period. Most related studies are published in ACS NANO, ADVANCED FUNCTIONAL MATERIALS, NANOSCALE, and other journals, and they have high academic research value. The hot research field of degradable plastics focuses on polylactic acid materials and their mechanical properties. Various research hotspots are very closely related, with strong correlation and complementarity.

Keywords

Biodegradation, Degradable Plastics, CiteSpace, Visualisation Analysis

1. Introduction

Plastic is one of the most important chemical products, which provides unprecedented convenience for human beings and has been widely used in many fields. However, when plastic products are discarded after completing their mission, they are difficult to degrade, thus forming "white pollution" and causing serious harm to the ecological environment, and all countries have introduced strict bans on plastics [1]. Compared with ordinary plastics, the degradation process of degradable plastics is more rapid, and the natural environment can be harmonious symbiosis, thus solving the problem of "white pollution" from the source, which is receiving wide-spread attention. In recent years, with the introduction of a

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series of new green policies, such as the plastic restriction order, waste classification and treatment, and the promotion of the use of biodegradable plastic products, the demand for biodegradable plastics is gradually accelerating, and biodegradable plastics may become a new blue ocean. [2]

Degradable plastics are a new composite polymer material with the same kind of ordinary plastics equivalent or similar application performance and health performance. After completing its function of use, it can be degraded faster under natural environmental conditions, become fragments or fragments that can be easily used by the environment, and finally return to nature. The substances produced in the degradation process and remaining after degradation are harmless or potentially harmful to the environment. It has good physical properties, such as strength, hardness, flexibility, and transparency, and at the same time, it is superior to traditional plastics in terms of thermal stability. [3] Biodegradable plastics can degrade naturally in the earth, usually between a few months and a year. The decomposition time in different media (e.g. rivers, soil, oceans) may vary slightly, but all can degrade and decompose in a relatively short period. The degradation process usually occurs through microorganisms or natural oxidation. Microorganisms first break down degradable plastics into smaller fragments, then convert them into small molecules such as water and carbon dioxide through chemical reactions and physical processes, eventually degrading completely into natural environmental substances. It uses raw materials derived from natural organic materials, which usually have minimal toxicity to the environment and organisms and will not pollute or damage groundwater and biological resources. [4]

Polylactic Acid (PLA) is a common biodegradable plastic made from glucose produced by photosynthesis of various natural plants and processed through fermentation and polymerisation. PLA can degrade quickly in the environment without polluting the environment and is now used in food packaging, medical devices and 3D printing. The physical properties of PLA differ from traditional petrochemical plastics in that it has high transparency and good flexibility. [5] As a biodegradable plastic, PLA is biodegradable in its natural environment and can be decomposed by microorganisms into natural elements such as carbon dioxide and water, so using PLA can make our environment cleaner. PLA has a wide range of applications, most commonly for food packaging. [6]

2. Data Sources and Methods of Research and Analysis

2.1. Data Sources

The data in this paper are based on the Web of Science (WOS) Core Collection database, and the search time is set from 1 January 2013 to 1 January 2023. the search formula is "Biodegradable plastics", and 357 related documents were retrieved. A total of 357 articles were searched and exported in plain text format with the content of "full record and cited references" and analysed as samples.

2.2. Methods of Research and Analysis

After importing the data into CreateSpace, using "Remove Duplicates" to carry out literature de-duplication analysis, we can get 357 independent literature from WOS, of which the statistics of independent entities (Unique Entities) are shown in Table 1. Then, using the obtained data, the annual volume of publications was calculated using Excel for the histogram (Table 1 statistics of independent entities and the number of). The analyses of the number of publications by authors, author collaborations, etc., are based on all authors listed in the paper, i. e., all authors in the same paper are included in the analyses. Country, region and institution attributions are counted according to all locations labelled in the paper. Visual analyses were performed using CiteSpace 6.2. R3 (64-bit) Basic version. The attributions were visualised by "Author", "Institution", "Country", "Keyword Author", "Institution", "Country", "Keyword", "Cited Author", and "Cited Journal" nodes are used for visual analysis of authors, institutions, countries, keywords, author co-citations, and journal co-citations.

Table 1. *Independent entities and number of statistics.*

Category	Quantities
Articles	357
Journals	187
Authors	1498
Institutions	870
Countries/Regions	106

3. CiteSpace-Based Visualisation and Analysis of Biodegradable Plastics Literature Researchand

3.1. Number of Publications

Statistics on the annual publication volume of the research on plastics in degradation in the Web of Science Core Collection database from 2013 to 2023 (Figure 1), the publication volume of the WOS database during 2015-2019 is slowly increasing, and the research on degradable plastics is in the preliminary development stage; the publication volume of articles related to degradable plastics during 2020-2023 is increasing sharply, indicating that the research During the period of 2020-2023, the number of articles related to degradable plastics increased sharply, indicating that the research enthusiasm continues to rise. The excellent performance of degradable plastics has been explored. Among them, the growth rate of articles published from 2019 to 2022 is 120%. The research belongs to the stage of rapid development, in which the largest number of related articles was published in 2021, indicating that the research theories on degradable plastics have been underway in the past two years. The research fever continues to be high.

3.2. Institutional and National Communications

An analysis of the authors' affiliation with the published articles through CiteSpace software reveals that the authors of the published articles were distributed among 870 institutions from 2013 to 2023. The top 10 organisations in terms of number of publications are shown in Table 2, with the CSIR Council of Scientific Industrial Research, India, having the highest total number of publications.

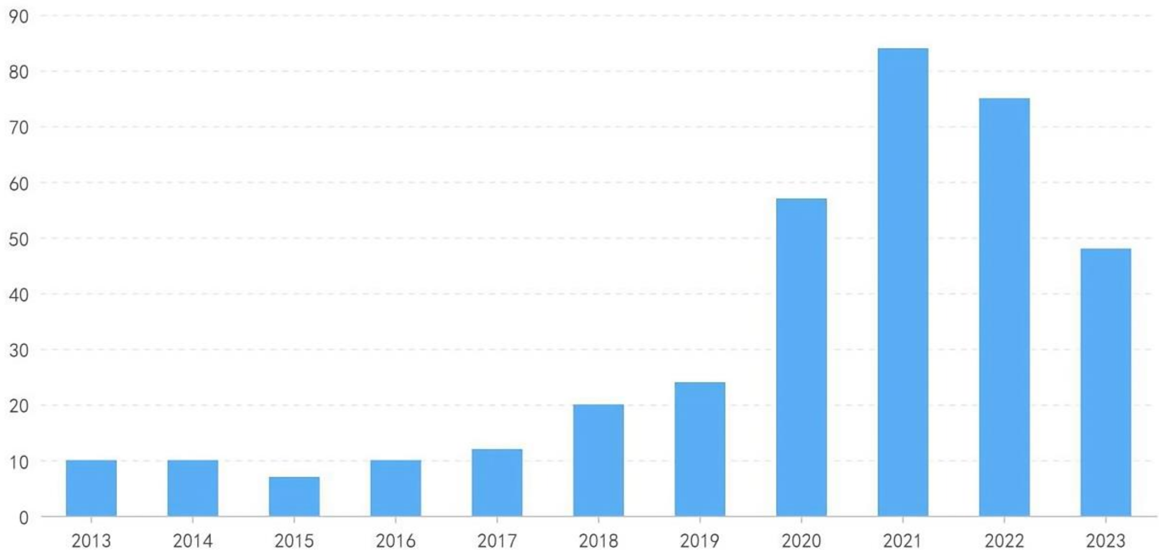

Figure 1. *Degradable Plastics Related Research Literature Annual Publications 2013-2023.*

Table 2. *Top 10 institutions in terms of publications.*

Rankings	Mechanism	Quantities	Percentage/(%)
1	Council of scientific industrial research csir India	10	2.80
2	Centre national de la recherche scientifique cnrs	8	2.48
3	Indian institute of technology system iit system	7	1.96
4	National institute of technology nit system	6	1.68
5	Universiti sains malaysia	6	1.40
6	Chinese academy of sciences	5	1.40
7	Egyptian knowledge bank ekb	5	1.40
8	Universiti putra malaysia	5	1.40
9	University of oueensland	5	1.40
10	Consiglio nazionale delle ricerche cnr	4	1.12

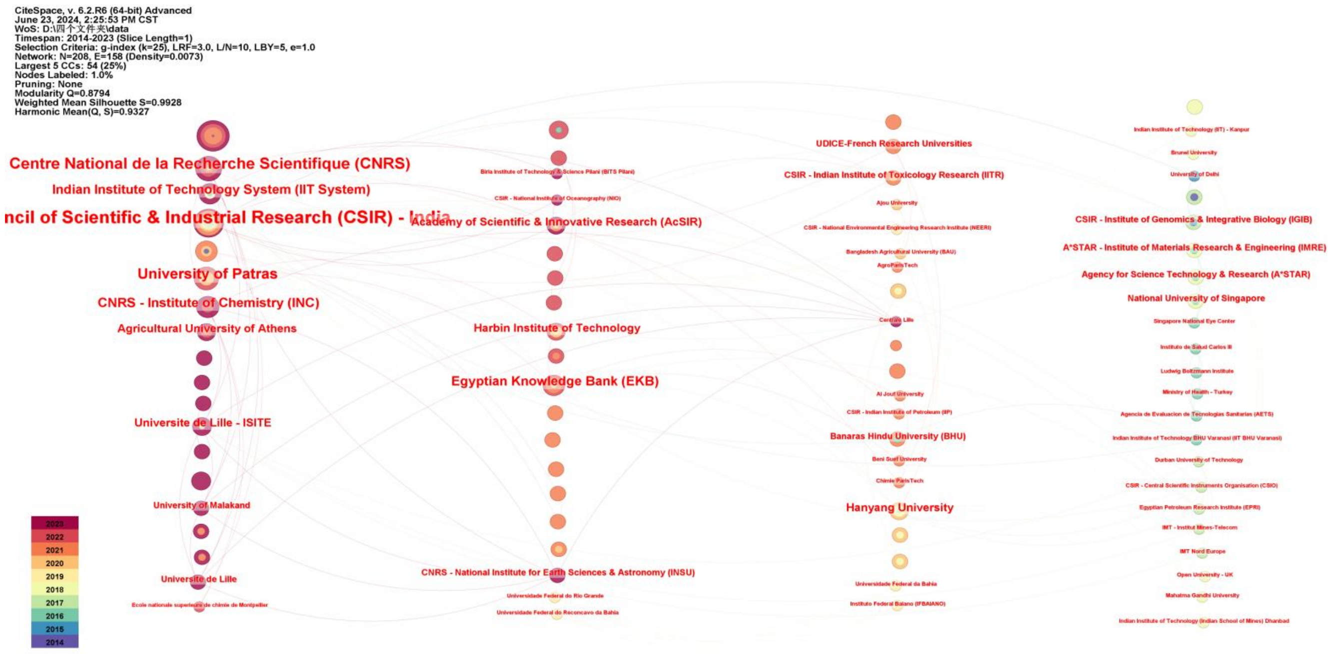

Figure 2. *Map of research organisations' partnerships.*

According to the statistics of CiteSpace, there are 13 countries/regions where the relevant articles belong, and the top 9 countries/regions in terms of the number of articles are shown in Table 3. The number of articles is relatively small, and a complete research system must exist. India has the most research publications on degradable plastics, accounting for 30%. Our country also accounts for as much as 24%, ranking second, which is related to a large number of colleges and, universities, scientific research institutions in China, as well as the number of scientific researchers engaged in the relevant direction, and at the same time, the overall number of research publications on degradable plastics is small, and the density of the connection of domestic institutions is lacking. Compared with the USA, ITALY, CANADA, JAPAN and BRAZIL, there is a certain gap in basic research and technology, but there has been greater development and more in-depth research. In the author collaboration graph (Figure 3), it can be seen that N=13 and E=7; on the other hand, observing from the centrality degree, the nodes with centrality value greater than or equal to 0.1 are regarded as critical nodes, which are usually regarded as important factors that lead to changes in the research field. Moreover, the centrality is much larger than the centrality of the research institutions' partnership, indicating that the research links between countries/regions on degradable plastics are becoming closer than the links between institutions.

Table 3. *Top 10 countries/areas in terms of publications.*

Rankings	Countries	Quantities	Percentage/(%)
1	INDIA	49	0.29
2	PEOPLES R CHINA	40	0.24
3	USA	14	0.08
4	ITALY	13	0.07
5	CANADA	13	0.07
6	JAPAN	8	0.05
7	BRAZIL	8	0.05
8	SOUTH KOREA	8	0.05
9	ENGLAND	3	0.02

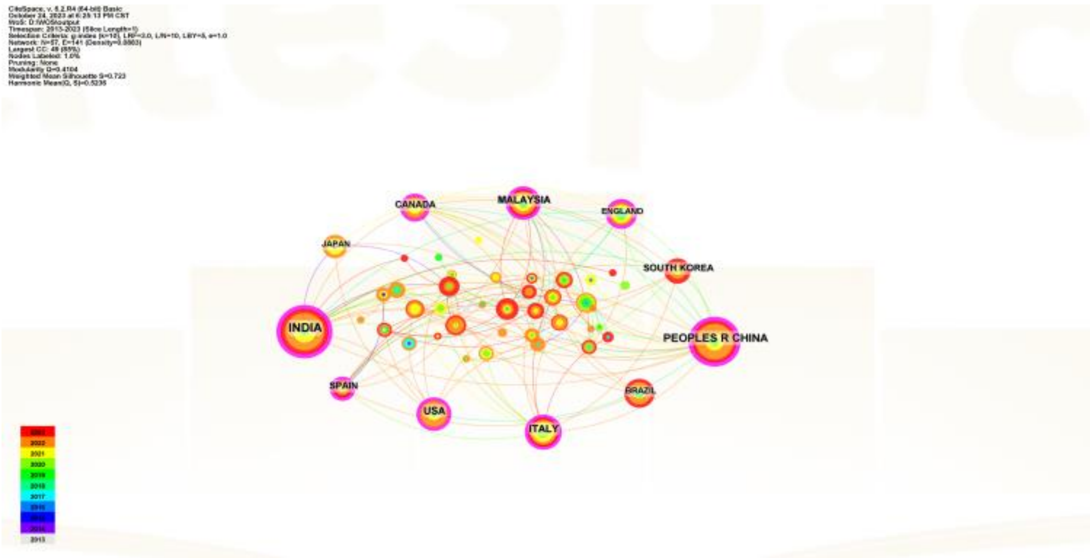

Figure 3. *Chart of national/regional co-operation.*

3.3. Analysis of Authors in the Field of Study

The node sizes in Figure 4 represent the number of papers published by the authors, and the connecting lines represent the mutual collaborative relationships. By analysing the statistics of the authors of the papers issued in the field, it is possible to get a picture of the connections between the contributors and authors who have made a large contribution to the field. The data shows that the authors of publications in this field form a collaborative network from 2013 to 2023, and the data shows that the authors of publications in this field form a collaborative network of 182 nodes and 237 connecting lines, with a density Density of 0.0144. The size of the nodes is proportional to the number of publications in Figure 4, and the overall sizes are similar. The connecting lines between the nodes represent the collaboration between the authors, and the thickness of the lines is positively correlated with the Degree of collaboration. The Degree is positively correlated. This indicates that 182 authors have published papers in this research area in the past ten years. However, the cooperation cooperation between authors is more dispersed, and they are in a more independent research status. The overall number of papers published is relatively even; we are still in the primary research stage. The cooperation in the field is relatively close, and the research power in this field is relatively concentrated. The connection between scholars needs to be strengthened, which is of great significance to the in-depth exploration of this field.

Figure 4. *Author collaboration chart.*

3.4. Keyword Cluster Analysis

Keywords are highly condensed points of an article which fundamentally reflect the article's main content. The higher frequency of keywords means they occupy a higher position in this research. Based on the CiteSpace software, the keywords in the study of "Biodegradable plastics" were analysed visually, and there were 223 keywords in total, of which 67 keywords appeared more than 20 times. As shown in Figure 5, the keywords were divided into six clusters, and the correlation between the same clusters was large.

To begin with, L. Egghe proposed the g-index as an improvement of the H-index, indicating the performance of authors' popular articles, etc. The g-index is very sensitive to citation frequency. In the cluster analysis of keywords and timeline mapping analysis, changing the g-index in the Selection Criteria from 25 to 15 takes care of the low-cited articles while controlling the role of high-cited articles.

The core and salient contents emphasised in the article can be obtained by studying the keywords. CiteSpace is an algorithm that clusters the closely related keywords, gives a value to each keyword, and the largest value in the same cluster represents the category and gives it a label. The clustering of keywords, as shown in Figure 5, is drawn using CiteSpace in the pathfinder clipping algorithm to simplify the keyword network and highlight its important structural features. The figure shows that the clustering structure of Q=0.506>0.4 is significant, and the clustering of S=0.8155>0.7 is highly efficient and convincing. From the analysis, it can be concluded that the keywords can be classified into six categories: polylactic acid, polyhydroxybutyrate, active packaging, plastic particles, mechanical properties, and environmental regulations. From this, it can be understood that research related to degradable plastics is more centred around biodegradable plastics and so on.

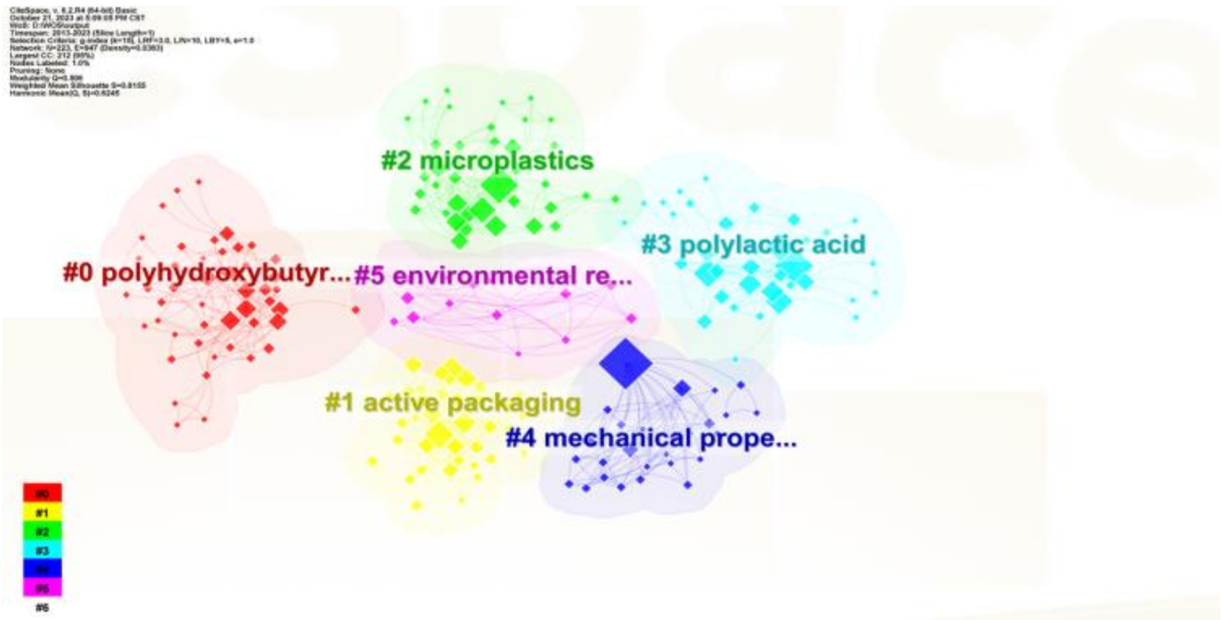

Figure 5. *Keyword cluster analysis chart.*

The keywords that appear more frequently in the first category of clusters are polylactic acid, polyhydroxybutyrate, microplastic, biodegradable plastics, degradable plastic, etc. This section is mainly about research on raw materials and mechanisms for degradable plastics. The research shows that polylactic acid (PLA) is one of the important components of eco-friendly polymers, which has the characteristics of easy moulding, high strength, high modulus and better biocompatibility and has been widely used in the fields of film, packaging field, biomedicine, fibre spinning, and 3D printing consumables. Li Guili, in the article Progress in toughening and modification of degradable plastic PLA blends proposed that blending with elastomers or flexible polymers is an effective way to toughen PLA. [7] PLA, as a continuous phase, keeps the mechanical strength of the blended material at a high level; flexible polymers or elastomers, as a dispersed phase, can initiate a large number of microcracks/silver lines when subjected to external forces, inhibit or slow down the rate of crack expansion, and have the role of toughening.[8] R. A. iiyas in the article "Natural Fiber-Reinforced R. A. iiyas in "Natural Fiber-Reinforced Polylactic Acid, Polylactic Acid Blends and Their Composites for Advanced Applications" suggests that PLA offers several advantages over other biopolymers, including being environmentally friendly, i. e., biodegradable, compostable and recyclable. Compostable and recyclable. [8] The production of PLA consumes carbon dioxide, which comes from renewable resources such as sugar cane, corn, potatoes, cassava, wheat and rice. Degradation of PLA occurs over months to years as lactic acid is hydrolysed to water, carbon monoxide and humus, which is metabolised by microorganisms. Urayama et al. found that the molecular weight of PLA sheets decreased by 20% after 20 months in soil. According to Teixeira et al., the degradation of PLA is affected not only by the characteristics of the sample, such as crystallinity, molecular weight, sample morphology and molecular structure but also by the surrounding environmental conditions. [9] In addition, PLA has a highly permeable surface. Therefore, natural microorganisms can easily enter and assist in the rapid decomposition of PLA. In addition, PLA can recycle back to lactic acid through hydrolysis or alcoholysis, thus making PLA an attractive biopolymer option.

The keywords that appear more frequently in the second category of clusters are mechanical behaviour, active packaging, aerogel, biodegradation, tensile strength, thickness, etc. This section focuses on the study of the properties of degradable plastics. One of the typical research hotspots is the study of mechanical properties of degradable plastics; Lin Xiaoyu, in the LDPE/algae powder degradable plastics preparation and its mechanical properties, biodegradation properties of the analysis of the paper, proposed to use algal powder as a filler and pure LDPE blended and modified, the modified LDPE/30% algal powder composites prepared with good mechanical properties and biodegradation effect. [10] The mechanical properties of LDPE/algae powder composites with different algal powder additions showed a decreasing trend in tensile strength and elongation at the break of LDPE/algae powder composites with increasing algal powder additions. With the increase of algal powder addition, the flexural modulus of LDPE/algal powder composites was generally on the rise. In contrast, the flexural strength showed a trend of rising and falling. When the additional amount of algal powder is 30%, the highest flexural strength is 8.34 MPa, which is 15.3% higher than that of pure LDPE material. Pure LDPE resin material has a large molecular weight, no polar groups in the molecular chain, and strong hydrophobicity. At the same time, algae powder contains many hydrophilic groups such as -OH, -C=O, -COOH, etc. Hence, the compatibility of LDPE resin and algae powder could be improved. When a large number of algae powder is added to the resin, the dispersibility of the alga powder in the resin decreases. The alga powder is aggregated due to the role of intermolecular hydrogen bonding, which reduces the stability of the composite material. The stability of the composite material is reduced. When an external force occurs, the fracture can easily occur at the algal powder aggregation, decreasing the tensile strength of LDPE/algal powder composites. [11] The flexural strength of the composite material appeared to rise first and then decline in the trend, which may be due to a small amount of algal powder added to improve the toughness of the LDPE resin material, increasing the flexural strength of the composite material, with the increasing amount of algal powder added, the material tensile strength and the elongation at fracture are reduced, so that the material breaks, so that the flexural strength of the composite material and then reduced. Among them, the best mechanical effect is obtained with 30% algal powder addition, and the bending strength has a high improvement compared with the pure LDPE group, which increases its toughness and can meet more applications in life. The modified LDPE/30% algae powder composites also performed well, with the highest degradation rate of 22.5% in the anaerobic experiment. Therefore, the modified LDPE/30% algae powder composites have potential market applications as biodegradable plastics compared to pure LDPE materials. [12]

3.5. Keywords Timeline Mapping

The study of timeline mapping can deduce the evolution of research in degradable plastics and predict future development trends. Moreover, by presenting clustering and keyword information in multiple dimensions, hotspots in the same year are arranged chronologically and assembled in a designated area, which helps researchers understand the temporal path of the evolution of important keywords. In the mapping, the circle indicates the keyword node, and the larger the circle, the higher the frequency of the corresponding topic. The colour and thickness of the node annual rings indicate the period of occurrence, i. e., the thicker the colour ring inside the circle, the higher the frequency of occurrence of the corresponding year of the colour. Figure 6 shows that polylactic acid, polyhydroxybutyrate, degradable plastic and so on have been studied in the past ten years, in which the keywords "biodegradable plastic", "biodegradable", and "biodegradable" are similar to other clusters. " and other keywords are closely related to the keywords in other clusters.

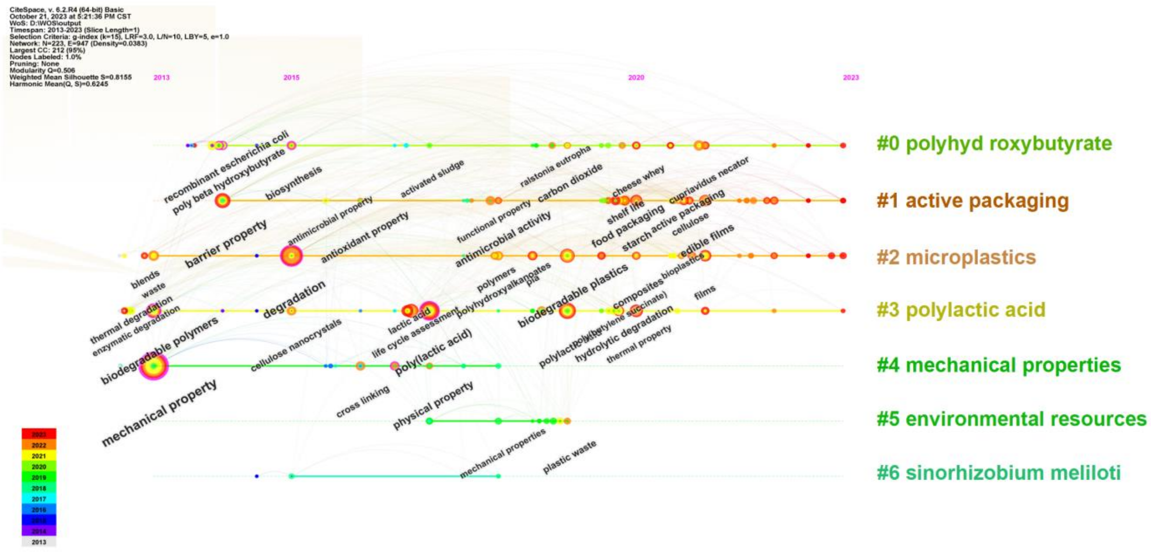

Figure 6. Keywords timeline spectrogram.

3.6. Keyword Highlighting Analysis

Through keyword burst analysis, we can get the frequency of the use of a word in a specific period within the statistical time, reflecting the research frontiers and the historical evolution of the development over time in that specific time. As shown in Table 4, Top 25 Keywords with the Strongest Citation Bursts, analysing the top 25 keywords with the strongest citation bursts reveals that Professor Wu Jianmin's work has the greatest citation intensity and lasts from 2018 to 2020 as a research frontier. Researchers choose feedstocks for biodegradable materials, which can come from plants, animals or microorganisms. Common biodegradable plastic materials include polylactic acid (PLA), polyhydroxyalkanoate (PHA), polycaprolactone (PCL), etc., and the researchers will investigate different polymerisation methods to obtain high-quality biodegradable plastics. The resulting degradable plastics will also be tested and analysed for physical and mechanical properties, including density, melt flowability, thermal stability, tensile strength and fracture toughness. Degradation properties will be assessed to understand the material's rate and mechanism of degradation under different environmental conditions. This can be done through in vitro and in vivo experiments to monitor the loss of mass, changes in molecular structure, and generation of degradation products of the plastic. [13] In addition, several standards and test methods can be used to assess the degradation performance of degradable plastics, such as ISO 14852 and ASTM D 5988.

Table 4. Table caption.

Keywords	Year	Strength	Begin	End	2014-2023
carbon source	2014	1.27	2014	2015	
biodegradable composite	2014	1.14	2014	2017	
biodegradable plastic	2014	1.09	2014	2015	
biodegradable polymer	2014	1.59	2015	2016	
Poly (lactic acid)	2015	1.14	2015	2017	
biomedical application	2016	1.66	2016	2018	
hydrolytic degradation	2016	1.65	2016	2017	
antibacterial property	2016	1.14	2016	2017	
natural fiber	2017	3.82	2017	2019	

Keywords	Year	Strength	Begin	End	2014-2023
mechanical property	2014	2.86	2017	2018	
renewable resource	2017	2.18	2017	2019	
physical property	2017	1.93	2017	2018	
life cycle assessment	2017	1.34	2017	2018	
biodegradable implant	2017	1.09	2017	2019	
microbial degradation	2018	2.6	2018	2019	
polyester	2018	2.33	2018	2019	
ring opening polymerization	2017	1.99	2019	2020	
enzymatic degradation	2016	1.86	2019	2021	
poly beta hydroxyl butyrate	2020	2.08	2020	2021	
shelf life	2020	1.78	2020	2021	
composite	2020	1.57	2020	2021	
behavior	2020	1.48	2020	2021	
active packaging	2020	1.48	2020	2021	
Poly (butylene succinate)	2020	1.17	2020	2021	
waste	2021	1.86	2021	2023	

4. Conclusions

Degradable plastics are a new composite polymer material with comparable or similar application performance and health performance to similar ordinary plastics. After the completion of the use function, it can be degraded faster in the natural environmental conditions and become fragments or fragments that can be easily used by the environment, and finally return to nature. Substances produced during degradation and remaining after degradation are harmless or not potentially harmful to the environment.

Polylactic acid (PLA) is a biodegradable polymer that can be easily processed and shaped, has high mechanical strength, etc. It is widely used in biomedical, fibre spinning, food packaging and other fields. However, it suffers from defects such as slow crystallisation rate, brittleness and poor heat resistance, which limit the engineering applications of PLA. Combined with the degradability, interfacial capacitance enhancement, and toughening mechanism of polymers, the research progress in toughening and modification of PLA blends in recent years is outlined, and it is found that the effect of toughening and modification of PLA by bio-based, biodegradable and flexible polymers is close to that of traditional petroleum-based polymers. Biodegradable polymers toughening PLA have outstanding effects and are the trend and focus of future research. Better interfacial bonding is the key factor in obtaining ultra-tough PLA products. [14] Synergistic reinforcement and toughening of PLA by modulating the moulding process, component content and phase morphology are not universal. Reactive bulking agents can form bridging structures at the interfaces of incompatible blending systems, effectively improving the interfacial bonding properties. However, it is difficult to control the blends' microstructure precisely. The selective dispersion of nanoparticles in PLA blending systems under thermal and force fields and their enhancement and toughening mechanisms need further investigation. The nucleation of nanoparticles is used to regulate the crystalline behaviour of PLA, and synergistic toughening can be achieved with capacitance enhancers. In addition, nanoparticles have special functions such as conductive, dielectric, magnetic, etc. Their incorporation into PLA materials provides a new idea for developing functional PLA nanocomposites and high-performance degradable plastics. [2] Finally, future research may expand the scope of degradable plastics to include a variety of composite organic compounds and the application of degradable plastics in household and military plastics to enhance the practicality of the material [15].

Abbreviations

PLA Polylactic Acid

LDPE	Low Density Polyethylene
PHA	Polyhydroxyalkanoates
PCL	Polycaprolactone
WOS	Web of Scienc

Conflicts of Interest

The authors declare no conflicts of interest.

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