Trends and evolution of research on genetic modification: A bibliometric analysis of scientific literature during 2000-2020

ABSTRACT

This analysis evaluates the most recent developments in genetic modification investigation worldwide. Recent challenges in genetically modified technology include regulatory hurdles, ethical concerns, and the ecological impacts of genetically modified organisms (GMOs). Developments such as CRISPR-Cas9 and other genome-editing technologies have revolutionized the field, offering more precise and efficient methods for genetic modification.We followed a bibliometric analysis approach based on the bibliographic details retrieved from the Web of Science core collection in January 2020. VOS viewer was used for visualizing the research networks in genetic modification research. From 2000 to 2020, we found an aggregate of 1172 records indexed in the Web of Science. These records received a total of 19052 citations, with an average of 16.26 citations per record. Entomology had the most significant share of GM articles (15.52%), followed by multi-disciplinary science (12.11%) and agronomy (11.17%). The top five journals in terms of citations are Science, Nature, Proceedings of the National Academy of Sciences of the USA, Soil Biology and Biochemistry, and World Development. Aside from BT cotton and its economic implications, academia has also shown research interest in subjects like resistance management, genetically modified food, and the impact on non-target pests. The United States, China, England, France, Germany, and India have made significant contributions to the literature on genetic modification, thanks to the efforts of many organizations and researchers in those countries.This manuscript is crucial as it provides a comprehensive overview of the global

research landscape in genetic modification, highlighting the collaborative efforts and scientific advancements that shape the future of this critical field. It serves as an essential resource for researchers, policymakers, and stakeholders aiming to understand the dynamics and impact of genetic modification research.

Keywords: Genetic modification, bibliometric analysis, Web of Science, VOS viewer

1. INTRODUCTION

The biotech revolution during the 1970s and 80s that led to the development of techniques to transfer genes of interest from other organisms to plants is believed to have opened a valuable option for improving crop yields, along with breeding for other characteristics like pest and disease resistance (Khush 2001). The subsequent creation of GM crops is seen as a significant technological advancement in global agriculture (Finger et al. 2011). Since 1996, the year in which it was first used for commercial agriculture in an area of 1.7 million ha., the world area under GM crops increased rapidly to 102 million ha in 2006 and further to 189.8 million ha by 2017 (ISAAA 2017). In light of the changing climate, feeding a growing population will be daunting, but genetically modified (GM) crops are poised to play a pivotal role in meeting this challenge (Sonnino et al. 2009). Yet, Genetic Modification (GM) continues to be one of the most controversial and debated scientific topics (Raparelli et al. 2017, 10-12).

There has been an explosion in studies examining the pros and cons of genetically modified (GM) crops, as well as their effects on humans and the environment, as well as their promise of improved crop yields and financial rewards for farmers. Thus, despite being a relatively newer field, the published peer-reviewed literature on GM is growing continuously. In this work, we undertake a worldwide bibliometric investigation of genetically modified (GM) topics, including GM crops, GMOs, GM food, BT cotton, and more. Understanding the sociology of genetic modification research and identifying domain-specific

areas of concentration are the goals of this work. The analysis also helps in understanding the academic collaborations between various leading institutes in the research area. The contribution of the paper is to highlight the recent research trends and collaborations in the field of GM crops that can aid the field of technology foresight and guide future research activities.

2. MATERIAL AND METHODS

A bibliometric analysis of genetically modified organisms (GM) was conducted in January 2020 utilizing the Web of Science for a literature search. We specifically chose articles, excluding other sorts of documents, that were published in English from 2000 to 2020. The search criteria employed to identify studies include the following terms: TITLE: ("GM crop" OR "genetically modified crop" OR "genetically modified organism" OR "BT cotton" OR "BT corn" OR "BT brinjal" OR "genetically modified food"). This search yielded a total of 1172 studies. Subsequently, we compiled the bibliometric data of all the studies that were retrieved, which included the following: author names, publication dates, journal names, article titles, citations, etc. According to Fu and Ho (2016) and Barbosa and Schneck (2015), scholars view articles mentioned over a hundred times as highly cited. Using a VOS viewer and the information available on the Web of Science, bibliometric analysis was conducted using the concept mapping technique. We produced link strengths by network analysis utilizing author keywords, institutions, and nations. This would facilitate the identification and delineation of the extent and organization of the subject matter under consideration. The fractional counting approach was employed due to its ability to effectively display field-normalized outcomes (Zhang et al., 2019). This method enabled us to visualize the network in which keywords co-occur, as well as the networks of co-authorship across writers, institutions, and nations.

3. RESULTS AND DISCUSSION

3.1 Publications and citations

On a worldwide scale, there was a rising trend in the number of papers discussing genetic modification (Fig. 1). Throughout our research period (2000–2020), a total of 1,172 records were found to be indexed in the Web of Science. Of these, 19052 were cited, with an average of 16.26 citations per record. Among the different subject groups, the highest share in GM publications was occupied by the subject field of Entomology (15.52%), followed by multi-disciplinary science (12.11%), Agronomy (11.17%), Agriculture multi-disciplinary (10.75%), Biotechnology and applied microbiology (8.36%) and Economics (7.67%) respectively (Fig. 2). The allocation of highly cited papers over time is illustrated in Figure 3. Of the research published in the last two decades, 29 were considered highly referenced due to receiving 100 or more citations. The first half of the study period, from 2000 to 2010, saw the most publications (26 in total), with an average of 2.6 articles released each year. From 2008–2019, a total of 4745 citations were made to this research, with the most cited papers receiving over 200 citations annually. There was a decline in the total number of highly cited papers, even if their citation counts were on the rise. This is primarily due to the fact that we did not include research published within the last several years in our analysis due to a lack of citations. At the time of this bibliometric analysis, not a single study published between 2013 and 2020 had 100 citations or more. Citations are on the rise, which indicates that researchers are becoming more interested in the subject. The rising trend in scientific publications on GM technologies can be attributed to several key factors. Technological advancements, such as the development of CRISPR-Cas9, have significantly increased the precision and efficiency of genetic modifications. These innovations have spurred extensive research and publications due to their potential to revolutionize crop improvement and other applications. Additionally, the increasing global population has intensified the need for sustainable agricultural practices. GM crops offer solutions for higher yield, pest resistance, and improved nutritional content, making them a critical area of study to address food security challenges. Furthermore, the ongoing debates regarding the safety, ethics, and regulatory frameworks of GM products have led to a surge

in publications. Researchers are keen to explore and address the concerns surrounding GM technologies, contributing to a growing body of literature. The field of GM technology intersects with various scientific disciplines, including biology, agriculture, environmental science, and ethics. This interdisciplinary nature has broadened the scope of research and increased the volume of publications. These factors collectively contribute to the rising trend in scientific publications on genetically modified technologies, reflecting the field's dynamic and rapidly evolving landscape.

3.2 Influential journals

The journals that have highly referenced articles are listed in Table 1, which shows bibliometric information. Throughout the research period, two highly referenced articles were published by each of the following journals: Science, World Development, and Proceedings of the National Academy of Sciences of the USA. The top five journals in terms of total citations are Science, Nature, Soil Biology and Biochemistry, World Development, and Proceedings of the National Academy of Science of the USA of America. Transdisciplinary journals with the capacity to publish articles on a multitude of sub-topics related to GM have emerged as the most productive journals. Figure 4 displays the co-citation evaluation map of the journal, which groups the journals based on their co-citation frequency. This map aids in identifying journals that publish comparable themes. Articles published in journals that are geographically closer together and linked by similar colored nodes tend to have more commonalities. We were able to incorporate 236 of the 9513 sources for the articles into the map by establishing a citation criterion of 20. Six separate clusters were produced by the map, the largest of which had sixty-four objects. Several entomology-related publications, such as the Journal of Economic Entomology (citing 1779, link strength 1305) and Environmental Entomology (citation 813, link strength 682), are part of this red-colored cluster that reflects the co-citation network. Prominent journals like Science (citing 560, link strength 520) are represented by the second cluster, which is green in colour and has 59

items, World Development (citation 160, link strength 145) and other journals publishing in economics like the American Journal of Agricultural Economics (citation 226, link strength 184). Agbioforum, Food Policy, Journal of Agricultural and Resource, etc., are other journals in this cluster. There are 48 entries in the third cluster, several of which are cotton-related journals. Current Science and the Indian Journal of Agricultural Sciences are two of the Indian periodicals that are part of this cluster. Journals publishing Biochemistry, Biotechnology, and Microbiology were clubbed together based on their co-citation frequency to form the other clusters.

3.3 Focus areas for GM research

Using a co-occurrence network of the most commonly used author terms, we may identify the study interests and preferences of the researchers on the GM and related papers. According to the data, the term "Bt cotton" drew the most attention (143 instances). Other vital keywords are *Bacillus thuringiensis* (75), genetically modified food (47), Bt corn (44), *Helicoverpa armigera* (39), resistance management (39), biotechnology (37), cotton (36), GMO (29), and transgenic bt cotton (29). Bt cotton has the most vital link strength (109 out of all the author keywords), next to *Bacillus thuringiensis* (69). Bt cotton was highly connected to *Helicoverpa armigera*, natural enemies, resistance, and transgenics, and *Bacillus thuringiensis* was well connected to insect resistance, transgenic plants, bt corn, etc. (Fig. 5). Prior to mapping, eleven clusters of author-specific keywords were discovered. In the first grouping of 25 terms, terms like GM food, transgenic Bt cotton, cotton bollworm, Lepidoptera, non-target effect, and genetic alteration could be observed. According to the data, out of all the fields of genetic modification, the most researched topic is the application of Bacillus thuringiensis in crops to make them resistant to lepidopteran pests like Helicoverpa armigera. Academics are very interested in Bt cotton and Bt brinjal due to their experimental successes; many studies are being conducted to learn about the agronomic performance and insect effectiveness of these crops.

3.4 Influential articles and authors

Based on the total number of citations, we were able to determine which GM papers were the most important during the research period (Table 2). The articles that are cited most of the time are the ones that have attracted the interest of the researchers working on GM and, hence, are likely to have influenced the development of research evidence on the topic the most. All the articles identified have been published in highly prestigious journals like Nature, Science, Food Policy, etc. Published in 2012, the paper "Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services" by Lu, Wu, Yanhui, Kongming, Yuying, Jiang, Desneux, Guo, and Yuyuan, Nicolas has had 379 citations since its release. The article emphasized that insect populations have decreased and predator populations have increased as a result of Bt cotton adoption (Lu et al. 2012). The second most cited article on GM is titled “Mirid Bug Outbreaks in Multiple Crops Correlated with Wide-Scale Adoption of Bt Cotton in China," authored by Lu, Wu, Yanhui; Jiang, Xia, Kongming; Li, Yuying; Feng, Bing; Wyckhuys, Yuyuan, Ping; Hongqiang; Kris A. G and Guo. There are 365 citations to this article from 2010 that appeared in Science. Other highly-cited articles on the same list address similarly weighty subjects, such as the question of whether or not genetic modification (GM) affects non-target organisms, the advantages of GM, and the level of acceptance among consumers of GM food. The most influential authors publishing on GM are listed in Table 3. The most prolific writers in this area are Bruce Tabashnik from the University of Arizona and Lu Yanhui and Kongming Wu from the Chinese Academy of Agricultural Sciences. Contributing authors include Guo Yuyuan of the Chinese Academy of Agricultural Sciences, Jiang Yuying of the National Agro-Technical Extension and Service Centre Beijing, and Deepak Saxena and Stotzky, G. of New York University.

3.5 Most active countries and organizations

From 2000 to 2020, the total number of publications linked to genetic modification (GM) was highest in the United States, followed by China, India, England, and Australia (Table 4). The United States of America appeared first with 358 articles and 9614 citations, then China with 207 publications and 4582 citations, and finally India with 162 publications and 992 citations. This can be attributed to several factors. Firstly, these countries have a significant prevalence of GM farms, which drives research and development in this area. The extensive cultivation of GM crops in these nations necessitates ongoing studies to monitor their impact, improve their traits, and address any emerging issues, thereby contributing to a higher volume of scientific literature.

While the USA leads in GM research, it is followed closely by Asia (China, India, Pakistan, and Japan) and European countries (England, France, Australia, Germany, and the Netherlands). Among the top countries' networks of co-authors, only South Africa has made an appearance. Based on the current status of international partnerships, the United States has the strongest link strength (101) and, consequently, many connections, including those with China, India, and Brazil. It is also clear that India is contributing significantly to the publishing of scientific literature on GM. According to the number of citations published on genetic modification (GM) between 2000 and 2020, the top five universities in the world are the following: University of Arizona, Chinese Academy of Sciences, Rutgers State University, and USDA ARS. Central Institute for Cotton Research from India is an organization that contributed significantly, with 25 articles cited 292 times. The United States, with the highest number of publications and citations, has been at the forefront of GM technology adoption and innovation. The presence of leading research institutions, such as the University of Arizona and USDA ARS, further bolsters the country's output in GM research. Similarly, China's robust agricultural sector and substantial investment in biotechnology research, exemplified by the contributions of the Chinese Academy of Sciences, have positioned it as a major player in GM publications. India's significant contributions, mainly from institutions

like the Central Institute for Cotton Research, highlight the country's focus on improving agricultural productivity and pest resistance through GM crops.

International collaborations also play a crucial role in the dissemination of GM research. The strong network of co-authors and partnerships between countries such as the United States, China, India, and Brazil facilitates knowledge exchange and increases publication outputs. Additionally, the interdisciplinary nature of GM research, encompassing fields such as biology, agriculture, environmental science, and ethics, attracts a wide range of researchers, further contributing to the growing body of literature.

To better understand the research trends and researcher sociography surrounding genetically modified (GM) crops, this article conducts a bibliometric study of the relevant literature. According to the data, curiosity about genetically modified (GM) crops has persisted for over 20 years, with BT crops receiving the most significant percentage of GM crop research. Since numerous important articles included topics from Entomology, Agronomy, Economics, and other sub-disciplines within agriculture, the results reflect the multi-disciplinary character of GM research. Researchers from the United States and China have contributed the majority of the highly referenced articles on genetic modification (GM) to transdisciplinary journals. According to the organizations and academics in those countries, GM is mainly focused on the United States, China, England, France, Germany, and India.

Table 1. Top journals with highly cited articles on GM

Journal	Number of highly cited articles (NA)	Number of citations (NC)	NC/NA	IF
Science	2	621	0.5	41.31

				36.
			37	55
Nature Biotechnology	1	379	9	8
Proceedings of the National Academy of			18	9.4
Sciences of the United States of America	2	364	2	12
			28	5.7
Soil Biology & Biochemistry	1	281	1	95
			13	3.8
World Development	2	260	0	69
			23	3.0
American Journal of Botany	1	231	1	38
			23	6.1
Plant Journal	1	230	0	41
			22	4.1
Food Policy	1	225	5	89
Journal of Agricultural and Resource			17	1.1
Economics	1	175	5	84

Table 2. Influential articles on GM

Title	Authors	Source title	Publication year	Total citations
Widespread adoption of Bt cotton and insecticide decrease promotes	Lu, Yanhui; Wu, Kongming; Jiang,	Nature	2012	379

biocontrol services	Yuying; Guo, Yuyuan; Desneux, Nicolas			
Mirid Bug Outbreaks in Multiple Crops Correlated with Wide-Scale Adoption of Bt Cotton in China	Lu, Yanhui; Wu, Kongming; Jiang, Yuying; Xia, Bing; Li, Ping; Feng, Hongqiang; Wyckhuys, Kris A. G.; Guo, Yuyuan	Science	20 10	36 5
*Bacillus thuringiensi*s (Bt) toxin released from root exudates and biomass of Bt corn has no apparent effect on earthworms, nematodes, protozoa, bacteria, and fungi in soil	Saxena, D; Stotzky, G	Soil Biology & Biochemistry	20 01	28 1
Impact of Bt corn pollen on monarch butterfly populations: A risk assessment	Sears, MK; Hellmich, RL; Stanley-Horn, DE; Oberhauser, KS; Pleasants, JM; Mattila, HR; Siegfried, BD; Dively, GP	Proceedings of The National Academy of Sciences of The United States of America	20 01	26 2
A meta-analysis of effects of Bt cotton and maize on non-target invertebrates	Marvier, Michelle; McCreedy, Chanel; Regetz, James; Kareiva, Peter	Science	20 07	25 6
Bt corn has a higher lignin content than non-Bt corn	Saxena, D; Stotzky, G	American Journal of	20 01	23 1

		Botany		
Five years of Bt cotton in China - the benefits continue	Pray, CE; Huang, JK; Hu, RF; Rozelle, S	Plant Journal	20 02	23 0
Consumer acceptance, valuation of and attitudes towards genetically modified food: Review and implications for food policy	Costa-Font, Montserrat; Gil, Jose M.; Traill, W. Bruce	Food Policy	20 08	22 5
A meta-analysis of genetically modified food valuation studies	Lusk, JL; Jamal, M; Kurlander, L; Roucan, M; Taulman, L	Journal Of Agricultural And Resource Economics	20 05	17 5
Early Warning of Cotton Bollworm Resistance Associated with Intensive Planting of Bt Cotton in China	Zhang, Haonan; Yin, Wei; Zhao, Jing; Jin, Lin; Yang, Yihua; Wu, Shuwen; Tabashnik, Bruce E.; Wu, Yidong	Plos One	20 11	17 4

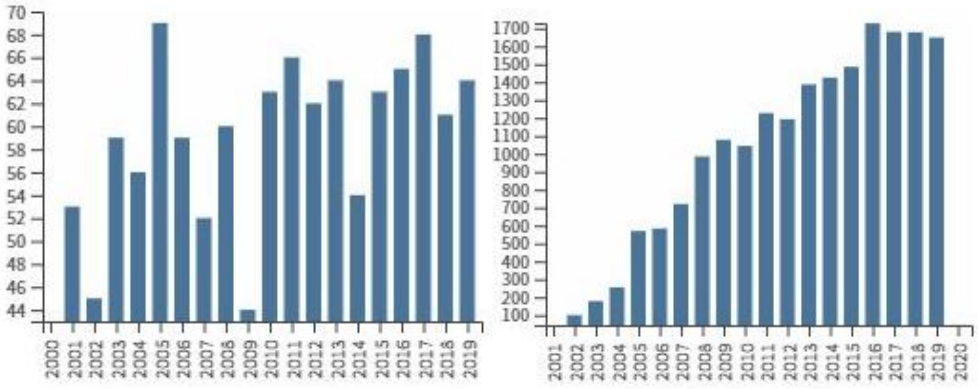
Table 3. Influential authors on GM

Author	Number of articles	Number of citations
Wu, Kongming	15	1060
Tabashnik, Bruce E.	21	849
Lu, Yanhui	6	770
Jiang, Yuying	5	768
Guo, Yuyuan	2	744
Saxena, D	3	671
Stotzky, G	3	671
Huang, Jk	3	525

Desneux, Nicolas	6	430
Wu, Yidong	6	427

Table 4. Active countries and organizations

Country	Documents	Citations	Link strength	Organization	Documents	Citations	Link strength
USA	358	9614	110	Chinese Acad Agr Sci	52	1785	30
Peoples R China	207	4582	91	Univ Arizona	32	1246	19
England	84	1974	31	Chinese Acad Sci	40	1188	24
France	42	1089	27	Rutgers State Univ	14	888	8
Germany	42	1005	17	USDA ARS	30	836	20
India	162	992	17	Univ Reading	13	758	3
Canada	34	935	15	Nanjing Agr Univ	21	662	18
Australia	43	617	18	Monsanto Co	17	589	12
Italy	19	585	10	Iowa State Univ	23	563	12
Spain	18	536	7	Univ Minnesota	21	562	14



Publications Citations

Fig. 1. Year-wise publication and citation on GM (numbers)

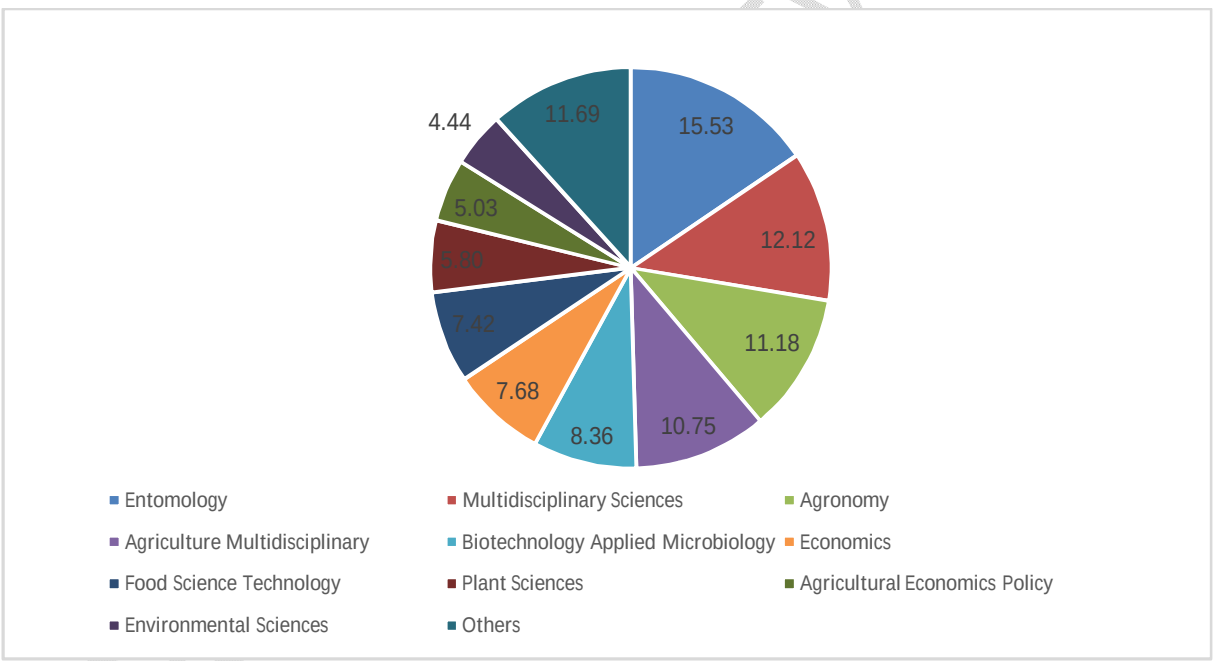


Fig. 2. Subject wise share in GM publications (per cent)

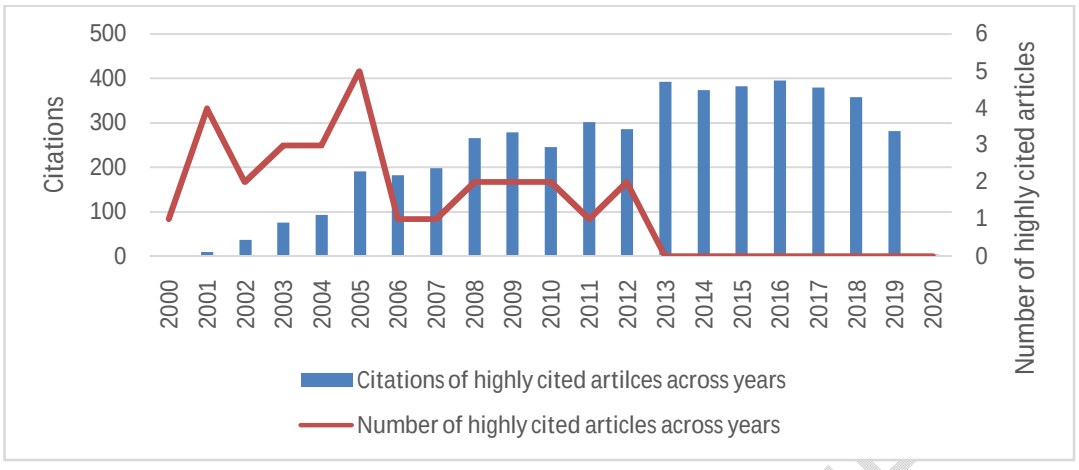


Fig. 3. Highly cited articles on GM and the number of times they are cited

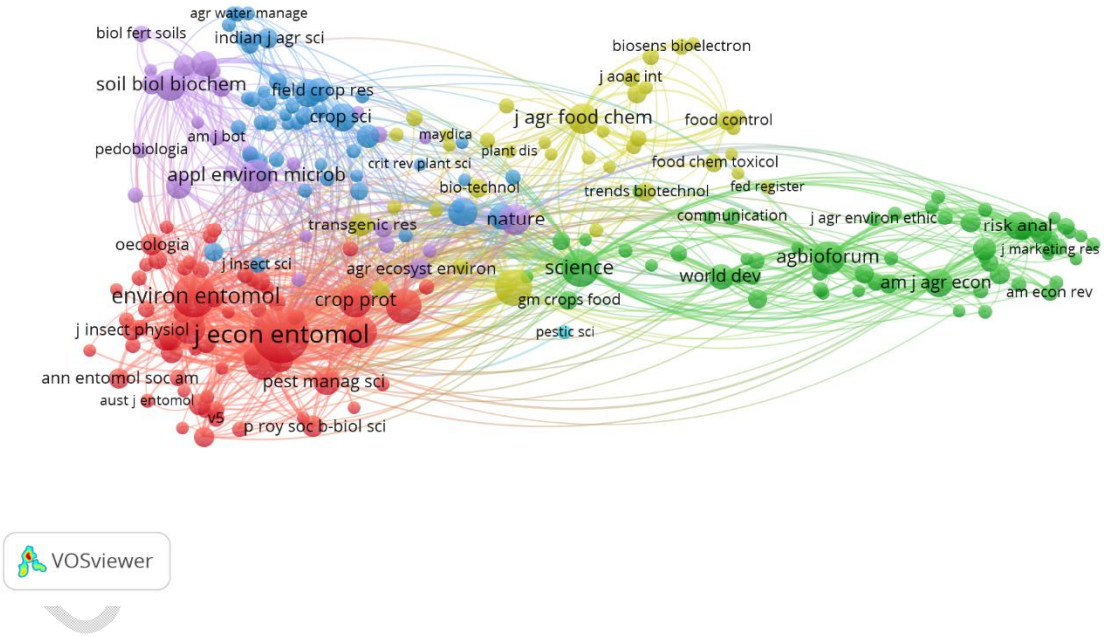


Fig. 4. Co-citation network of journals

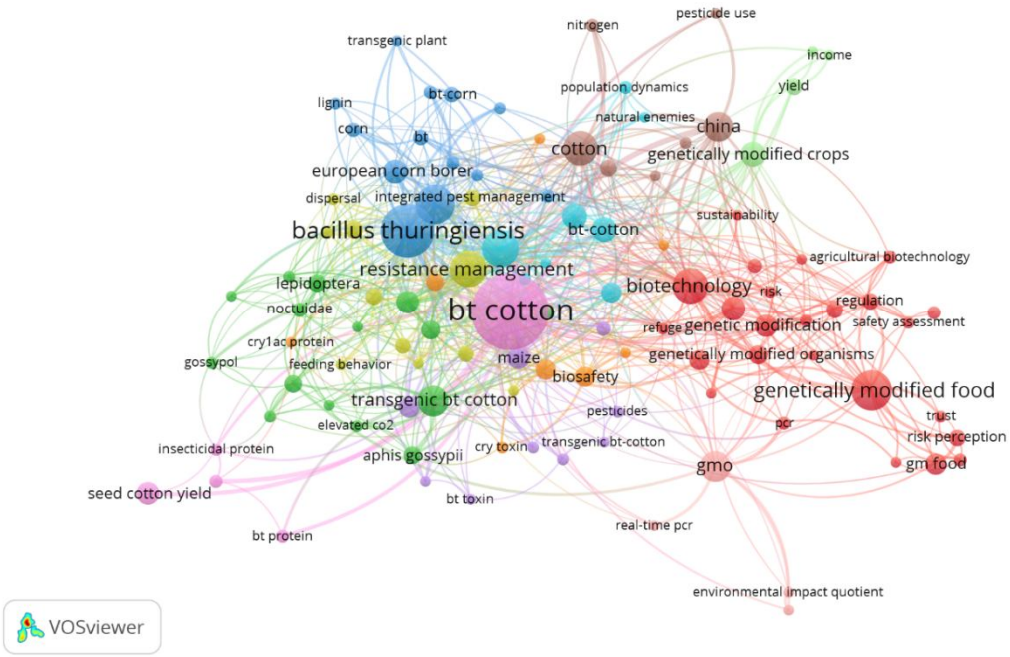


Fig. 5. Co-occurrence network of the most frequently used author keywords

4. CONCLUSION

Examining the patterns and development of genetic modification research from 2000 to 2020 makes it clear that the number of papers covering genetic modification has skyrocketed globally. Authors like Wu, Kongming and Tabashnik, Bruce E., who have written extensively on genetically modified crops and received several citations and articles, were singled out in the study. Science and Nature Biotechnology are two of the top publications in this field that have published extensively on genetically modified crops, and the study has brought their articles to light. Several studies have examined how genetically modified crops affect non-target creatures and the environment. Researchers have looked at how Bt crops affect insect populations and biodiversity, and some of their findings point to dangers that could arise from growing genetically modified crops on a large scale. Nonetheless, some studies have demonstrated the advantages of GM crops, including higher yields and less pesticide usage. To sum up, the studies conducted on GMOs between 2000 and 2020 have shed light on the developments, influential figures, and effects of this technology in farming.

Although there are continuing discussions on GM crops' potential health and environmental impact, this research has helped shed light on the pros and cons of this technology. Further study and monitoring are required to determine how GMOs will affect ecosystems and human health in the long run.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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