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# Scientometrics Visualization of Plant Biochemistry Using Pubmed API from 2000 To 2024

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**ABSTRACT:** Plant biochemistry is essential for tackling global challenges, including food security, climate change, and sustainable development. We analyzed the trends in plant biochemical research from 2000 to 2024 employing scientometric methodologies. The PubMed API provided 304 documents, of which 303 were preserved after cleaning for analysis by Bibliometrix. This study identifies key research themes, prominent authors and institutions, and collaboration networks, and explores the evolution of the research focus over two decades. Visualization tools, such as VOSviewer, Infranudus, and Bibliometrix, created network maps, keyword co-occurrence analyses, and temporal trend visualizations. The research revealed a steady increase in publications, new areas of study such as metabolic engineering and stress responses, and notable contributions from prominent institutions and nations. Collaborative networks enhance research productivity and innovation. This study examined the implications for various stakeholders and proposed future research directions in plant biochemistry, providing valuable information for researchers, policymakers, and funding organizations. A thorough bibliometric analysis was conducted to examine the methodological factors of plant biochemistry, photonic distribution patterns, and other important factors. This study expands its depth through different visual representations that produce separate analytical views of investigative research. This research analyzes mapping techniques for identifying future paths in plant biochemistry studies, as well as strategic program development models.

**KEYWORDS**: Scientometrics, Plant Biochemistry, Research Trends, PubMed API, Data Visualization, and Bibliometric Analysis

## 1. BACKGROUND

The field of plant biochemistry has solved issues regarding sustainable development systems, environmental adaptation, and food shortage problems. Evaluating plant biochemical actions leads to higher agricultural productivity and better farming methods while improving plant production. Through PubMed API access, one can obtain data concerning plant biochemistry research from 2000 to 2024. The use of sustainable farming techniques, together with field research, has improved crop stability. The efficient advancement of scientific methods for protecting environmental sustainability and food security has occurred alongside increasing human numbers and global environmental changes.

Plant biochemistry research encompasses three main sections: molecular biology, genomics, and sustainable technology. After creating bioengineering solutions for plant adaptation, scientists have managed to discover crucial aspects of plant metabolism and stress responses. Plant biochemistry serves as the basic foundation for contemporary agricultural and environmental sciences, because research teams have achieved disruptive changes by using genetic and molecular biology approaches together with sustainable technology over the past 20 years (Storm et al., 2024). A clear understanding of field evolution requires intensified study as global difficulties continue to grow. The scientific field of sociometry provides researchers with a valuable tool for uncovering patterns between research production, collaboration, and new developments (Yan and Zhiping, 2023). The analysis benefits from the PubMed API datasets between 2000 and 2024 for creating a visualization of plant biochemistry research growth within a temporal intellectual connection framework. This study helps society understand research responses through the discovery of open research possibilities and unanswered scientific questions (Wei et al., 2024). The evolution of plant biochemistry requires better analytical devices such as metabolomics, proteomics, and CRISPR-based genome editing systems. Scientific tools enhance plant metabolic pathway knowledge, stress reaction comprehension, and bioengineered solution discovery (Raza et al., 2024). Research expansion leads to new possibilities and obstacles in conducting research synthesis. Scientific methods allow researchers to study large datasets to identify core research works and active institutions, as well as project changes in research direction patterns. A 24-year analysis of global priorities and technology evolution in the field was enabled by PubMed database information (Xu et al., 2024). Plant biochemistry operates across three integrated fields: ecology, computational biology, and climate science. Academic institutions and industries, along with government bodies, connect through network links to handle complex issues, such as crop tolerance improvement and carbon storage (Benitez-Alfonso et al., 2023). The research presented co-author relationships in graphical form and keyword co-appearance diagrams to assess interdisciplinary collaboration intensity. Research has established that partnerships between researchers foster a connection between plant chemical research and pharmaceutical development techniques. This research evaluates practical solutions through the study of contemporary scientific connections between worldwide networks using network analytical techniques (Zhao et al., 2023).

Plant biochemistry has progressed significantly over the past two decades. However, a comprehensive assessment of research practices and collaborations has yet to be conducted. To elucidate the field's primary contributors, significant institutions, and pivotal shifts in focus, a critical review of its historical development is imperative.

Scientific investigation methods deliver an established approach to detect intellectual development along with the identification of scientific relationship development and emerging academic directions. Scientific analysis brings important new knowledge to scientists, decision makers, and funding entities by showing them prospective research directions and capital allocation opportunities in plant biochemistry. This study aimed to answer multiple essential research questions.

How has plant biochemistry research evolved in the last 20 years?

Which researchers, institutions, and nations are at the forefront of the field?

How has research focus shifted over time?

Scientometric research and graphical analysis of plant biochemistry research were conducted between 2000 and 2024 using PubMed API database data. This study focused on performing an extensive field-wise evaluation through an analysis of collaboration network publication patterns.

This study investigated major scientific priority shifts while identifying researchers and their collaborative methods and how they produced developments in plant biochemistry. The constructed research knowledge integrates international problems with technological progress to direct future scientific inquiries into plant biochemistry.

## 2. MATERIALS AND METHODS

### *2.1 Data retrieval using PubMed API*

Data retrieval was conducted using a predefined search strategy in PubMed: 'plant biochemistry'[Title/Abstract] AND 'english'[Language] AND 'journal article'[Publication Type] AND 2000/01/01:2024/12/31[Date - Publication]. This query aimed to capture journal articles published in English between January 1, 2000, and December 31, 2024, focusing on plant biochemistry. The search initially retrieved 304 documents, but one document was excluded because of incomplete metadata, resulting in 303 documents being processed for analysis. Data cleaning revealed missing fields, including cited references, corresponding author information, science categories, and total citation counts, which were addressed during processing.

### *2.2 Data processing and analysis using Bibliometrix package*

A Bibliometrix package with its Biblioshiny interface for R conducted the scientometric analysis and visualization of plant biochemistry research. The bibliometrix R package functions as a tool for extensive bibliometric analysis and was used to extract and evaluate PubMed API data. The analysis was performed using R Studio, an environment that facilitates the execution of Bibliometrix functions and generation of visualizations (Aria & Cuccurullo, 2017). The Biblioshiny interface was launched using the command biblioshiny() in R, providing an interactive platform for data exploration and visualization at the local address http://127.0.0.1:3563/.

### *2.3 Visualization tools and techniques*

The analysis consisted of a publication trend analysis, citation analysis, collaboration network mapping, keyword co-occurrence analysis, and journal-author productivity assessment. Research in plant biochemistry has received visibility through Biblioshiny's tools, which produce network maps and three different chart types, as well as histograms and line graphs to understand the field's historical development and research effects. The complex visualization software implemented VOSviewer and Bibliometrix together with Infranudus to create network diagrams, perform keyword relationship assessments, and display timeline shifts (Belfiore, Cuccurullo & Aria, 2022).. Utilizing these tools, researchers have successfully generated three-field plots, co-occurrence networks, thematic maps, and collaboration networks that collectively depict the comprehensive research landscape in plant biochemistry (Aria et al, 2024).

The researcher conceded the limitations arising from missing data as they could reduce the comprehensiveness of the analysis. This approach implements existing scientometric standards to create a comprehensive system for studying plant biochemical research developments and patterns.

## 3. RESULTS

### 3.1 Annual Scientific Production

Scientific research in Plant Biochemistry has shown significant variations since 2000, when an upward trend began. During 2000–2001, yearly publications remained below three items. The major growth phase began in 2013, after which researchers published 25 articles in 2013 and 2014. Plant biochemical research encountered its production peak in 2015 with reported 28 articles while attracting stronger international curiosity throughout that year. Plant Biochemistry research will continue to exhibit steady production through the annual release of 17 research articles by 2024, after having been reduced to 16 articles per year between 2021 and 2023. This study indicates that plant biochemistry research remains dynamic, as it provides evidence of continuous active development. Figure 1 shows the annual scientific production in plant biochemistry between 2000 and 2024.

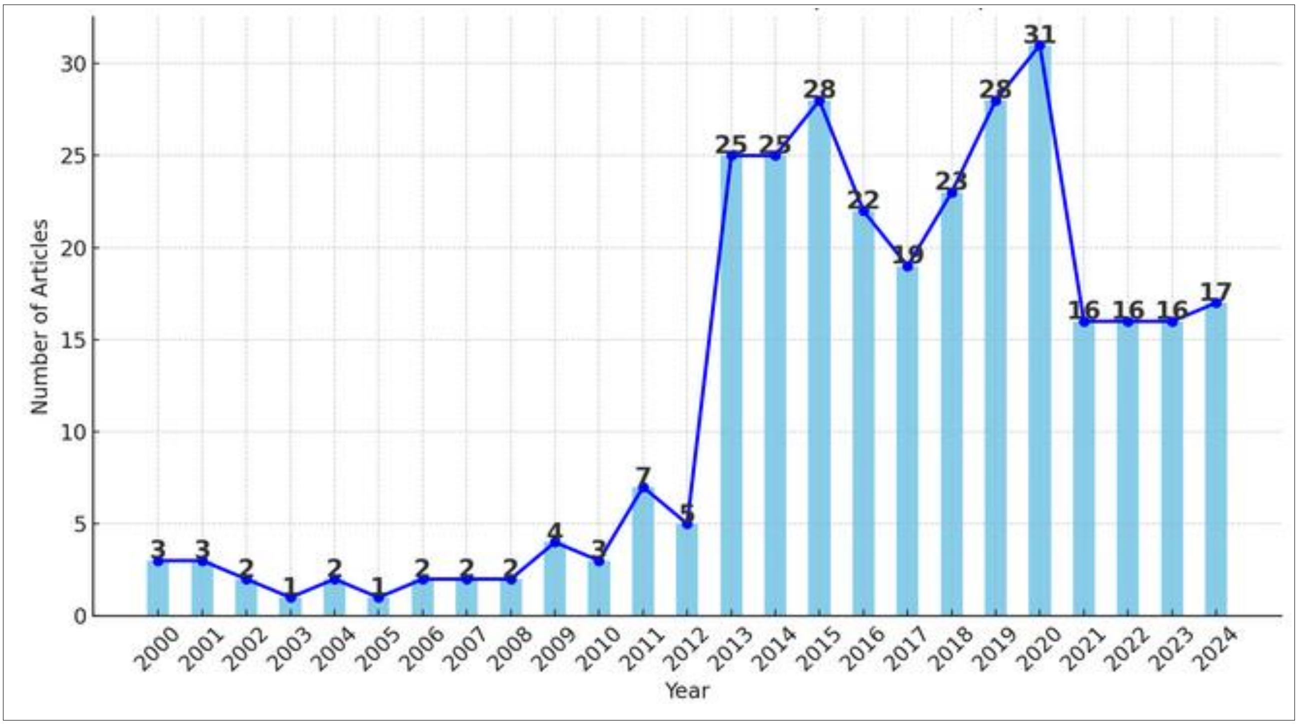


**Figure 1: Annual scientific production**

### 3.2 Three-Field Plot

The Three-Field plot implemented scientific procedures to identify the relationships between authors, titles, and keywords. Academic authors implement scientific research methods to build relationships between keywords that determine their research boundaries within the framework. The depiction uses line thickness as a method to illustrate the relationship strength, as strong correlations show thick lines and weak correlations show thin lines. Facchini and Lee focused on plant biochemical protein structures and plant defence subjects. The research domain advances through studies combining multiple keywords in article titles such as "biosynthesis" with "enzyme structure" and other terms. The plot displays scholarly contributions to the understanding of the network of scientific knowledge in plant biochemistry research and related fields. Figure 2 represents the Three-Field plot visualization based on author, topic, and keywords.

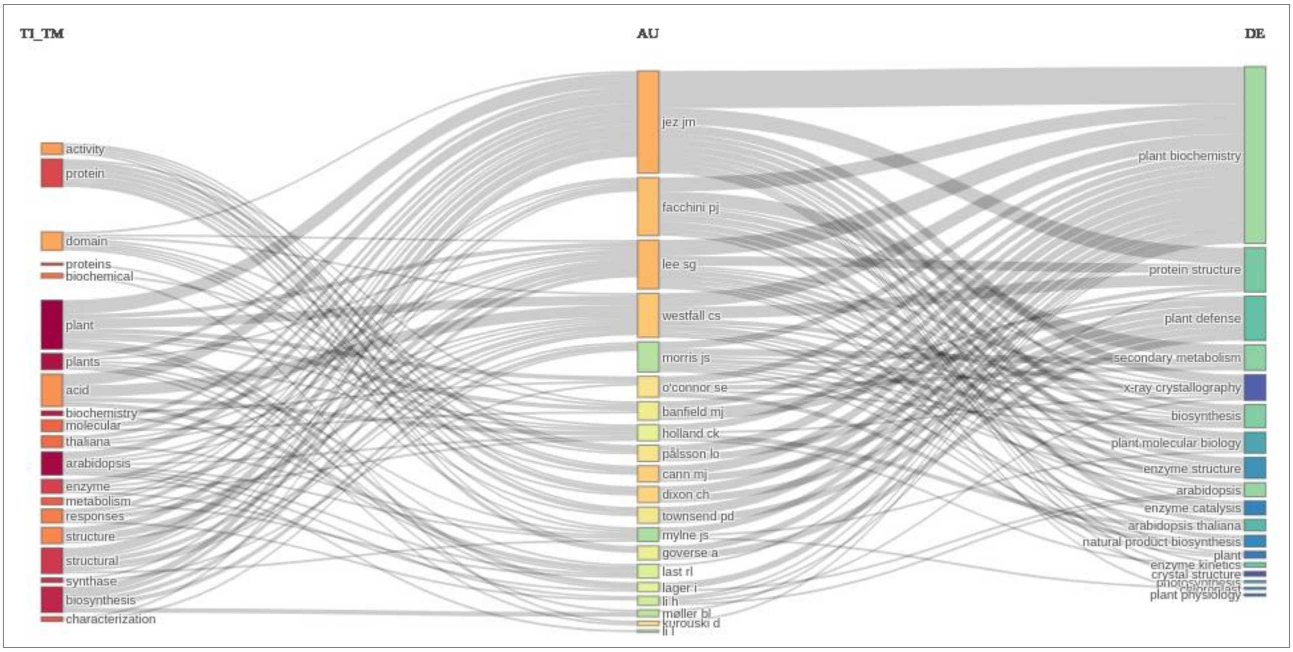


**Figure 2: Three-Field Plot map**

### 3.3 Most Relevant Sources

Plant biochemistry research has been established in multiple academic journals that provide essential documentation. Plant biochemical research has expanded to 129 articles published in the Journal of Biological Chemistry. Plant biology research received 12 innovative articles from Frontiers on the Plant Science publication platform. The scientific journals of iScience and Phytochemistry released eight and seven articles, respectively, that demonstrated connections between plant science and chemical and molecular perspectives. Biochemistry and Molecular Biology Education and Methods in Molecular Biology contributed six articles each, providing educational and methodological insights. Plant Journal and Journal of Experimental Botany published research on plant cell biology and experimental techniques. Published research supports both academic and agricultural developments in plant biochemistry. Table 1 shows the most important academic journals.

**Table 1: Most Relevant academic journal**

| Sources | Articles |
|---|---|
| THE JOURNAL OF BIOLOGICAL CHEMISTRY | 129 |
| FRONTIERS IN PLANT SCIENCE | 12 |
| ISCIENCE | 8 |
| PHYTOCHEMISTRY | 7 |
| BIOCHEMISTRY AND MOLECULAR BIOLOGY EDUCATION : A BIMONTHLY PUBLICATION OF THE INTERNATIONAL UNION OF BIOCHEMISTRY AND MOLECULAR BIOLOGY | 6 |
| METHODS IN MOLECULAR BIOLOGY (CLIFTON, N.J.) | 6 |
| JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY | 5 |
| PLANTS (BASEL, SWITZERLAND) | 5 |
| THE PLANT JOURNAL : FOR CELL AND MOLECULAR BIOLOGY | 5 |
| JOURNAL OF EXPERIMENTAL BOTANY | 4 |

### 3.4 Core Sources by Bradford's Law

The methodology used for identifying vital research sources in plant biochemistry obeys Bradford's Law of Scattering. According to the law, the journals showing the highest publication rates exist in the first zone, and subsequent zones show a declining publication number. In plant biochemistry, The Journal of Biological Chemistry emerged as the largest source, with 129 articles comprising Zone 1. Zone 2 contains journals such as Frontiers in Plant Science, iScience, Phytochemistry, and others with fewer articles. Bei diesen Veröffentlichungen, die allesamt zwischen 4 bis 12 Artikel pro Einzelwerk produzieren, handelt es sich um eine komprimierte Sammlung wissenschaftlicher Publikationen, die den methodologischen Ansatz für grundlegendes Forschungsfragen der Pflanzenbiochemie darstellen. The movement from Zone 2 indicates the gradual reduction of articles in each journal, since only a few journals evaluate most scholarly output, while the remainder remains less common. Plant biochemistry research depends on the importance of high-impact journals, whereas scholarly publications demonstrate an established hierarchy. Table 2 core sources in plant biochemistry as per Bradford's Law.

**Table 2: Core sources as per Bradford's Law**

| Sources | Rank | Freq | cumFreq | Zone |
|---|---|---|---|---|
| THE JOURNAL OF BIOLOGICAL CHEMISTRY | 1 | 129 | 129 | Zone 1 |
| FRONTIERS IN PLANT SCIENCE | 2 | 12 | 141 | Zone 2 |
| ISCIENCE | 3 | 8 | 149 | Zone 2 |
| PHYTOCHEMISTRY | 4 | 7 | 156 | Zone 2 |
| BIOCHEMISTRY AND MOLECULAR BIOLOGY EDUCATION : A BIMONTHLY PUBLICATION OF THE INTERNATIONAL UNION OF BIOCHEMISTRY AND MOLECULAR BIOLOGY | 5 | 6 | 162 | Zone 2 |
| METHODS IN MOLECULAR BIOLOGY (CLIFTON, N.J.) | 6 | 6 | 168 | Zone 2 |
| JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY | 7 | 5 | 173 | Zone 2 |
| PLANTS (BASEL, SWITZERLAND) | 8 | 5 | 178 | Zone 2 |
| THE PLANT JOURNAL : FOR CELL AND MOLECULAR BIOLOGY | 9 | 5 | 183 | Zone 2 |
| JOURNAL OF EXPERIMENTAL BOTANY | 10 | 4 | 187 | Zone 2 |

The diagram illustrates Bradford's law by depicting the distribution of texts among sources in the field of plant biochemistry. The Journal of Biological Chemistry was identified as the primary source, with a marked decrease in the number of articles as the rank diminished. Few journals have contributed to the publishing of most articles on this pattern. This law applies to both metrics, establishing a direct connection between the journal rank position and article numbers. This illustration demonstrates how pre-eminent publications greatly contribute to the educational development of their discipline by advancing research. The closeness to an asymptote demonstrates that important research exists in smaller specialized publications that reinforce the academic hierarchy in plant biochemistry publishing. Figure 3 shows the Bradford's law diagram.

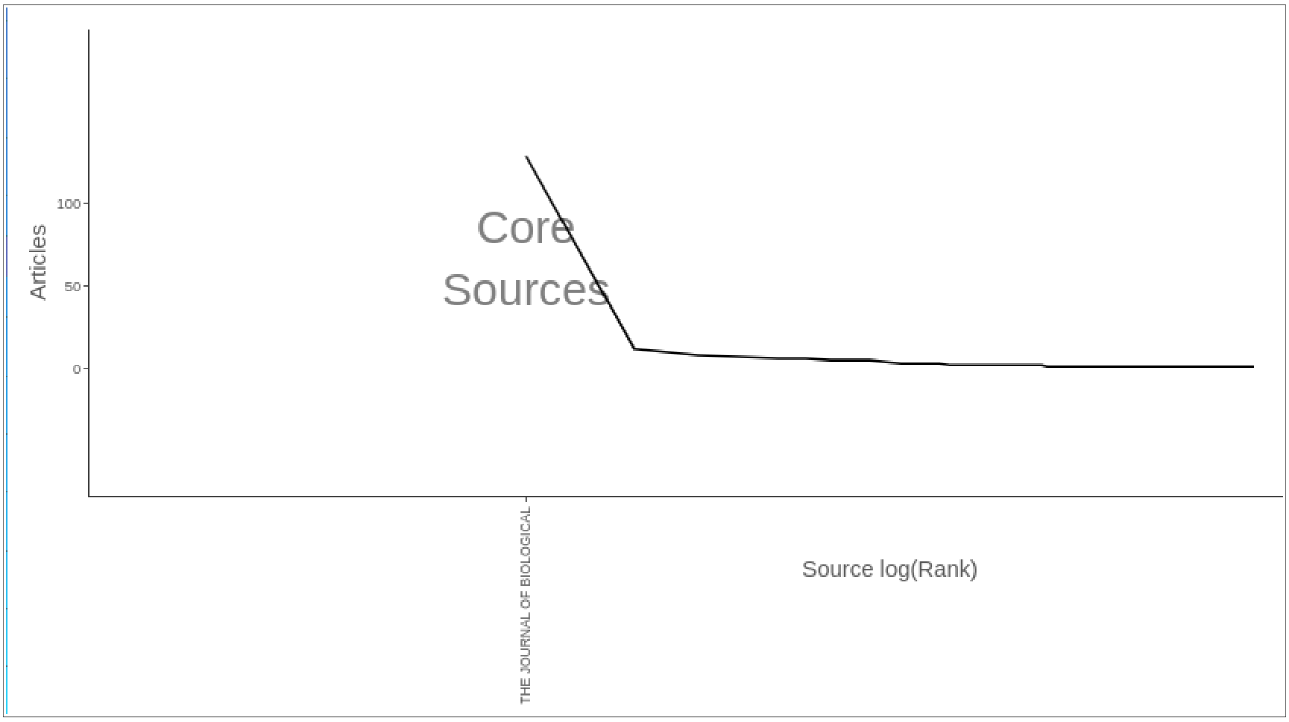


**Figure 3: Bradford's law diagram**

### 3.5 Sources' Production over Time

The contribution of crops to plant biochemistry has changed dramatically, with The Journal of Biological Chemistry at the top. Absent in the early 2000s, this journal saw a significant increase in its output in 2013, reaching 129 articles by 2024, indicating its pivotal role in biochemical research. Recent publications, such as Frontiers in Plant Science and iScience, have gradually enhanced their visibility, demonstrating the diversification of publication media. Phytochemistry continued at steadily low levels, whereas Biochemistry and Molecular Biology Education and Methods in Molecular Biology sustained slow but steady growth. This trend suggests an expanding academic periphery with a common resolution to central sources, reinforcing a pyramidal form of academic publication in plant biochemistry.

**Table 3: Sources' Production over Time**

| *Year* | *THE JOURNAL OF BIOLOGICAL CHEMISTRY* | *FRONTIERS IN PLANT SCIENCE* | *ISCIENCE* | *PHYTOCHEMISTRY* | *BIOCHEMISTRY AND MOLECULAR BIOLOGY EDUCATION : A BIMONTHLY PUBLICATION OF THE INTERNATIONAL UNION OF BIOCHEMISTRY AND MOLECULAR BIOLOGY* | *METHODS IN MOLECULAR BIOLOGY (CLIFTON, N.J.)* |
|---|---|---|---|---|---|---|
| 2000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2002 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2003 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2004 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2005 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2006 | 0 | 0 | 0 | 2 | 0 | 0 |
| 2007 | 0 | 0 | 0 | 3 | 0 | 0 |
| 2008 | 0 | 0 | 0 | 3 | 0 | 0 |
| 2009 | 0 | 0 | 0 | 3 | 0 | 0 |
| 2010 | 0 | 0 | 0 | 3 | 0 | 0 |
| 2011 | 1 | 0 | 0 | 4 | 0 | 0 |
| 2012 | 1 | 0 | 0 | 4 | 0 | 0 |
| 2013 | 22 | 0 | 0 | 5 | 2 | 0 |
| 2014 | 41 | 0 | 0 | 5 | 2 | 0 |
| 2015 | 58 | 1 | 0 | 5 | 2 | 2 |
| 2016 | 67 | 5 | 0 | 5 | 2 | 2 |
| 2017 | 79 | 6 | 0 | 5 | 2 | 2 |
| 2018 | 88 | 6 | 1 | 5 | 3 | 5 |
| 2019 | 99 | 7 | 2 | 5 | 4 | 5 |
| 2020 | 116 | 8 | 4 | 6 | 6 | 5 |
| 2021 | 120 | 9 | 4 | 7 | 6 | 5 |
| 2022 | 123 | 11 | 7 | 7 | 6 | 5 |
| 2023 | 125 | 11 | 7 | 7 | 6 | 6 |
| 2024 | 129 | 12 | 8 | 7 | 6 | 6 |

Graphically provided is the cumulative number of scholarly publications across journals, showing The Journal of Biological Chemistry as the preferred choice, with a significant increase since 2013. This trend underscores its impact on biochemical research. Other publications, including Frontiers in Plant Science, iScience, and Phytochemistry, have shown gradual growth. Specialized periodicals such as Methods in Molecular Biology and Biochemistry and Molecular Biology Education maintain a stable trajectory. The distribution aligns with Bradford's law, emphasizing a core group of highly productive sources alongside a broader array of less frequently contributing journals. Figure 4 shows the cumulative occurrences graphs.

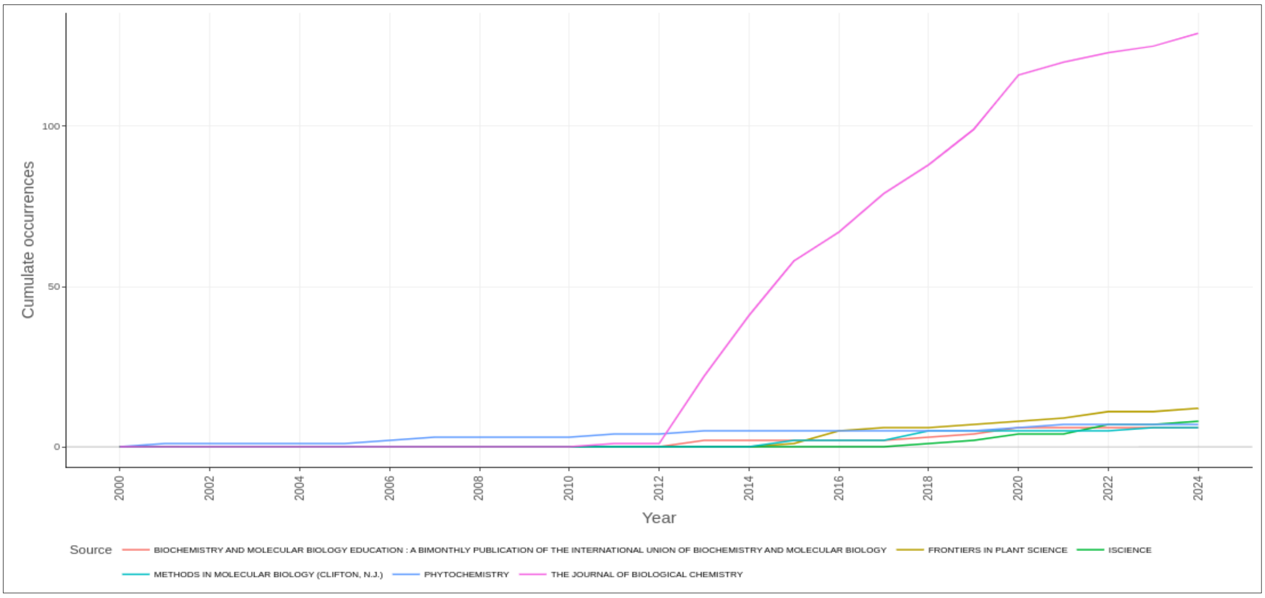


**Figure 4: Visualization of sources production over time**

**3.6 Most Relevant Authors**

The interactive visualization illustrates the distribution of research contributions among the most relevant authors in scientometric analysis on Plant Biochemistry from 2000 to 2024. Among them, JEZ JM stands out as the most prolific author, with 16 articles, while the fractionalized count of 6.2 indicates a significant level of collaboration. FACCHINI PJ and LEE SG also contribute substantially, with six and seven publications, respectively, though their fractionalized counts (2.45 and 1.27) suggest varying degrees of co-authorship.

Notably, WESTFALL CS, O'CONNOR SE, and KUROUSKI D exhibit fractionalized article counts above 1.0, signifying stronger individual contributions relative to other authors with similar total article counts. On the other hand, authors like CANN MJ, DIXON CH, PÅLSSON LO, and TOWNSEND PD display consistently low fractionalized values (0.4), implying extensive multi-authored research efforts with shared credit distribution.

The difference between total articles and fractionalized articles reflects the extent of collaboration within the field of plant biochemistry. Higher fractionalized counts indicate primary authorship roles, whereas lower values suggest involvement in larger collaborative networks. This analysis underscores the evolving research landscape in plant biochemistry, emphasizing the contributions of key authors and their influence on scientific discourse. Further investigation into citation networks, institutional affiliations, and research impact metrics could provide deeper insights into the field's development over the past two decades. Figure 5 shows the most relevant authors analysis charts.

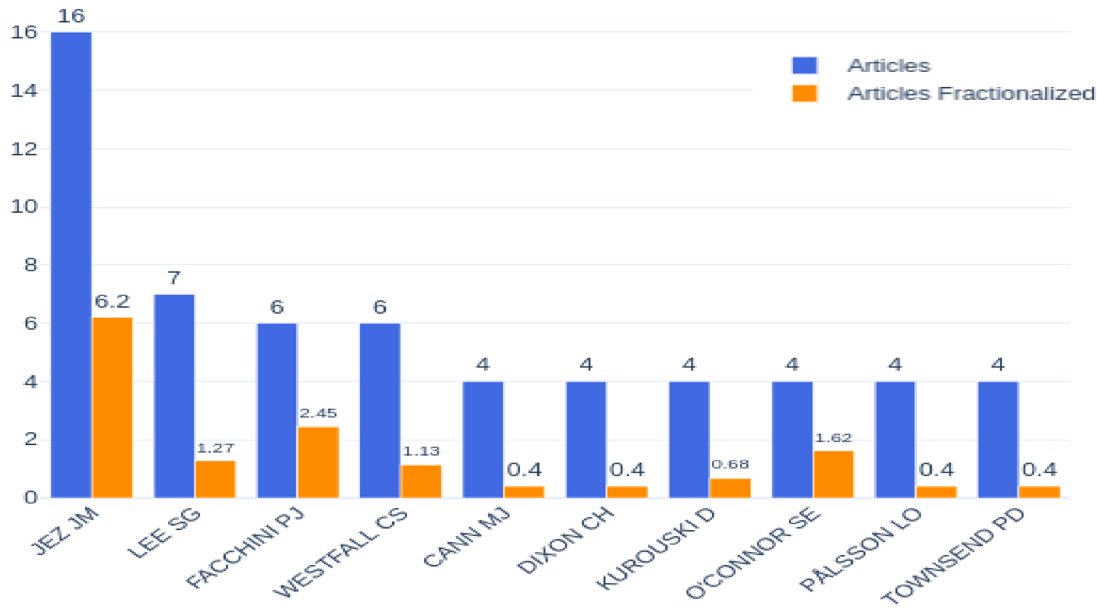


**Figure 5: Most relevant authors**

### 3.7 Author Productivity through Lotka's Law

Lotka's research demonstrates that authors publish at distinct speeds, leading to an opposite correlation between research output and author frequency. According to the research findings, most scientists (1,417 people) represented 92.4% of the total group who published one article in this study. Few authors managed to produce substantial amounts of work, whereas most researchers contributed a minimal number of publications. A single researcher published 16 documents that demonstrated exceptional work production. Academic literature evidence suggests that highly productive authors account for the bulk of scholarly work with multiple publications, although most researchers contribute few documents. Table 4 represents the data for authors productivity based on Lotka's Law.

**Table 4: Author Productivity as per Lotka's Law**

| Documents written | No. of Authors | Proportion of Authors |
|---|---|---|
| 1 | 1417 | 0.924 |
| 2 | 89 | 0.058 |
| 3 | 17 | 0.011 |
| 4 | 6 | 0.004 |
| 6 | 2 | 0.001 |
| 7 | 1 | 0.001 |
| 16 | 1 | 0.001 |

Lotka's law of author productivity appears in this illustration because it presents an inverse correlation linking document number to the author percentage. At the beginning of the curve, most authors created only one or two documents before the number of prolific authors gradually increased. The elongated section of the graph demonstrates the scarcity of prolific authors based on the concept that a few scientists create the most scholarly publications. Figure 6 has shown the Lotka's Law for authors productivity.

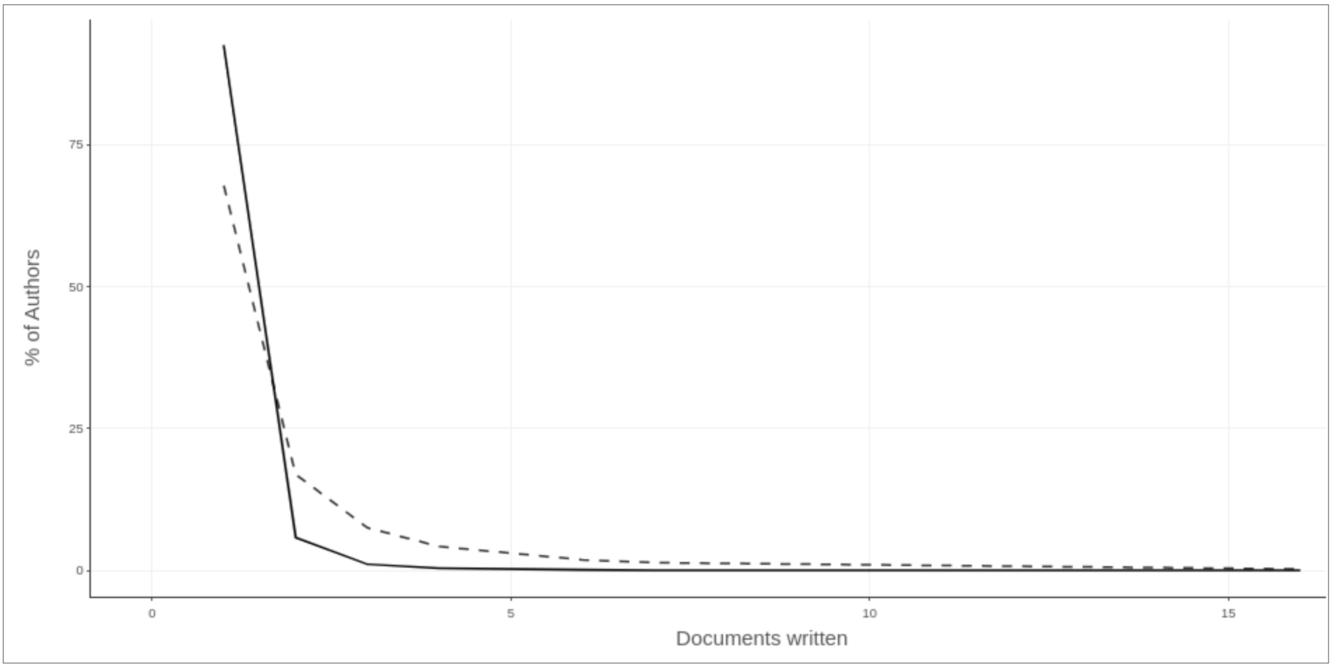


**Figure 6: Authors productivity in accordance with Lotka's Law**

### 3.8 Affiliations' Production over Time

The Department of Biology at Washington University in St. Louis has generated stable annual research output through scholarly publications during the past decade. Every year from 2016 to 2024, the department maintained steady production of 14 academic papers, which demonstrates their strong research agenda. These research achievement levels show effective research practices that stem from strong funding support and high academic involvement in biological studies. The department released 12 articles in 2015, which indicated potential growth since these numbers marginally decreased in later years. Research excellence remains a core value for the department, as demonstrated by their consistent articles, which table 5 show their influential position in the scientific world.

**Table 5: Affiliations' Production over Time**

| Affiliation | Year | Articles |
|---|---|---|
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2016 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2017 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2018 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2019 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2020 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2021 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2022 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2023 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2024 | 14 |
| FROM THE DEPARTMENT OF BIOLOGY, WASHINGTON UNIVERSITY, ST. LOUIS, MISSOURI 63130. | 2015 | 12 |

The chart illustrates the trends in research publications from various academic institutions over time, emphasizing their scientific contributions. Since 2013, the Department of Biology at the Increasing University St. Louis has consistently maintained its publication rate. In contrast, the Department of Biological Sciences at the University of Calgary experienced a gradual increase, eventually stabilizing. Other institutions, such as the National Institute of Plant Genome Research in India and the State Key Laboratory of Bioactive Substances in China, have recently observed a significant rise in publications, indicating burgeoning research activities. These findings underscore the role of institutions in contributing to the scientific literature, with some maintaining steady output and others demonstrating growth. Figure 7 shows the Affiliations' Production chart.

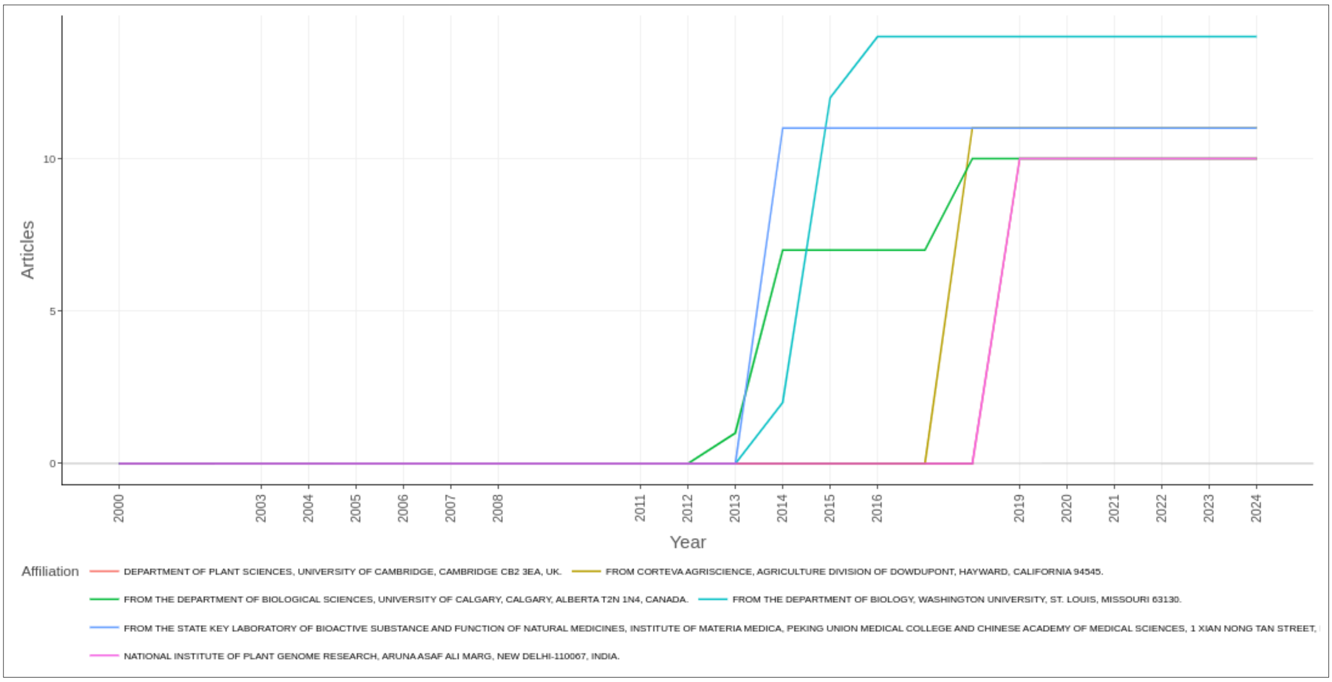


**Figure 7: Affiliations' Production wise trends**

### 3.9 Trend of Topics

The trajectory of research priorities in plant biochemistry has changed significantly, reflecting shifts in scientific interest. In the early 2010s, foundational areas such as biochemistry, agriculture, and ecosystems provided a basis for subsequent research. Over the past decade, molecular and genetic studies have increased and are characterized by terms such as amino acid sequences, molecular sequence data, and genes and plants. From 2014 to 2018, the model plant Arabidopsis and its proteins were extensively studied, highlighting their importance in functional genomics. By the late 2010s and the early 2020s, research expanded to applied and ecological aspects, focusing on volatile organic compounds, plant extracts, antioxidants, and host-pathogen interactions. Recently, emphasis has shifted towards understanding plant physiological mechanisms and biochemical pathways, including photosynthesis, kinetics, and substrate specificity. The prominence of flowers from 2021 to 2023 indicates growing interest in plant reproductive systems. These developments illustrate the transition in plant chemical research from biochemical and genetic approaches to more practical and ecological perspectives. Table 6 shows the topic wise trend.

**Table 6: Trend of Topics**

| Term | Frequency | Year (Q1) | Year (Median) | Year (Q3) |
|---|---|---|---|---|
| biochemistry | 8 | 2010 | 2012 | 2018 |
| agriculture | 5 | 2003 | 2012 | 2016 |
| ecosystem | 5 | 2009 | 2012 | 2015 |
| base sequence | 7 | 2013 | 2013 | 2014 |
| genes, plant | 7 | 2010 | 2013 | 2016 |
| molecular structure | 5 | 2007 | 2013 | 2017 |
| amino acid sequence | 35 | 2014 | 2014 | 2017 |
| molecular sequence data | 25 | 2013 | 2014 | 2014 |
| plants, genetically modified | 20 | 2012 | 2014 | 2016 |
| arabidopsis | 65 | 2014 | 2015 | 2018 |
| arabidopsis proteins | 48 | 2014 | 2015 | 2017 |
| animals | 25 | 2012 | 2015 | 2019 |
| plant proteins | 58 | 2014 | 2016 | 2019 |
| plant leaves | 24 | 2013 | 2016 | 2019 |
| nicotiana | 18 | 2013 | 2016 | 2019 |
| plants | 45 | 2012 | 2017 | 2020 |
| substrate specificity | 26 | 2015 | 2017 | 2019 |
| humans | 24 | 2014 | 2017 | 2019 |
| gene expression regulation, plant | 20 | 2016 | 2018 | 2019 |
| kinetics | 20 | 2015 | 2018 | 2020 |
| photosynthesis | 13 | 2015 | 2018 | 2020 |
| plant extracts | 7 | 2019 | 2019 | 2020 |
| tandem mass spectrometry | 6 | 2016 | 2019 | 2020 |
| volatile organic compounds | 6 | 2018 | 2019 | 2020 |
| antioxidants | 12 | 2018 | 2020 | 2022 |
| plant diseases | 12 | 2016 | 2020 | 2020 |
| host-pathogen interactions | 6 | 2019 | 2020 | 2020 |
| flowers | 5 | 2021 | 2022 | 2023 |

The field of plant biochemistry has evolved from fundamental molecular research to addressing practical and ecological concerns. Initially (2003-2010), research focused on biochemistry, agriculture, and ecosystems, establishing a foundation for understanding plant biochemical pathways. From 2010 to 2015, molecular and genetic research surged, particularly regarding amino acid sequences, genes, plants, and Arabidopsis, providing deeper molecular-level insights. Between 2015 and 2020, the focus shifted to physiological and regulatory aspects of photosynthesis, gene regulation, substrate specificity, and plant functions. Recently (2019-2023), the scope has expanded to include plant-environment interactions, biochemical compounds, and applied fields, emphasizing volatile compounds, plant extracts, antioxidants, and host-pathogen interactions. This evolution indicates a move towards a comprehensive, interdisciplinary approach that merges molecular perspectives with ecological and practical considerations, shaping future research. Figure 8 shows the Trend of Topics chart.

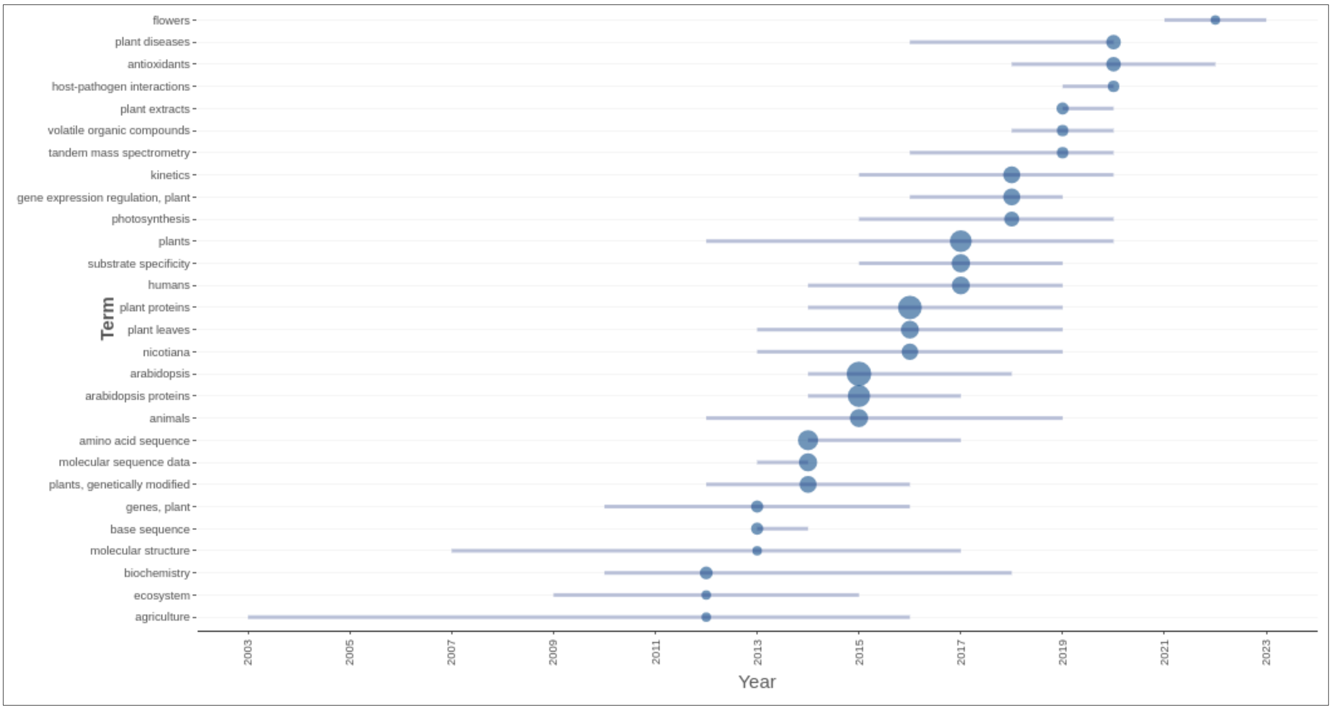


**Figure 8: Visualization Trend of Topics**

### 3.10 Co-occurrence Network

Network analysis of plant biochemistry revealed research clusters. Cluster 1, with the highest betweenness (60.226) and PageRank (0.028), connects biochemistry, human studies, metabolomics, and genomics. Cluster 2 highlights comparative biology and plant-animal interactions, with plant leaves showing a betweenness of 40.865 and animals at 24.658. Cluster 3 explored structural and molecular dimensions, emphasizing Arabidopsis (232.887 betweenness, 0.079 PageRank) and Arabidopsis proteins (73.319 betweenness, 0.058 PageRank). They also include substrate specificity, molecular sequence data, crystallography, and X-ray studies. Cluster 4 focused on applied and regulatory elements, featuring plant proteins (200.433 betweenness, 0.061 PageRank), gene expression regulation, genetic modifications, and stress responses. The distribution of betweenness, closeness, and PageRank values indicates the progression of plant biochemical research from molecular to ecological and applied contexts. Table 7 shows of betweenness, closeness, and PageRank values wise Co-occurrence Network analysis.

**Table 7: Co-occurrence Network**

| Node | Cluster | Betweenness | Closeness | PageRank | Node | Cluster | Betweenness | Closeness | PageRank |
|---|---|---|---|---|---|---|---|---|---|
| plants | 1 | 60.226 | 0.012 | 0.028 | protein binding | 3 | 1.521 | 0.012 | 0.017 |
| humans | 1 | 20.53 | 0.012 | 0.017 | catalytic domain | 3 | 2.304 | 0.013 | 0.021 |
| metabolomics | 1 | 0.065 | 0.009 | 0.007 | protein structure, tertiary | 3 | 3.553 | 0.013 | 0.022 |
| crops, agricultural | 1 | 3.497 | 0.01 | 0.008 | binding sites | 3 | 0.492 | 0.012 | 0.017 |
| biochemistry | 1 | 0 | 0.01 | 0.006 | cloning, molecular | 3 | 0.91 | 0.011 | 0.011 |
| genomics | 1 | 0.278 | 0.008 | 0.006 | chloroplasts | 3 | 0.146 | 0.011 | 0.009 |
| animals | 2 | 24.658 | 0.012 | 0.02 | oxidation-reduction | 3 | 1.604 | 0.012 | 0.014 |
| plant leaves | 2 | 40.865 | 0.013 | 0.023 | sequence homology, amino acid | 3 | 1.857 | 0.013 | 0.018 |
| photosynthesis | 2 | 2.661 | 0.011 | 0.009 | signal transduction | 3 | 0.673 | 0.011 | 0.007 |
| antioxidants | 2 | 0.158 | 0.01 | 0.006 | adenosine triphosphate | 3 | 0.811 | 0.012 | 0.013 |
| plant diseases | 2 | 1.055 | 0.01 | 0.008 | amino acid substitution | 3 | 0.236 | 0.012 | 0.013 |
| seeds | 2 | 1.02 | 0.011 | 0.008 | catalysis | 3 | 0.033 | 0.011 | 0.011 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| chlorophyll | 2 | 0.602 | 0.01 | 0.007 | escherichia coli | 3 | 0.309 | 0.011 | 0.011 |
| arabidopsis | 3 | 232.887 | 0.018 | 0.079 | thylakoids | 3 | 0 | 0.01 | 0.006 |
| arabidopsis proteins | 3 | 73.319 | 0.016 | 0.058 | acyl coenzyme a | 3 | 0.391 | 0.011 | 0.008 |
| amino acid sequence | 3 | 70.827 | 0.016 | 0.052 | base sequence | 3 | 0.418 | 0.011 | 0.009 |
| substrate specificity | 3 | 24.392 | 0.014 | 0.037 | biocatalysis | 3 | 4.163 | 0.011 | 0.013 |
| molecular sequence data | 3 | 22.176 | 0.014 | 0.038 | plant proteins | 4 | 200.433 | 0.017 | 0.061 |
| models, molecular | 3 | 26.28 | 0.014 | 0.037 | gene expression regulation, plant | 4 | 5.52 | 0.012 | 0.018 |
| crystallography, x-ray | 3 | 7.328 | 0.013 | 0.03 | plants, genetically modified | 4 | 7.97 | 0.012 | 0.019 |
| kinetics | 3 | 11.219 | 0.014 | 0.03 | nicotiana | 4 | 2.542 | 0.012 | 0.016 |
| recombinant proteins | 3 | 17.695 | 0.014 | 0.032 | phylogeny | 4 | 3.819 | 0.011 | 0.014 |
| protein conformation | 3 | 6.649 | 0.013 | 0.024 | stress, physiological | 4 | 2.257 | 0.011 | 0.012 |
| mutation | 3 | 7.269 | 0.013 | 0.026 | cytochrome p-450 enzyme system | 4 | 0.094 | 0.011 | 0.007 |
| mutagenesis, site-directed | 3 | 4.163 | 0.013 | 0.024 | biosynthetic pathways | 4 | 0.128 | 0.01 | 0.008 |

Analysis of co-occurrence networks in plant biochemistry has revealed distinct thematic clusters. The prominent green cluster, focusing on Arabidopsis and plant proteins, highlights their critical roles in scientific research. Large nodes and bold labels indicate high betweenness centrality and PageRank, marking key connectors across research domains. Terms such as amino acid sequence, substrate specificity, and protein binding indicate molecular structure, enzymatic activity, and protein interactions. The red cluster highlights biological systems and practices, with terms such as biochemistry, genomics, metabolomics, crops, and agriculture pointing to biochemical pathways, genetic analysis, and agricultural applications. The blue group, which is associated with plant growth, photoreaction, chlorophyll, and antioxidants, emphasizes energy production and environmental adaptation. The purple cluster concentrates on gene expression regulation, biosynthetic pathways, and phylogenetics, which are related to genetic modifications, evolutionary biology, and regulatory mechanisms. Varied node sizes illustrate the relationships among molecular research, agricultural science, and ecological considerations. This visualization captures the interdisciplinary nature of plant biochemistry, linking molecular discoveries to sustainable agriculture. Figure 9 Analysis of co-occurrence networks.

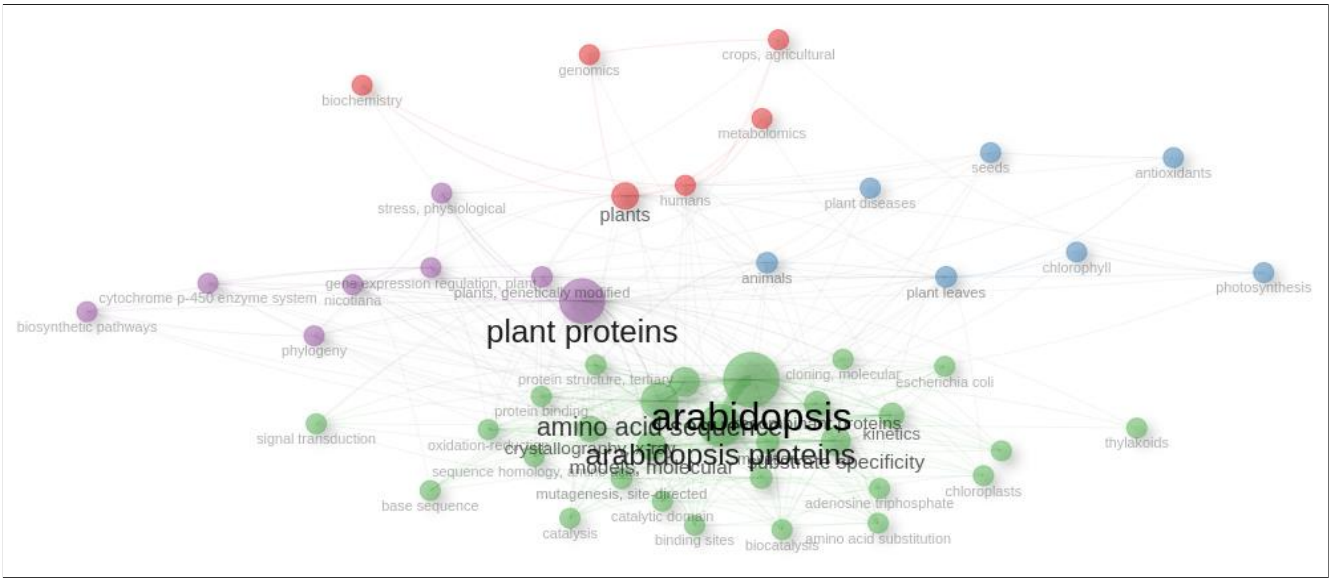


**Figure 9: Visualization of Co-occurrence Network**

## Scientometrics Visualization of Plant Biochemistry Using Pubmed API from 2000 To 2024

The conceptual framework of plant biochemistry reveals complex connections between research fields, highlighting relevant relationships and scoring frequencies. "Arabidopsis" has the highest CallonCentrality (17.255) and RankCentrality (4), underscoring its central role in plant molecular research, with a high cluster frequency (795). The "plant proteins" group follows with CallonCentrality of 18.17 and RankCentrality of 5, emphasizing plant protein functions. The "stress, physiological" group, with CallonCentrality of 6.571 and ClusterFrequency of 183, is crucial in plant stress response study. The "crops, agricultural" set, with CallonCentrality 5.964 and ClusterFrequency 117, underscores its importance in agricultural studies. The "plant diseases" group, with smaller frequency (41) and CallonCentrality = 1,561, indicates focused research on plant pathogen control. Varied CallonDensity and RankDensity numbers reflect the research intensity. This framework serves as a multidisciplinary platform where molecular, agricultural, and physiological interactions converge to enhance the understanding of plant biochemistry. Table 8 shows the Framework of Cluster.

**Table 8: Framework of Cluster**

| Cluster | CallonCentrality | CallonDensity | RankCentrality | RankDensity | ClusterFrequency |
|---|---|---|---|---|---|
| crops, agricultural | 5.964 | 49.956 | 2 | 2 | 117 |
| stress, physiological | 6.571 | 60.79 | 3 | 4 | 183 |
| plant diseases | 1.561 | 58.951 | 1 | 3 | 41 |
| arabidopsis | 17.255 | 71.543 | 4 | 5 | 795 |
| plant proteins | 18.17 | 43.895 | 5 | 1 | 484 |

The biochemical analysis of the plants identified distinct thematic clusters. The lower section shows a purple cluster focused on Arabidopsis and plant proteins, highlighting their importance in genetic and molecular processes. This research includes terms such as molecular sequence data, kinetics, and site-directed mutagenesis, which suggest studies on protein structure and genetic modifications. The orange and blue clusters are related to plant physiology, metabolism, and ecological interactions. The blue cluster focuses on photosynthesis, chlorophyll, and plant leaves, emphasizing energy production and adaptation. The orange cluster addresses plant stress molecular physiology, gene expression regulation, phylogeny, evolution, and stress response. The red cluster represents general biological research, biochemistry, genomics, metabolomics, and human studies, showing links between research domains and biochemical methods across biological systems. The green cluster covers crops and agricultural pathways oriented towards food production sustainability. This illustrates the role of plant biochemistry in connecting molecular processes, physiology, and research areas such as genetics and agriculture. Node size and connectivity patterns highlight key research areas and theme interactions. Figure 10 Visualization of Cluster wise Network map.

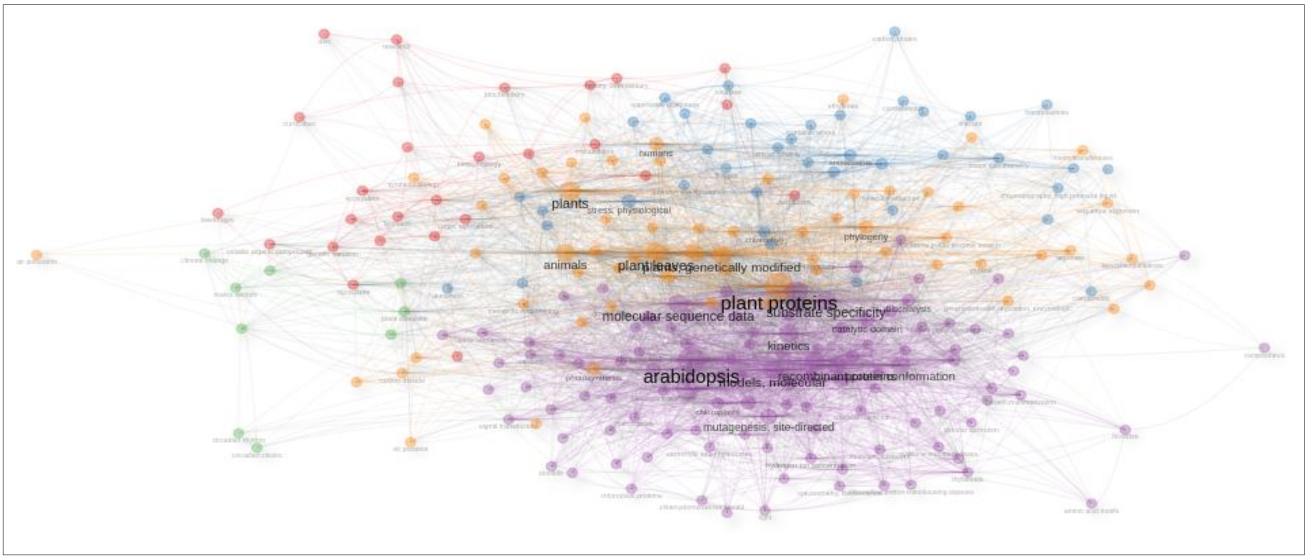


**Figure 10: Visualization of Cluster Network**

### 3.11 Collaboration Network

Definitions of the most successful researchers among the plant biochemistry research network were given by betweenness, proximity, and PageRank measures. With a score of 6.181, Jez had the highest influence level among the betweenness ratings. Located in Cluster 4, the betweenness metrics and PageRank measurements of Westfall CS obtained rather high values of 0.569 and 0.045. Researchers with high closeness values maintain direct and efficient connections within a network. Facchini and Morris hold the top place in Cluster 2 with a closeness score of 1.0 while Brandstetter, Cabrele and Dall located in Cluster 6 possess a score of 0.5. Out of research results, Xu Y was able to generate a PageRank value of 0.047. The PageRank values show that in Cluster 3 the literature with 0.049 is the best. Cluster 5 corresponds with the network association index value ascribed to the Rolland, Seigneurin-Berny, and Catty alliances—0.333. Compared to other team members who achieve impact by their great closeness or PageRank features, key knowledge connectors have substantial betweenness characteristics. The main subjects of the analysis applying this approach are biochemical plant research teams. Table 9 analysis of Collaboration Network.

**Table 9: Collaboration Network**

| Node | Cluster | Betweenness | Closeness | PageRank | Node | Cluster | Betweenness | Closeness | PageRank |
|---|---|---|---|---|---|---|---|---|---|
| xu y | 1 | 2 | 0.333 | 0.047 | chen s | 4 | 0 | 0.1 | 0.011 |
| benning c | 1 | 0 | 0.2 | 0.013 | rolland n | 5 | 0 | 0.333 | 0.036 |
| caldo kmp | 1 | 0 | 0.25 | 0.037 | seigneurin-berny d | 5 | 0 | 0.333 | 0.036 |
| chen g | 1 | 0 | 0.25 | 0.037 | catty p | 5 | 0 | 0.333 | 0.031 |
| facchini pj | 2 | 0 | 1 | 0.033 | crouzy s | 5 | 0 | 0.333 | 0.031 |
| morris js | 2 | 0 | 1 | 0.033 | brandstetter h | 6 | 0 | 0.5 | 0.033 |
| last rl | 3 | 1 | 0.5 | 0.049 | cabrele c | 6 | 0 | 0.5 | 0.033 |
| li l | 3 | 0 | 0.333 | 0.019 | dall e | 6 | 0 | 0.5 | 0.033 |
| pichersky e | 3 | 0 | 0.333 | 0.033 | cann mj | 7 | 0 | 0.167 | 0.036 |
| jez jm | 4 | 6.181 | 0.167 | 0.068 | dixon ch | 7 | 0 | 0.167 | 0.036 |
| lee sg | 4 | 0.25 | 0.111 | 0.036 | pålsson lo | 7 | 0 | 0.167 | 0.036 |
| westfall cs | 4 | 0.569 | 0.143 | 0.045 | townsend pd | 7 | 0 | 0.167 | 0.036 |
| holland ck | 4 | 0 | 0.125 | 0.02 | goverse a | 7 | 0 | 0.167 | 0.03 |
| zubieta c | 4 | 0 | 0.125 | 0.027 | sharples gj | 7 | 0 | 0.167 | 0.029 |
| alvarez s | 4 | 0 | 0.125 | 0.027 | slootweg ej | 7 | 0 | 0.167 | 0.03 |

The scholarly connections between top researchers within plant biochemistry serve to show how they relate to each other. The central position belongs to Jez JM, who maintains high betweenness centrality to facilitate connections between different research groups. The research collaborations of Jez JM point toward major partnerships with Westfall CS, Chen S, and Lee SG. The visual presentation demonstrated separate zones that implemented unique research fields. Westfall CS and Chen S work on enzyme mechanisms as a single research group. However, Townsend PD and his coworkers Dixon CH and Pålsson LO show patterns of co-authorship in studies of molecular dynamics. The biochemical research area specializes in its own cluster containing Catty P with Slootweg EJ and Crouzy S. The thickness of lines and their colors in the network illustrate co-authorship frequency, whereby thicker edges signify numerous collaborations between authors. The sizes of nodes within the diagram correspond to the research impact of individual researchers; Jez JM and Westfall CS have larger nodes compared to others. The network visualization visualizes academic relationships between plant biochemistry scholars who drive molecular and physiological research development at various levels. Figure 11 authors wise network visualization diagram.

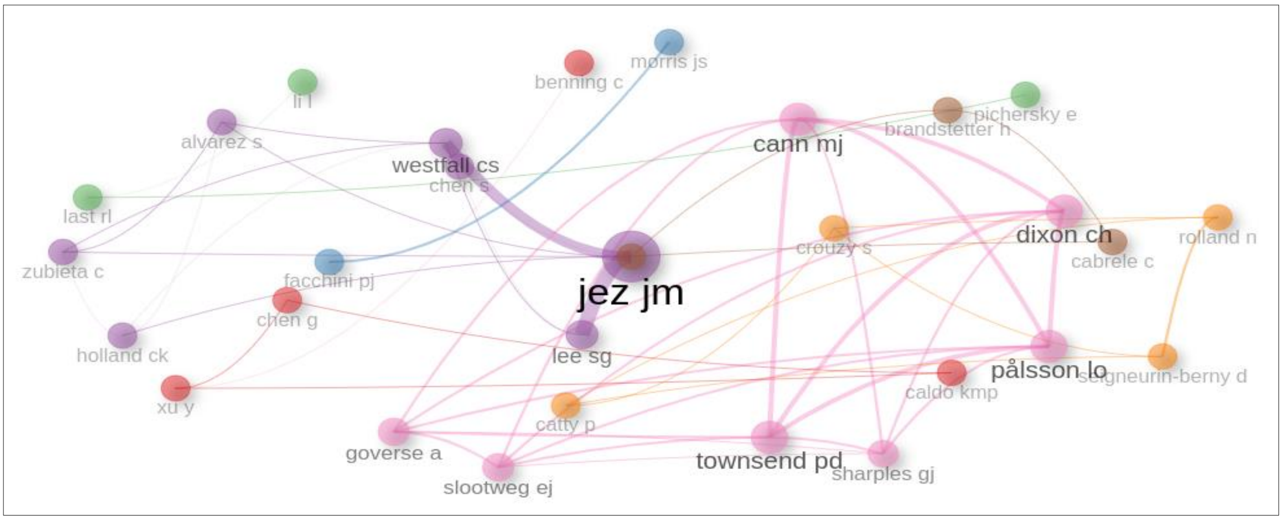


**Figure 11: Visualization of Collaboration Network**

### 3.12 Countries' Collaboration World Map

Through its visualization, the Countries' Collaboration World Map displays worldwide research collaboration networks among different nations. The visual display connects various nations through research exchanges where connection strength is measured through frequency values. Three notable bridge connections exist between Germany-Russia and the USA-Germany, while China-France maintains two joint research initiatives depending on recent data. France works together with Germany. Italy, Belgium, and Pakistan (Frequency 2). Germany conducted research exchanges between its institutions and various European counterparts, including Austria, along with Italy and Sweden. Research collaborations extend between North American and Asian countries as well as between Asian countries and Australia, according to the map, which demonstrates increasing global research connections. Partners of advanced and developing economies, including France, Pakistan, Egypt, South Africa, and Turkey-Uzbekistan, experience inter-regional knowledge exchange. The visualization shows LIB projects and partner universities with smaller but significant collaborations, such as Denmark-Bolivia, Sweden-Bolivia, and Poland-Tunisia. This map demonstrates how scientific knowledge enriches borders through collaborative partnerships, highlighting the necessity of crossing national thresholds in academic discourse to address global challenges and advance science. Table 10 display the Countries' Collaboration World Map.

**Table 10: Countries' Collaboration World Map**

| From | To | Frequency | From | To | Frequency | From | To | Frequency |
|---|---|---|---|---|---|---|---|---|
| AUSTRALIA | DENMARK | 1 | EGYPT | SAUDI ARABIA | 1 | PAKISTAN | KOREA | 1 |
| AUSTRALIA | INDIA | 1 | EGYPT | SOUTH AFRICA | 1 | POLAND | BELGIUM | 1 |
| AUSTRALIA | IRAN | 1 | FRANCE | AUSTRALIA | 1 | POLAND | SWEDEN | 2 |
| AUSTRALIA | SPAIN | 1 | FRANCE | BELGIUM | 2 | POLAND | SWITZERLAND | 1 |
| AUSTRALIA | UNITED KINGDOM | 2 | FRANCE | DENMARK | 1 | POLAND | TUNISIA | 1 |
| BELGIUM | TUNISIA | 1 | FRANCE | GERMANY | 2 | SOUTH AFRICA | SAUDI ARABIA | 1 |
| CANADA | AUSTRALIA | 1 | FRANCE | ITALY | 2 | SWEDEN | BOLIVIA | 1 |
| CHILE | SERBIA | 1 | FRANCE | PAKISTAN | 2 | SWITZERLAND | ITALY | 1 |
| CHINA | FRANCE | 2 | FRANCE | POLAND | 1 | TURKEY | UZBEKISTAN | 1 |
| CHINA | GERMANY | 1 | FRANCE | SPAIN | 1 | UNITED KINGDOM | ITALY | 1 |
| CHINA | JAPAN | 1 | FRANCE | SWITZERLAND | 1 | UNITED KINGDOM | NETHERLANDS | 2 |
| CHINA | KOREA | 1 | FRANCE | TUNISIA | 1 | USA | AUSTRALIA | 1 |
| CHINA | NETHERLANDS | 1 | GERMANY | AUSTRIA | 2 | USA | BRAZIL | 1 |
| CHINA | PAKISTAN | 1 | GERMANY | ITALY | 1 | USA | CHINA | 1 |
| DENMARK | AUSTRIA | 1 | GERMANY | JAPAN | 1 | USA | DENMARK | 1 |
| DENMARK | BOLIVIA | 1 | GERMANY | PHILIPPINES | 1 | USA | GERMANY | 3 |
| DENMARK | ITALY | 1 | GERMANY | RUSSIA | 3 | USA | ITALY | 1 |
| DENMARK | RUSSIA | 1 | GERMANY | SWEDEN | 1 | USA | KOREA | 1 |
| DENMARK | SWEDEN | 1 | JAPAN | SPAIN | 1 | USA | SPAIN | 1 |
| DENMARK | SWITZERLAND | 1 | JAPAN | THAILAND | 1 | USA | TURKEY | 1 |
| EGYPT | HUNGARY | 1 | JAPAN | UNITED KINGDOM | 2 | | | |

### Scientometrics Visualization of Plant Biochemistry Using Pubmed API from 2000 To 2024

According to the provided map, the frequency and strength of international academic collaborations define the main interface type. Darker blue indicates strengthened partnerships. Countries from different continents show global interconnectedness through this illustration while establishing global academic and research cooperation levels. Figure 12 provid the Visualization of Countries' Collaboration World Map.

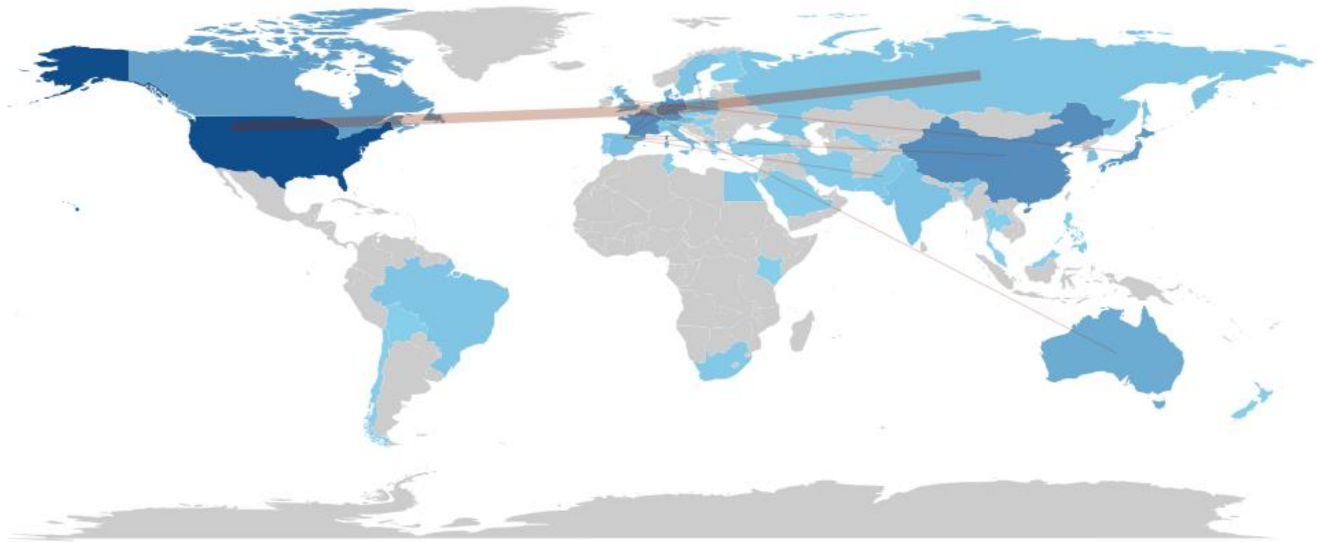

**Figure 12: Visualization of Countries' Collaboration World Map**

### 4. DISCUSSIONS

The bar chart illustrates international academic cooperation levels through a nation-based analysis among the top 20 countries. All world research networks saw extensive participation from the United States, China, the United Kingdom, Germany, and India. France, Canada, Australia, Italy, and Spain are key players in international research collaborations. Japan, South Korea, Brazil, the Netherlands, and Russia are notable for participating in cross-border scientific projects. Traditional R&D powerhouses dominate this list, with their influence reaching Sweden, Switzerland, Turkey, Iran, and Saudi Arabia. This depiction examines the dynamics of the global knowledge exchange. Figure 13 Countries wise collaboration frequency chart.

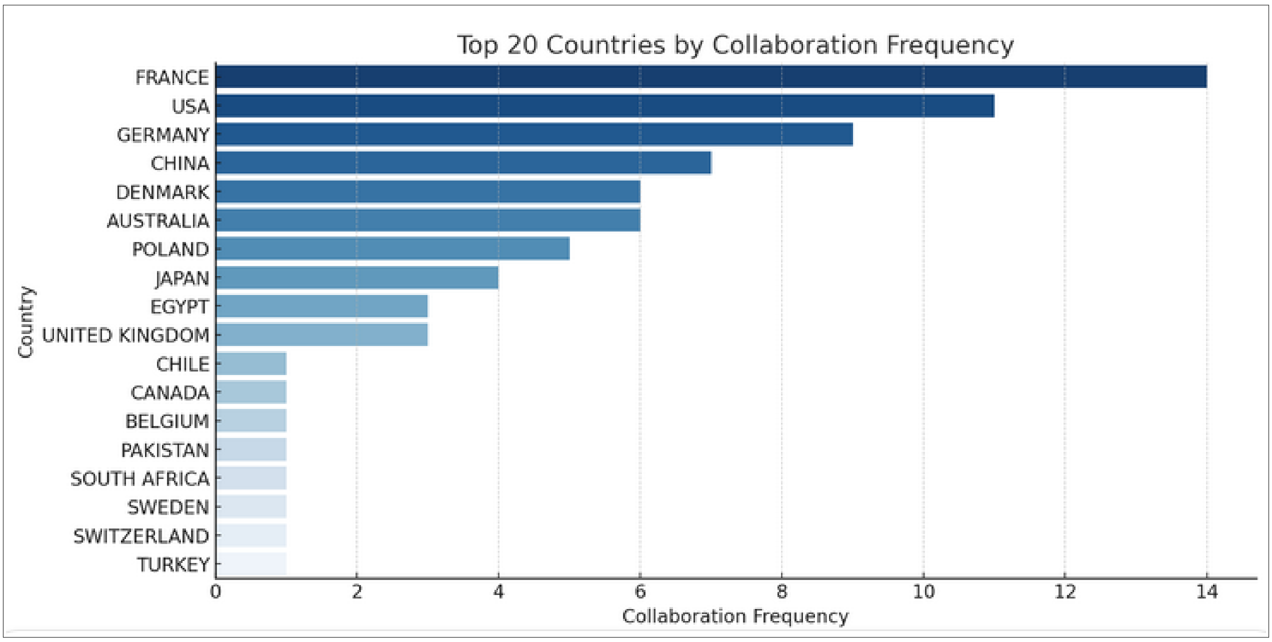


**Figure 13: Countries by collaboration frequency**

Scientists mapped plant biochemistry data using the Infranodus and PubMed API databases to illustrate how different fields interact from 2000 to 2024. The main concepts, together with the subjects and driving methods, appear on the network map. The important facets "photosynthesis," "proteins" along with "Arabidopsis" demonstrate the relevance of plant procedures and experimental organisms. Scientific visualization confirms the progressively vital role of "molecular" techniques and "genetically" modified organisms and "genetics" throughout the field of plant biochemistry. Links between "plant" and terms like "agriculture," "ecosystem," or "diseases" diseases the illustrate the impact of biochemist toydepicts worldwide. The diagram presents both the relevant research relationships among scientific fields and knowledge gaps in the field for future studies. The representation AI and insights network indicate that modern scholars display a growing interest in AI deductions from plant biochemistry research. This study investigated contemporary research on plant biochemistry. Figure 14 shows the Visualization of facets wise Network illustrate.

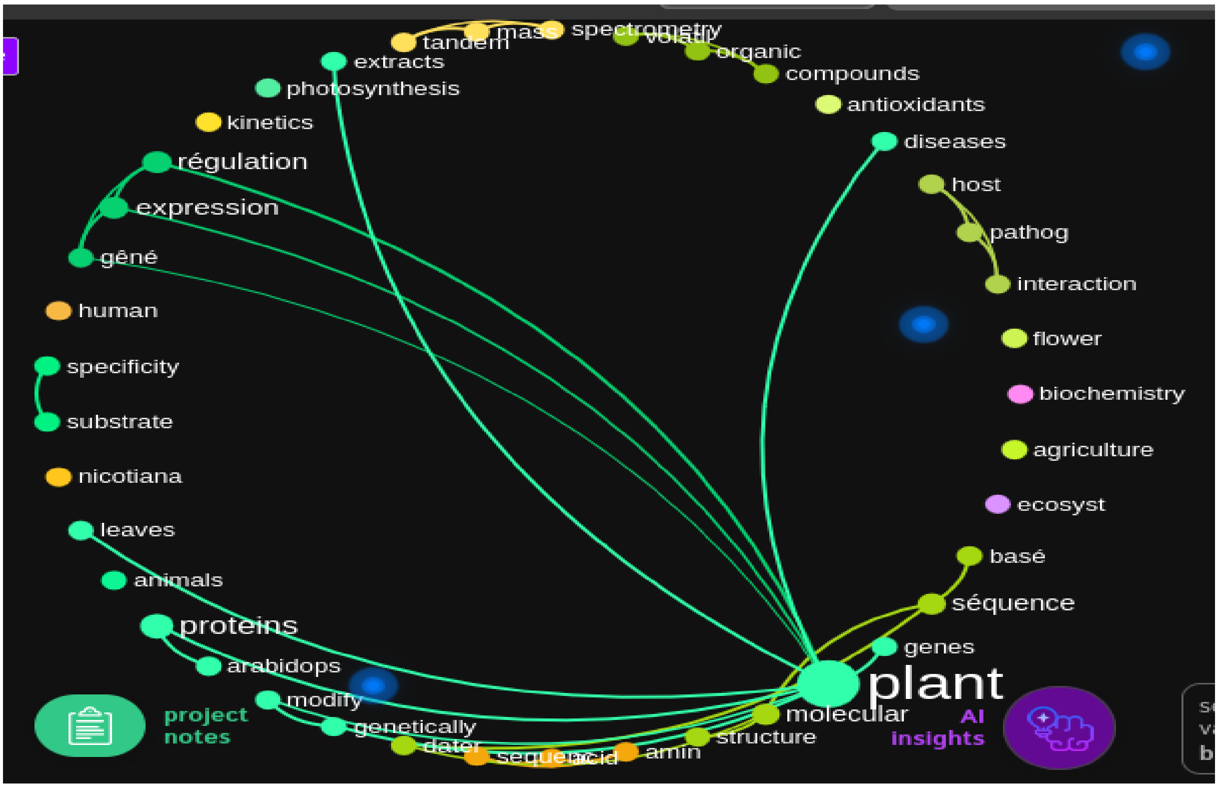


**Figure 14: Visualization of facets wise Network map**

Network graphs visualizing plant biochemistry research have revealed key study areas and their interconnections. Centered on "plant," the graph highlights research themes. The Arnold group, led by Krishna Niyogi, and the Viselab, spotlighted topics through a cluster named "photosynthesis," expression, "regulation," and "kinetics." Studies regarding plants use molecular biology and genetics terminology marked by phrases "genes," "molecular," "genetically," "proteins," and "arabidopsis." References to "agriculture," "ecosystem," "diseases," "host," and "pathogen" show plant biochemistry's applicability to ecology, biological interactions, and plant diseases. The significance of MS and mass spectrometry analytical techniques is evident. AI algorithm-based research demonstrates the future possibilities for plant biochemistry advancement and current scientific research conditions. Figure 15 display the Visualization of Network graphs.

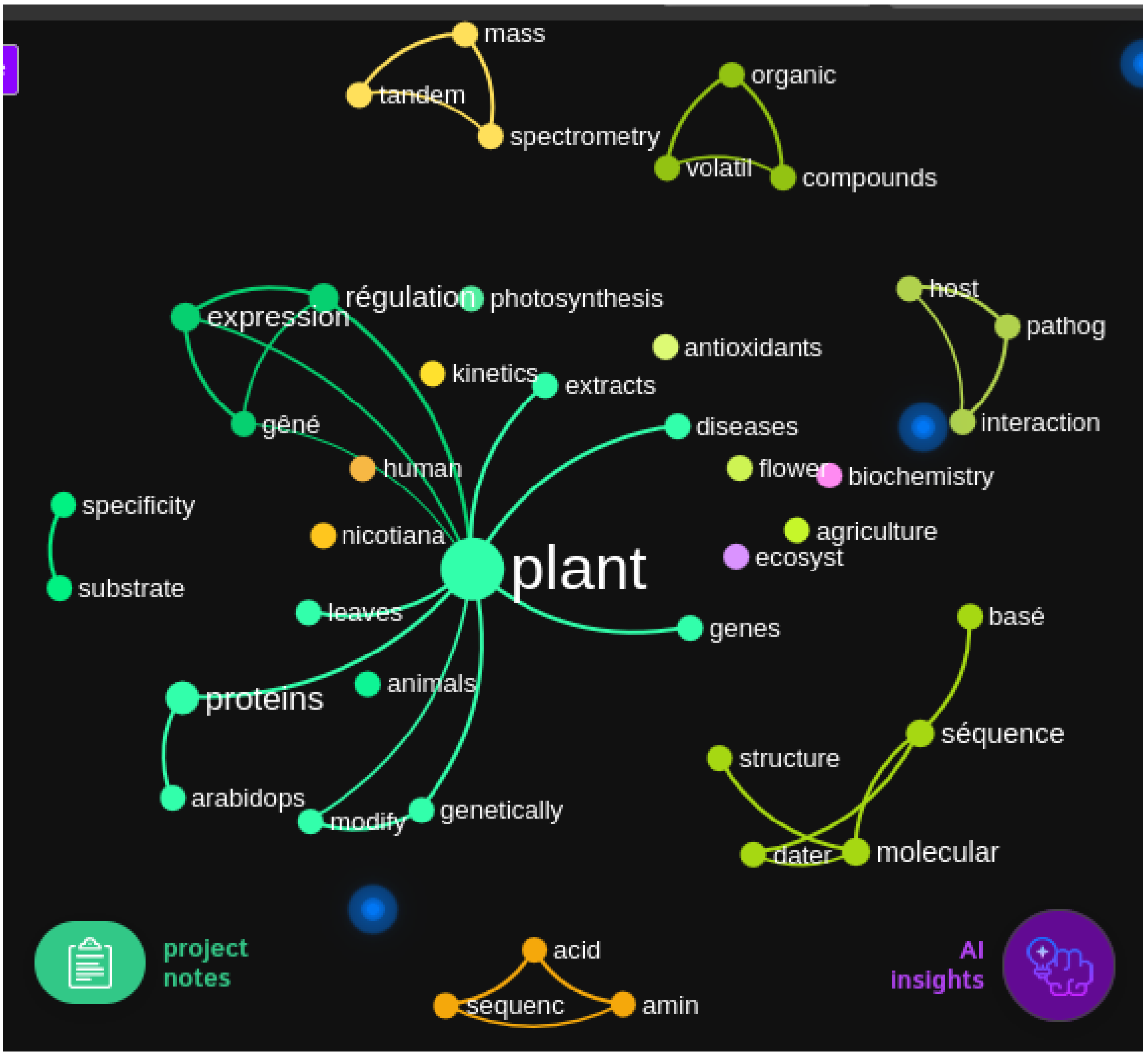


**Figure 15: Visualization of Network graphs**

The plant biochemistry research collaboration network is complex, with central positions as key players. Jez JM has the highest betweenness, while Westfall and Xu spread influence through modest betweenness and high PageRank. Facchini and Morris JS have strong closeness, enhancing information flow in Cluster 2. Centrality measures emphasize the importance of interactions, with some facilitating cluster communication and others excelling in local collusions. The co-occurrence network shows topic clusters progressing from molecular studies to agricultural and environmental applications. The roles of Arabidopsis and plant proteins have been highlighted in plant molecular biology.

The green cluster provides links between the fundamental concepts related to protein structures, enzyme activities, and genetic modifications. Research conducted on the red and blue clusters uses biological applications to investigate metabolomics, photosynthesis, and plant stress responses. Genetic regulation and biosynthetic pathway research in the purple cluster have led to progress in both genetic modification and evolutionary biology. The research network shows how plant biochemistry transfers knowledge between molecular and physiological research, and applied applications for problem solving. Regarding practice, the bibliometric analysis documentation demonstrated a pattern between research output and changes to prominent journals and their author contributors. The number of published scientific studies increased after 2013 because researchers began to adopt molecular methods and work across different fields of science. The research activity is concentrated primarily in the Journal of Biological Chemistry and secondarily in Frontiers in Plant Science and Phytochemistry according to Bradford's law. Research articles in this field demonstrate molecular and biochemical orientations, including key works from researchers Jez JM and Facchini PJ.

Lotka's law governs the publication output of scientists, so most of them only produced one paper, while others produced many papers. Based on records from consistent outputs, the output stream at Washington University, St. Louis, MO, USA) was kept constant. Academic institutions in India and China are developing their research output, indicating a changing global trend for research participation, which has emerged from computational methods that combine with artificial intelligence research through global partnerships. Metabolic engineering development requires this field to improve agricultural production and environmental sustainability.

## 5. CONCLUSION

### 5.1 Summary of Findings

Research publications in plant biochemistry have shown major changes when analyzed through scientometric methods during the period of 2000 to 2024. The number of scientific studies within the scope of plant biochemistry experienced rapid growth, which culminated in 2015, after 2013, when interest and funding dramatically increased. Plant biochemistry research depends heavily on the Journal of Biological Chemistry since it serves as a main research publication platform. A scientific review identified JM Jez as the main figure within collaborative research networks during the investigation. The thematic analysis showed that Arabidopsis biological systems and plant proteins developed into strong research clusters along with stress physiology processes. This is because scientists focused their studies on molecular processes and how plants respond to stress.

### 5.2 Implications

The research findings were significant. Research clusters together with collaborative networks provide scientific researchers with directional information for developing potential alliances with newly emerging research fields. The collected data permit the government to determine monetary allocations according to current plant biochemistry trends. These trends focus on stress responses and molecular mechanisms, as these areas hold promise for helping agriculture and the environment. Research collaborations that unite molecular findings with agricultural field applications gain funding support from agencies because of established thematic relationships.

### 5.3 Limitations

Nevertheless, this study had some limitations. Using PubMed's API for data collection may have omitted significant publications that were not listed in this repository. Focusing on English-language journal articles potentially overlooks insights from other languages and publication types. The selected period (2000-2024) may not have captured the most recent trends or preprints awaiting publication. Moreover, incomplete field information, such as cited references and citation counts, could have impaired the comprehensiveness of citation analysis.

### 5.4 Future Work

Further studies should have a framework based on this analysis. An extensive database search on the Web of Science or Scopus will provide enhanced research field insights. Investigations into funding patterns, along with their effects on performance evaluation, would reveal the level of support for plant biochemistry research. Testing artificial intelligence applications requires analyzing the 'AI' term in network mapping to discover new methods for future use. An analysis of plants in genetics and agriculture would provide additional data on research achievements and the connection between plant biochemistry through comparative evaluation.

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