

Research trend analysis of *Leucojum aestivum* based on Citespace visualization software

Abstract

The secondary metabolite of *Leucojum aestivum* lycorine, is of high medicinal value and has attracted much attention internationally. Therefore, it is essential to review and analyze the existing literature on *L. aestivum* to clarify the research progress, research bottlenecks, and applications of lycorine in landscapes. In this study, we used the Web of Science (WOS) and CNKI Chinese journal database as data sources to analyze the bibliometric analysis of *L. aestivum*-related literature in terms of the number of publications, journal sources, research institutions, keywords, and co-cited literature using Citespace visualization software. The results showed that the number of *L. aestivum*-related studies decreased compared to previous years, but the number of publications showed a high growth trend in this research frontier. Bulgaria has a significant dominance in *L. aestivum*-related research, while China has fewer publications in this field but focuses more on the frontiers of the discipline. The frontiers of *L. aestivum* research concentrate on

- improving in vitro culture devices, changing plant culture strategies, and adding chemical additives to improve the yield of compounds in plants;
- new methods for lycorine synthesis;
- identification of ornamental plant species and detection of compounds by electrochemical methods;
- practical applications of lycorine in medicine and its mechanism of action. It is inferred that future research will focus on the ornamental value, medicinal value, cultivation methods, and innovation of lycorine synthesis methods of *L. aestivum*.

Keywords: *Leucojum aestivum*, lycorine, bibliometrics, research trends, research hotspots

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Introduction

Leucojum aestivum L. is a perennial bulb flower of Amaryllidaceae, which has been known for the higher content of active alkaloids.¹ Over 500 active substances of antitumor, antiviral, antibacterial, antifungal, antimalarial, and analgesic s have been isolated.² *Leucojum* genus has two species worldwide, *L. aestivum* and *L. vernum*. The former is a native species in southern Europe, Turkey, the Balkans, the Caucasus, and northern Iran and is widely distributed in moist environments, swamps, and wetlands of 1100m.³ *L. aestivum* prefers moist environments and loose, fertile porous soils.⁴ It blooms from March to June, with the number of flowers per plant ranging from 1 to 5.2.⁵⁻⁸ and is propagated by bulb division, tissue culture, or seed propagation. Since its introduction into China, this species has been cultivated on a small scale in some provinces as an important ornamental flower with high medicinal value.

The progress of a discipline cannot be separated from the advancement of research methods. Whether possessing mature research rules has become a vital factor affecting its academic position.⁹ The knowledge mapping method is an important research method for analyzing and visualizing various academic fields. Its analyzing scope can be a discipline, a research field, or a subject area of an independent problem.¹⁰ In general, the knowledge mapping method analyzes the units in a particular lot of scientific knowledge, which is reflected by the collection of intellectual contributions of a scientific institution, a team, or a professional within it.^{11,12} The literature analysis is an essential reference to developing a specific research field. In the case of *L. aestivum*, it has received extensive attention to the extraction and medicinal value of *Lycoris* Alkaloids, but few review articles have been published, especially the bibliometric

analysis has not been reported so far. Based on scientometric theory and Citespace visualization analysis software, this study carried out the identification and visualized research for the fruits and essential documents since 1998. Set the original literature as cited literature, extended the search of cited literature dataset, established a knowledge map of disciplinary fields, and mined and analyzed the trends of *L. aestivum* scientific research, special teams, and journals in recent years. In this study, we desire to understand that the research contents will become the focused research point in which disciplines, what the difference among different countries and the cooperation among nations, how changed of the research hot-point and trend of *L. aestivum*, the detailed research progress and how to change of the future researching directions.

Material and methods

Data sources

To comprehensively reflect the international research trends of *L. aestivum* in recent years, the data were obtained from the Web of Science core collection database and the literature sources in the China Knowledge Network (CNKI) core paper database in this study.

For the foreign language data, to ensure the completeness of the *L. aestivum* works of literature, a subject search was conducted in Web of Science Advanced Search using the search strategy developed in Table 1. The search terms were mainly *Leucojum aestivum*. The search yielded 64 good literature records, and 64 papers were obtained after de-duplication. Secondly, the citation analysis of the 64 documents in the WOS database revealed a total of 496 validly cited literature records and 409 papers after de-duplication. The knowledge

network analysis of the titular data of the two types of literature was conducted separately to analyze research trends through comparative studies further. For the Chinese data, an advanced search was selected in CNKI with “subject=(*L. aestivum*).” The time was chosen to be the same as the WOS database search, 1985–2022; the search time was January 15, 2022, and duplicate and invalid literature were screened. Finally, two papers were identified, and because of the small amount of data, they were not mapped and were only treated for discussion.

Table 1 Topic search queries used for data collection in *L. aestivum* literature

Set	Topic search
I	Topics=(“ <i>Leucojum aestivum</i> ” or “ <i>Leucojum aestivum</i> L.”) and Type of Literature=(Article) and Language=(English); Index=SCI-EXPANDED,SSCI;Year=1985–2022

Research methods

Citespace 5.8.R3 (64-bit) was used to visualize and analyze the literature dataset of *L. aestivum* and related fields. Citespace software is used to map the knowledge of a subject area through statistical data analysis, using the collaborative network of authors, research institutions, and co-occurrence mapping of keywords.¹³ Citespace presents the time series network model over time by time-slicing technology and summarizes it into a network, which facilitates scholars to systematically review related disciplines’ literature. The top 50 citation-ranked papers each year are used to construct a citation network for the corresponding year. The synthesized network is further divided into multiple co-cited literature clusters. Similar papers and related clusters are positioned nearby by the software, while different papers and clusters are further apart.¹⁰ Each cited literature cluster represents the knowledge base of the research area, and the literature citing these clusters is at the forefront of research in the field.^{11,12}

Results and Analysis

Analysis of the number of publications and trends

The annual number of international publications on *L. aestivum*-related studies obtained from WOS and CNKI is shown in Figure 1. The number of international publications on *L. aestivum* showed a flat trend. In contrast, the number of citations in the literature related to *L. aestivum* showed an increasing trend, and the number of publications in Chinese was much lower than that in English.

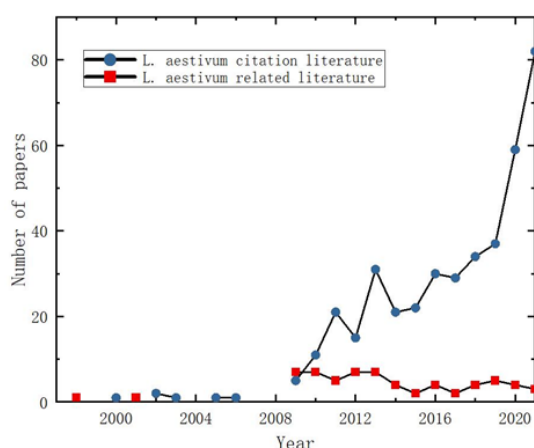


Figure 1 Volume of publications within the field, 1998–2021.

The study of *L. aestivum* dates back to 1909, and the species was first recorded in the literature in the Irish region and was in the stage of discovery of *L. aestivum* species until 1945.^{14–20} In 1962,

Gheorghiu first discovered the presence of lycorine and galanthamine in *L. aestivum* by dissecting the *L. aestivum* phytoplankton.²¹ Starting in 1987, researchers looked forward to achieving indoor production of lycorine and galanthamine through artificial plant cultivation.^{22–25} Some scholars have also made the assay and extraction of alkaloids more convenient by improving the assay and extraction methods.^{26–29}

As shown in Figure 1, the literature related to *L. aestivum* was sporadic before 2008, with one article per year. After 2008, the annual number of reports increased slowly (below ten pieces still) and was in a state of gentle fluctuation. After 2014 the change decreased to less than five per year; the research content includes the in vitro culture of *L. aestivum* determination and extraction of galanthamine and lycorine. The number of articles covering in vitro culture of *L. aestivum*, determination and extraction of galanthamine and lycorine fluctuated between 2008 and 2017, with an average annual growth rate of 37%. After 2017, the citation of *L. aestivum*-related literature entered a period of growth, with an average yearly increase of 31% and an overall surge. The number of articles exceeded 50 from 2020 onwards, with the highest number of articles in 2021, covering new technological advances in enzymology and engineering, technological innovations in the extraction and separation of biological compounds, and the production processes of natural products and biopharmaceuticals. The number of publications in 2021 was the highest. It can be seen that in recent years, *Lycoris* alkaloids are mainly used in pharmacology, and how to improve the efficiency of alkaloid extraction and synthesis has been becoming a popular research direction internationally, indicating that although the literature on *L. aestivum* is relatively small, it involves crucial disciplinary frontiers, which deserves further investigation by scholars; in addition, the potential of *L. aestivum* as a garden flower for application promotion cannot be ignored.

Analysis of journal sources and disciplines

As to the journal sources, *L. aestivum*-related papers have primarily concentrated in the fields of bioengineering and applied microbiology, medicinal chemistry, plant science, biochemistry, and molecular biology under the categories of engineering technology, biology, and environmental science; the publications of *L. aestivum*-related citations are primarily concentrated in the fields of bioengineering and applied microbiology, medicinal chemistry, plant science, organic chemistry, chemical synthesis under the categories of engineering technology, biology, chemistry, agricultural and forestry science, etc. The cited literature on *L. aestivum* is mainly published in bioengineering and applied microbiology, medicinal chemistry, plant science, organic chemistry, chemical synthesis, etc. The direct-cited literature and the originated literature are closely related, and the subject areas are highly overlapping. The top 10 foreign-language journals in terms of published citations and originated citations from 1985 to 2022 are presented in Tables 2&3, constituting an essential vehicle and source of knowledge for *L. aestivum*-related research. Researchers should pay more attention to these journals.

The double graph superposition knowledge map of journals with Cite Space software can show the distribution of literature and citation trajectory of each discipline, which can further study the pulse of knowledge development among journals and reveal the law of knowledge dissemination.³⁰ Figures 2&3 show the biplot overlay mapping of journals in *L. aestivum* research fields and related fields, with the cited literature (i.e., *L. aestivum*-related literature) on the left side representing the applied research field of the discipline and the cited literature on the right side describing the primary research field of the domain. The length of the horizontal axis of the oval in the figure is proportional to the number of authors, and the size of the

vertical axis is proportional to the number of papers published in the corresponding journals; the lines in the figure represent the connection between the cited literature and the cited journals in a particular field, and their thickness and density indicate the frequency and intensity of knowledge flow between journals;³¹ Comparing Figure 2 with Figure 3, that most of the cited literature related to *L. aestivum* is in the same field as the original literature, and is more widely studied in botany, environmental science, and biology proved that. This shows that most of the cited literature on *L. aestivum* is in the same field as the original literature and is more extensive in botany, environmental science, and biology. In summary, the research in this field crosses and integrates multiple disciplines such as geology, ecology, biology, botany, zoology, veterinary medicine, molecular science, and immunology. And with botany, environmental science, and ecology as the basic disciplines to expand to a broader range of disciplines, it has more significant potential development.

Table 2 Top 10 journals of paper amount

Top 10 journals of paper amount	Paper amount
ENGINEERING IN LIFE SCIENCES	5
BIOTECHNOLOGY & BIOTECHNOLOGICAL EQUIPMENT	4
PLANT CELL TISSUE AND ORGAN CULTURE	4
NATURAL PRODUCT COMMUNICATIONS	3
ZEITSCHRIFT FÜR NATURFORSCHUNG SECTION C A	3
JOURNAL OF BIOSCIENCES	3
APPLIED BIOCHEMISTRY AND BIOTECHNOLOGY	2
CENTRAL EUROPEAN JOURNAL OF BIOLOGY	2
FRESENIUS ENVIRONMENTAL BULLETIN	2
JOURNAL OF NATURAL PRODUCTS	2
JOURNAL OF PLANT PHYSIOLOGY	2

Table 3 Top 10 journals in terms of citation

Top 10 journals in terms of citation	Citation
INTERNATIONAL JOURNAL OF ELECTROCHEMICAL SCIENCE	27
PLANT CELL TISSUE AND ORGAN CULTURE	25
MOLECULES	19
INDUSTRIAL CROPS AND PRODUCTS	16
JOURNAL OF CHEMICAL EDUCATION	12
SOUTH AFRICAN JOURNAL OF BOTANY	12
ENGINEERING IN LIFE SCIENCES	11
FRONTIERS IN PLANT SCIENCE	10
NATURAL PRODUCT COMMUNICATIONS	9
JOURNAL OF NATURAL PRODUCTS	7

From the analysis of published papers involving disciplines (Figure 4), it can be seen that the literature related to *L. aestivum* is mainly concentrated in botany, biotechnology, biochemistry, followed by pharmacology, chemical analysis, etc.; the literature cited by *L. aestivum* is primarily focused in botany, multidisciplinary chemistry, biochemistry, followed by biotechnology applications, microbiology, medicinal chemistry, etc. This analysis indicates that this field has become a common research topic in botany, biology, chemistry, and other disciplines.

Analysis of national institutions and cooperation

Based on WOS data, the analysis of national and institutional cooperation networks reflects the development and closeness of cooperation among countries and institutions in these research areas. In the light of *L. aestivum*-related literature, the top 5 countries in terms

of the number of publications are Bulgaria, France, Poland, Spain, and Turkey, according to the country cooperation co-occurrence map (Figure 5). According to the institutional co-occurrence map, the top 5 institutions are the Bulgarian Academy of Sciences, University of Barcelona, University of Lorraine, Bulgarian Academy of Agriculture, and Krakow Agricultural University, which indicates that Bulgaria is internationally prominent in *L. aestivum*-related research. The centrality analysis showed that those published articles from German, Italian and Spanish researchers with higher centrality and more core literature. It is more intuitive from the figure that the University of Barcelona and the Bulgarian Academy of Sciences collaborate more closely, while the Chinese Academy of Sciences, Hangzhou University of Electronic Science and Technology, and the Chinese Academy of Sciences in Jiangsu Province collaborate the most. The results are consistent with previous studies on the bibliometry of *Lycoris*.³² At the frontiers of the discipline, there is a good partnership between some Chinese institutions with a more significant potential for growth.

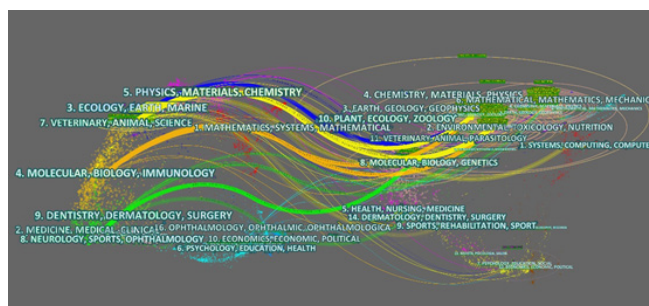


Figure 2 The double graph superposition knowledge map of *L. aestivum* related documents and journals.

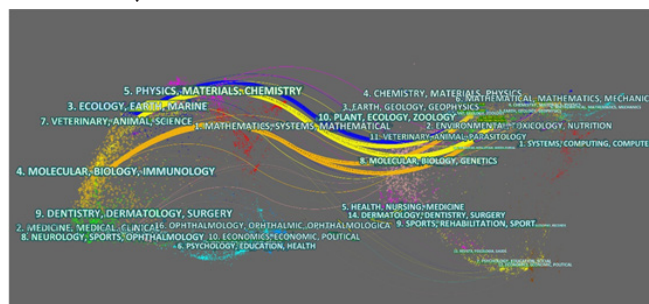


Figure 3 The double graph superposition knowledge map of *L. aestivum* citation documents and journals.

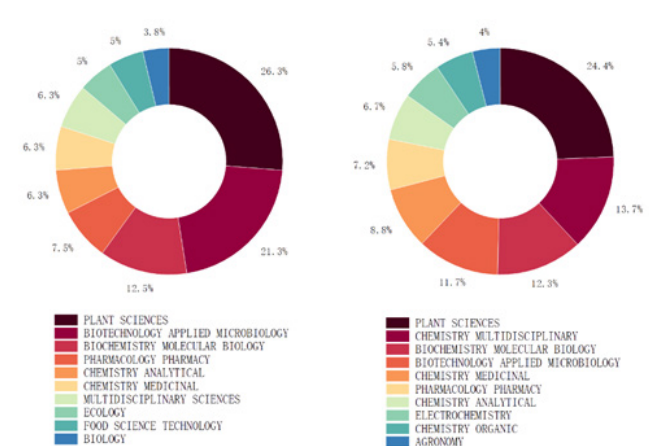


Figure 4 Subject category distribution of the papers.

(left, *L. aestivum* related literature, right, *L. aestivum* cited literature).

number of papers is stable, with the main keywords being “salicylic acid,” “microextraction,” “habitat fragmentation,” etc.

Keyword co-occurrence analysis

In the keyword co-occurrence data of *L. aestivum*-related literature, “*L. aestivum*” was the largest node in the network with 32 occurrences, followed by “*Lycoris* Herb.” “Biosynthesis” occurred more than ten times. In the keyword co-occurrence data of *L. aestivum* citation literature, i.e., the keyword co-occurrence data of the disciplinary frontier area, “galanthamine alkaloids” accounted for the largest number of nodes, with 59 occurrences. This was followed by “plant,” “biosynthesis,” “growth,” “alkaloids” and “Galanthamine,” all appearing more than 40 times. Other representative keywords include “Alzheimer’s disease,” “culture,” and “*Lycoris* plant.” From Figure 7, we can see that the keywords mainly focus on three aspects: *Lycoris* plant, alkaloid synthesis, and plant culture. Combined with the keyword analysis, it can be seen that the *Lycoris* plant is the primary source of alkaloids such as *Lycoris* alkaloids and galanthamine. Plant culture and the improvement of biosynthesis technology are the research hotspots in this field. Researchers have also carried out a series of investigations on the growth and reproduction breeding of *L. aestivum* in to hope that the improvement of external conditions of plants will increase the alkaloid production of *L. aestivum* through the advancement of external conditions.³³⁻³⁶

Keyword analysis revealed that alkaloids are substantial extracts in *L. aestivum*, which have received extensive attention from the medical and agronomic fields. The economic value of alkaloids in the medical industry was assessed as early as 14 years ago.³⁷ The excellent efficacy of galanthamine has also attracted researchers to explore the antioxidant and antibacterial efficacy of alkaloids in different *Lycoris* plants,^{38,39} and the available clinical trials have shown that galanthamine is effective in treating cancer.⁴⁰ Galanthamine of initial commercial use was extracted from *L. aestivum* growing in Bulgaria; intense exploitation (using about 10-15 tons of bulbs per year) led to a drastic decrease in the population of *L. aestivum* and it became an endangered species.^{41,42} For this reason, some scholars want to artificially intervene in *L. aestivum* habitats, improve plant transplanting success,⁴³ and ultimately reach the goal of conserving *L. aestivum* germplasm resources through population studies of *Lycoris* Herb. Plants and the assessment of pollinating insect capabilities.⁴³⁻⁴⁶

Studies have shown that alkaloid synthesis is dominated by the plant genotype, the activity of biosynthetic activities.⁴⁷⁻⁵² At present, there are three methods to produce galanthamine on a large scale viz complete chemical synthesis and extraction from field plants (e.g., *Narcissus tazetta* *L. var. chinensis* Roem., *L. aestivum*, *Lycoris radiata* var. *radiata*);^{53,54} the first two methods have been suffering from technical problems, so the in vitro culture technique can be an alternative source of galanthamine.⁵⁵ Scholars have carried out many tests about the effectors of in vivo culture in *L. aestivum*, such as mineral nutrients,⁵⁶ carbohydrate sources,^{57,58} auxins,⁵⁹ cytokinins,⁶⁰ ethylene and melatonin,⁶¹⁻⁶³ and physical factors (temperature and medium) on alkaloid synthesis,⁶⁴ in which Ptak’s team has made a remarkable contribution. In addition, studies on the induction of methyl jasmonate and salicylic acid⁶⁵⁻⁶⁷ and the use of labeling to determine the biotransformation of the precursor 4'-O-methylnorbelladine have also been reported.⁶⁸⁻⁷⁰ *L. aestivum* in vitro culture has been improving to aid production; the first document about temporary soaking measures in stem segment culture was from Ivanov, and the result showed that the highest production of galanthamine was achieved by soaking at a frequency of 15min at 26°C.⁷¹ Then a modified glass column bioreactor was used and showed peak alkaloid

content in stem segments cultured at 22°C and an inlet flow rate of 18 L/(L.h);⁷² subsequently, gas chromatography-mass spectrometry was used to explore new patterns of alkaloids in *L. Aestivum* stem cultures cultured under immersion conditions.⁷³ In recent years, the team continued to develop a two-stage bioreactor culture system, in which the reactor can be an essential tool to increase the production of secondary metabolites in plants.⁷⁴

The content of alkaloids in *L. aestivum* has been receiving more and more attention, and the techniques for their determination have been improving, such as high-performance liquid chromatography (HPLC) can be used for the quantitative determination of galanthamine and lycorine,⁷⁵ gas chromatography-mass spectrometry (GC-MS) is sensitive and informative,⁷⁶ the simple and accurate capillary zone electrophoresis (CZE) is unique in terms of time and cost savings and can be used in industry for galanthamine determination,⁷⁷ and ionic liquids (ILs) are incorporated into extraction systems to produce more efficient and time-saving extractions and to avoid the use of hazardous solvents in sample preparation when used in HPLC methods.⁷⁸

Research Frontiers and Trend Analysis

In this study, the “research frontiers” are the cited literature provided by the *L. aestivum* research field, and the cited literature is searched for papers cited, which together form a cluster of co-cited clusters, and then create a “professional research direction,” which to a certain extent reflects the frontier scientific issues and frontier research fields in *L. aestivum* research. This method is a way to monitor and analyze the scientific development of *L. aestivum* from a perspective that reflects the frontier scientific issues and frontier research areas.

Keyword Burst Analysis

The detection technique of Burst words in Citespace enables the prediction of research directions in the field by detecting the nodes where the frequency of citations or co-occurrence of bursts increases in a specific period.⁷⁹ In this study, the keyword emergence analysis was performed on the WOS data. The 14 keywords with the highest emergence intensity were selected (Figure 8). The results of the keyword emergence analysis show that the literature in the frontier field of *L. aestivum* covers a wide range of keywords. Keywords from different subject categories emerge at other times. The research area is divided into 2 phases (Figure 8).

- i. The keyword emergence continued to increase from 2009 to 2019, including “daffodil,” “galanthamine,” “apoptosis,” “regeneration,” and so on. Regarding keyword duration and mutation intensity, research on *Lycoris* has gradually gained international attention since 2009. In terms of the content reflected by keywords, it has been paid more attention to galanthamine extraction and synthesis, plant tissue culture technology, and so on. In addition, the induction of apoptosis and regeneration by lycorine is also the research direction in this field. For example, lycorine significantly induced apoptosis and autophagy in hepatocellular carcinoma (HCC) cells in vitro and in vivo, treatment with a specific autophagy inhibitor (3-methyladenine/bafilomycin A1) or removal of LC-3B/Atg5 with siRNA greatly enhanced apoptosis by promoting the switch from autophagy to apoptosis in cancer cells.⁸⁰
- ii. The most significant number of keywords mutated from 2020 onwards, including “identification,” “classification,” and “electrochemical sensor.” Regarding keyword duration and mutation intensity, the identification and extraction of *Lycoris*

alkaloids have received more scholarly attention since 2020; the contents of the keywords extracted indicate that electrochemical sensor identification techniques and ionic liquid mediation techniques are popular methods for scholars to conduct research. For example, coated polydopamine-functionalized graphene was covered on plant tissue-modified electrodes to enhance the signal, and the electric tension was recorded from plant tissues in different buffer solutions, which can be used as an indicator for the identification of this species; and phylogenetic studies of electrochemical fingerprinting was proposed as an effective method for plant phylogenetic analysis;⁸¹ the results of using ionic liquid processes for the extraction and separation/ purification of many bioactive compounds were compiled, and the main achievements and future challenges in this field were discussed.⁸²

Keywords	Year	Strength	Begin	End	2000 - 2022
narcissus confusus	2000	3.76	2009	2012	
galanthamine	2000	2.66	2010	2011	
apoptosis	2000	3.3	2012	2015	
regeneration	2000	4.04	2014	2017	
() galanthamine	2000	3.05	2015	2017	
induction	2000	2.72	2016	2017	
tissue culture	2000	2.94	2017	2018	
galanthamine	2000	2.92	2017	2019	
secondary metabolite	2000	3.01	2019	2022	
identification	2000	3.65	2020	2022	
classification	2000	3.65	2020	2022	
electrochemical sensor	2000	3.65	2020	2022	
ionic liquid	2000	3.06	2020	2022	
leave	2000	2.83	2020	2022	

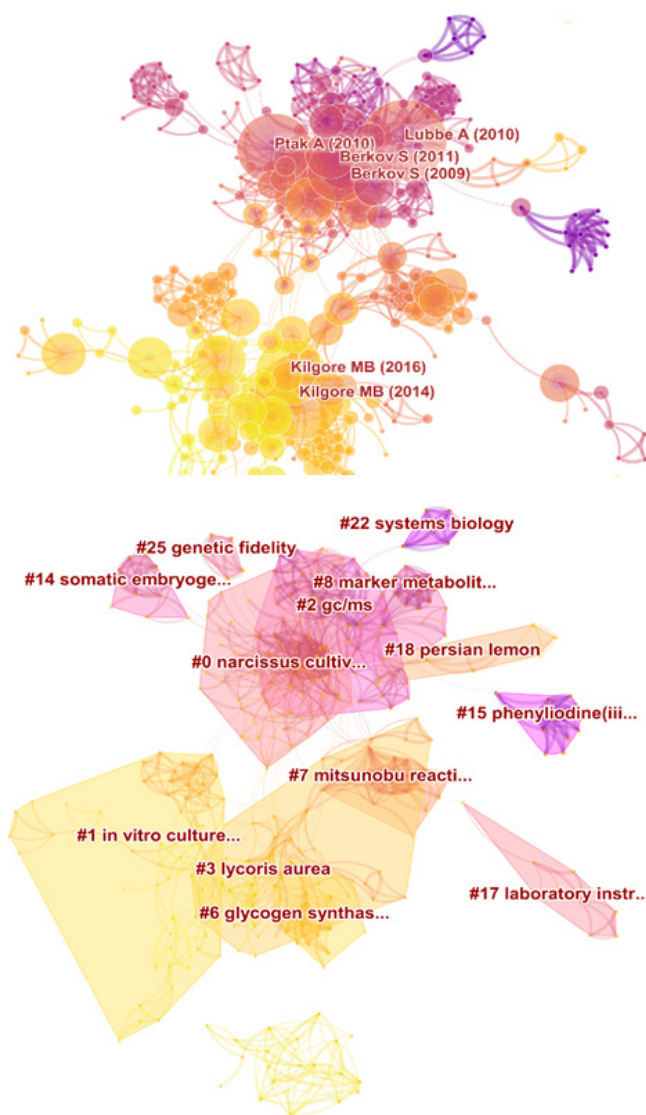
Figure 8

Active clustering analysis

The time span was set as 2000-2022 in Cite Space, the length of a single time partition was 1a, and the node type was selected as the reference. Then the clustering analysis was performed on the dataset to generate a linkage network map including 593 nodes and 2221 connected lines; the log-likelihood rate algorithm (LLR) was used to extract the noun terms of the cited literature for naming, and finally, the clustering analysis of literature co-citation was used to obtain the literature co-citation network map (Figure 9).

As shown in Figure 9, the top 5 clusters of network mapping are #0, #1, #2, #3, and #6, respectively. Cluster #0 consists of 73 members and focuses on stem segment culture and galanthamine production; the high citations literature was led by Georgiev in this cluster, and the team successfully cultivated stem segments of *L. aestivum* in an advanced modified columnar glass bioreactor by tissue, expecting to provide new access to *Lycoris* alkaloids using stem tip culture.^{83,84} The #2 cluster consists of 48 members and focuses on the production of *Lycoris* alkaloids and the evaluation of cholinesterase activity. The most cited article in the cluster is from the team of Parolo that concentrate on describing the habitat requirements, reproduction, and population biology of the species by discussing the taxonomy, status, morphology, distribution, ecology, and population biology of *L. aestivum*, and summarize the progress of *L. aestivum* research.⁸⁵ The #3 cluster consists of 45 members and focuses on the *Lycoris* area. These more cited articles were from Li⁸⁶ in this cluster. The team conducted treatment experiments on *Lycoris longituba* using MeJA to analyze the galanthamine content in plants under different treatment days and to study the MeJA-mediated mechanism of galanthamine synthesis in *Lycoris longituba* *Lycoris*. Cluster #6 consists of 22 members and focuses on stem tip culture and galanthamine production; Kohelová's team found out that derivatives of β -Crinine of *Lycoris*, which was cited are highly, and studied the inhibiting potential to

acetylcholinesterase and butyrylcholinesterase to evaluate inhibition capacity of the active derivatives on glycogen synthase 3p (GSK-3 β), which will offer the new drug for the treatment of Alzheimer's disease.⁸⁷

Figure 9 Co-citation network mapping of *L. aestivum* citation literature.

(The upper part is co-citation network mapping and the lower part is co-citation network clustering mapping).

Conclusion

In this study, the Citespace software was used to visualize and analyze *L. aestivum*-related studies based on bibliometric methods and provide an in-depth interpretation of the publication trends, disciplinary distribution, research strengths, research hotspots, and research frontiers of *L. aestivum*-related studies. The main research conclusions are as follows.

Firstly, in terms of publication trends and disciplinary distribution, *L. aestivum*, as a plant with high ornamental and medicinal value, has seen a decrease in research in recent years compared with previous years, mainly focusing on botany, biotechnology, and applied microbiology; however, in the frontier areas of research, the number of publications has shown a high growth trend, and the

academic influence has gradually increased, and there is a trend of cross-fertilization among botany, environmental science, ecology, chemistry, and medicine. However, in this frontier field, the number of publications has shown a high growth, the academic influence has gradually increased, and there is a trend of cross-fertilization between botany, environmental science, ecology, chemistry, medicine, and other disciplines.

Secondly, regarding research power, Bulgaria has a significant advantage in *L. aestivum*-related research. In contrast, China has fewer publications in the field but focuses more on the frontiers of the discipline and has a prominent influence in the frontier areas. The study shows that the cooperation among research institutions is not close enough, and international collaboration among research institutions needs to be further improved.

Thirdly, in terms of research hotspots, scholars focused on the improvement of lycorine production in *L. aestivum* through improved in vitro culture devices and chemical additives; new methods for lycorine extraction and determination; genetic conservation and population structure restoration of *L. aestivum* plants; discovery of lycorine biosynthesis utilizing gene identification and molecular identification.

Lastly, at the frontier of research, scholars focused on the improvement of in vitro culture devices, change of plant culture strategies, and addition of chemical additives to improve the yield of compounds in plants; new methods of lycorine synthesis; identification of ornamental plant species and detection of compounds by electrochemical methods; practical applications and mechanisms of action of lycorine in medicine.

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Conflicts of interest

The authors declare no conflicts of interest regarding the publication of this paper.

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