KNOWLEDGE MAPPING OF ALFALFA RESEARCH – A VISUAL ANALYSIS USING CITESPACE

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(Received 26th Nov 2022; accepted 27th Feb 2023)

Abstract. Alfalfa is an important crop for feed and green manure. To grasp the development process and current hot spots, the papers in the Web of Science were used as the data source. Based on CiteSpace, the papers on alfalfa research from 2012 to 2021 were visually analyzed from the aspects of literature volume, national contribution, institutional contribution, author group analysis, theme category and keywords, which provided a theoretical reference for alfalfa researchers to track the research frontier of alfalfa and grasp the research direction. The results showed that alfalfa research was paid more and more attention in recent years. The United States was the main country in alfalfa research. The cooperation between the United States and China, Spain and France, and France and Brazil in the field of alfalfa research was close. Most research institutions and researchers were closely linked, forming a core group of authors internationally, but most authors were scattered. The research hotspots of alfalfa mainly focused on the factors affecting the growth and quality of alfalfa, the influence of alfalfa on soil, the application of alfalfa in silage, the application of alfalfa in green manure, and the quality detection and evaluation of alfalfa.
Keywords: *knowledge mapping, alfalfa, CiteSpace, visual analysis, knowledge mapping, research direction*

Introduction

Alfalfa is a perennial legume forage with wide distribution, drought resistance, cold resistance, barren resistance, strong regeneration, high yield and good palatability, which can provide high-quality protein feed for livestock (Luo, 2021). At the same time, its roots use rhizobia to fix nitrogen, increase soil organic matter and improve soil physicochemical properties, which can be used as green manure to improve soil (Gao et al., 2022; Li et al., 2022). At first, alfalfa was mainly in the form of natural forage. With the familiarity with the characteristics of alfalfa, the gradual improvement of cultivation level and the development of animal husbandry production, the cultivation area of alfalfa was continuously expanding. Up to now, it has been widely distributed in North America, Europe, Asia, Africa, Latin America and Oceania. Among them, the United States is the main alfalfa planting country, followed by China, Argentina, and Russia.

After years of development, the research on alfalfa has been extended to include many different angles, such as green fertilizer resources (Tiwari, 2021), feed resources and feed development (Koninger et al., 2022), grass cultivation technology (Kozlowski et al., 2022). Research methods in this field are increasingly diversified, including comparative tests, quality evaluation models and so on. Therefore, it is necessary to integrate our current knowledge to clarify the evolution of this field and its future development direction.

In the previous research results of alfalfa, the representative reviews were mainly based on the induction and summary of relevant papers, combing the research results

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2103_19031916

and progress, the research direction was single, with only macroscopic qualitative description and conclusions. For example, some scholars paid attention to alfalfa breeding research progress (Diatta et al., 2021a; Yang et al., 2022), some paid attention to study on stress resistance of alfalfa (Diatta et al., 2021b), some paid attention to alfalfa planting management mode (Gerke, 2021). Although these existing reviews are very valuable for scholars to understand this field, they mainly rely on qualitative methods to review the content and theme of existing papers, which is difficult to comprehensively and objectively reflect the overall picture of alfalfa research and is difficult to systematically show the development process of alfalfa research.

As a research method in the field of scientometrics and information metrology, knowledge mapping can not only reveal the source and development law of knowledge but also reveal the relationship and evolution law of knowledge structure in related fields by the graphical expression (Azam et al., 2021). Therefore, based on the bibliometric analysis method and CiteSpace software, this paper makes a visual analysis of alfalfa-related papers in the Web of Science database from 2012 to 2021 and summarizes the development process, current situation and trend of alfalfa research, to provide a valuable reference for alfalfa researchers.

Materials and methods

Data collection

The papers were collected from the Web of Science Core Collection on 17 March 2022. The search strategy for the data was set as: Search term is topic, TS = ("alfalfa"). The term appeared in the title, abstract, author keywords and keywords, which ensures that the papers were related to alfalfa as much as possible. The timespan was from 2012 to 2021. The chosen database was Science Citation Index Expanded (SCI-E). Only English papers were searched for increasing readability (*Table 1*). Finally, a total of 7217 records that consist of articles, proceedings papers, reviews, editorial material, and letters were obtained. Among them, the number of articles accounted for the largest proportion, about 88%, followed by proceedings papers and reviews, both about 3%. These data were downloaded and exported in a text-based format, including full records and cited references.

Table 1. *Literatures data retrieval conditions setting the table*

Literature retrieval item	Literature retrieval settings
Document database	Web of Science core collection
Retrieval mode	TS
Retrieval terms	Alfalfa
Timespan	2012-2021
Genre	All document types
Language	English

Methodology

Excel was used to analyze the publication trend. The polynomial model $f(x) = ax^3 + bx^2 + cx + d$ was applied to forecast the growth of publications in the

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following year. Variable x stands for the publication year and $f(x)$ stands for the number of publications (Ma et al., 2022; Yuan et al., 2022).

CiteSpace software was used to analyze the distribution of publications, co-authors, institutional collaborations, international collaborations by subject category and burst detection analysis of keywords (Li et al., 2021; Zong et al., 2022).

Results

Trends in the number of published papers

The trend of the number of published papers over time can reflect the development trend of the field from a macro perspective, therefore it is an important indicator of its development and evolution (Bao et al., 2023). As shown in *Figure 1*, the literature on alfalfa research has shown a steady growth trend in the past 10 years. From January 2012 to December 2021, a total of 7217 related publications were retrieved and increased from 722 in 2012 to 925 in 2021. The third-order polynomial model described the relationship between the publication year and the number of publications. There was a significant indigenous correlation between the number of studies and the year, and the determination coefficient was high ($R^2 = 0.9$). It was expected that 950 papers will be exceeded in 2022. This field is receiving increasing attention from scholars, and alfalfa research is expected to be more in-depth and perfect with the continuous development of related research.

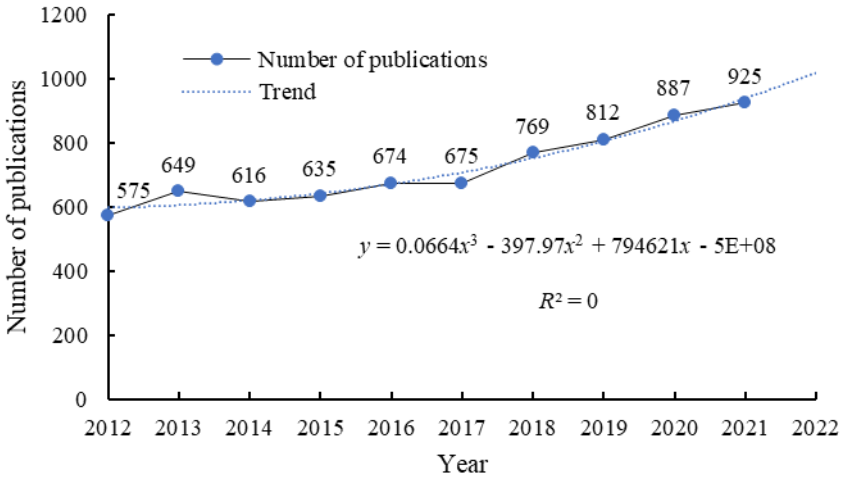

Figure 1. *Publication outputs and growth forecast*

National distribution characteristics

The analysis of a country's papers in a certain field can reveal the scientific research strength of each country in this field and the cooperative relationship between countries (Yin et al., 2023). It provides a new perspective for evaluating the academic influence of a country, helps to find national institutions worthy of attention, and has a macro understanding of the spatial distribution of countries in the research field.

The papers came from 79 countries around the world. The top 10 most productive countries were presented in *Table 2*. The USA had the largest number of publications (2177), followed by China (1711), Canada (586), Iran (405), and Spain (370). The distribution of countries/territories and the relationships of international co-operations

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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concerning the field of research was shown in *Figure 2*. The size of the circles represented the number of publications per country/territory, and the link between them indicated their collaborative relations. The colors corresponded to the temporal orders of co-occurrence links among countries/territories, with the oldest being presented in blue and the newest in orange. The purple circles outside indicated high centrality above 0.1. A node with high betweenness centrality scores was usually a key hub in the network, which connected two or more large groups of nodes. Centrality is an index to measure the importance of nodes in the network. The centrality of a node indicates the number of shortest paths passing through the node in a network. In the network, the greater the centrality of a node, the greater the role it plays in the communication between other nodes. Use the following formula to calculate:

$$C_b = \sum_{s \neq i \neq t} \frac{n_{st}^i}{g_{st}} \quad \text{(Eq.1)}$$

where, g_{st} is the number of shortest paths from node s to node t, and n_{st}^i is the number of shortest paths passing through node i among the g_{st} shortest paths from node s to node t.

Table 2. *The top 10 productive and influential countries from 2012 to 2021*

Rank	Country	Centrality	Count	Proportion	Top 10 national cooperation networks
1	USA	0.14	2177	22.97%	
2	China	0.08	1711	18.05%	
3	Canada	0.05	586	6.18%	
4	Iran	0.02	405	4.27%	
5	Spain	0.08	370	3.90%	
6	Italy	0.08	306	3.23%	
7	Australia	0.02	287	3.03%	
8	France	0.17	268	2.83%	
9	Germany	0.11	247	2.61%	
10	Brazil	0.01	218	2.30%	

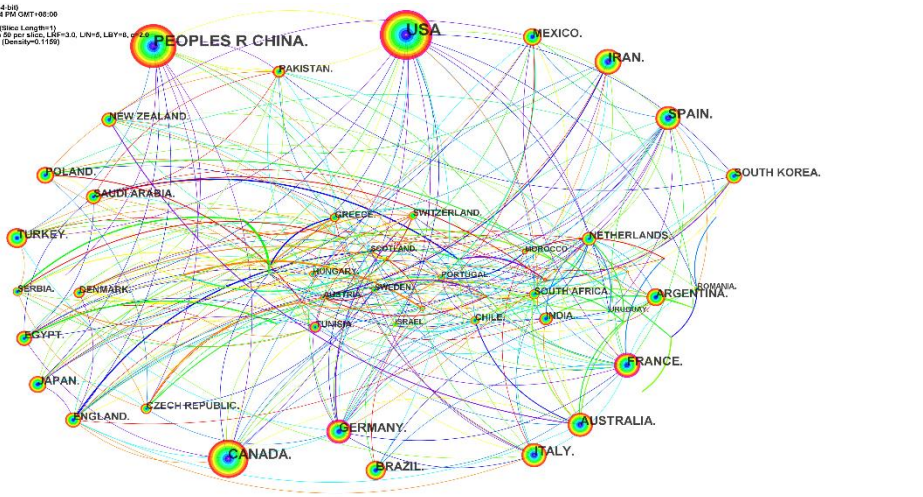

Figure 2. *Map of the international situation on alfalfa research between 2012 and 2021*

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The United States was the country with the highest productivity in this field. The intermediary centralities of the United States, France and Germany were high, indicating that the influences were large. Although China had a high number of publications, the intermediary centrality was low, indicating that the overall influence of the papers was weak, and the depth of research needed to be strengthened. The denser network of national cooperation (Density = 0.1159) indicated closer cooperation among countries. The connection lines of nodes showed that the cooperation between the United States and China, Spain and France, France and Brazil in the field of alfalfa research was close (*Fig. 2; Table 2*).

Institutional distribution characteristics

The overall understanding of high-level international research institutions about alfalfa can help clarify the distribution of alfalfa research institutions and the situation of international cooperation (Hu et al., 2021).

As shown in *Figure 3*, 518 nodes were generated in CiteSpace, representing 518 core research institutions in the field of alfalfa research. Among the top 15 research institutions, the United States and China accounted for the majority, indicating that the two countries had carried out a large number of studies in the field of alfalfa. The institutions affiliated to China were China Agricultural University, Chinese Academy of Sciences, Chinese Academy of Agricultural Sciences, Lanzhou University, Nanjing Agricultural University, Northwest A&F University and University of Chinese Academy of Sciences. The institutions affiliated to the United States were Agricultural Research Service, University of Wisconsin, Cornell University, University of Minnesota, Utah State University and University of California, Davis (*Fig. 3; Table 3*).

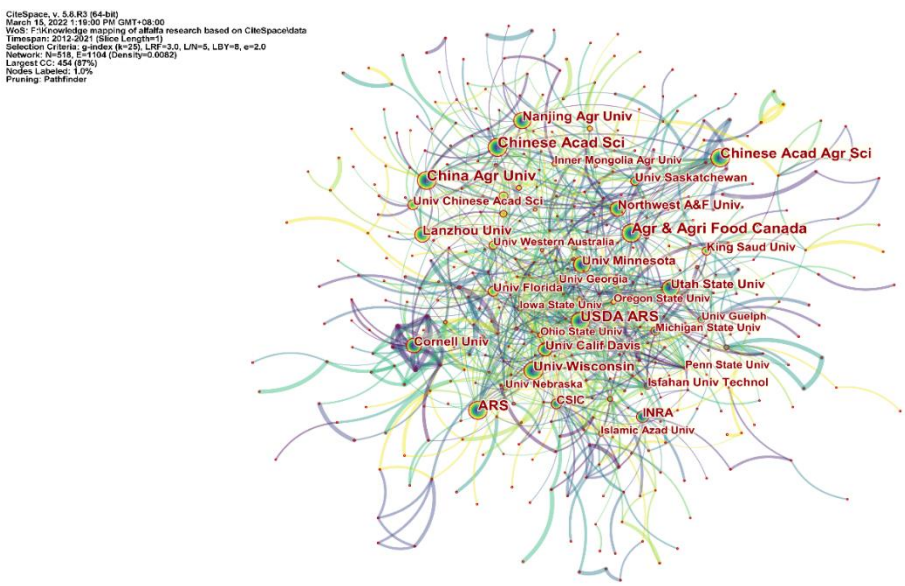

Figure 3. *Institutional cooperation network*

The characteristics of the authors

There were 965 authors involved in alfalfa research as shown in *Figure 4*, and the top 15 authors were listed in *Table 4*. The authors with a large number of papers were

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MARTHA P HAYNES (44), RICCARDO GIOVANELLI (42) and TAO SHAO (40). The mediation centralities of ZHU YU and K A BEAU CHEMIN were high. In addition, the top 15 authors from China accounted for 53% of the total, indicating that China had paid more attention to alfalfa research. The author cooperation network was sparse, while the network within the team was dense, which showed that cooperation between teams needs to be strengthened. In addition, VAN SOEST PJ had a high co-citation frequency (1007), followed by AOAC (767), BRODERICK GA (362), AOAC International (352) and National Research Council (342), indicating that the above researchers had a great influence on this field.

Table 3. *Top 15 productive institutions in the alfalfa research area from 2012 to 2021*

Rank	Institution	Number	Proportion	Centrality	Affiliation
1	USDA ARS	506	6.34%	0.14	The USA
2	Agr & Agri Food Canada	279	3.59%	0.12	Canada
3	China Agr Univ	271	3.48%	0.07	China
4	Chinese Acad Sci	258	3.32%	0.09	China
5	Chinese Acad Agr Sci	235	3.02%	0.09	China
6	Univ Wisconsin	161	2.07%	0.04	The USA
7	Lanzhou Univ	159	2.04%	0.08	China
8	Nanjing Agr Univ	152	1.95%	0.05	China
9	Northwest A&F Univ	120	1.54%	0.04	China
10	Cornell Univ	120	1.54%	0.1	The USA
11	Univ Minnesota	119	1.53%	0.01	The USA
12	Utah State Univ	115	1.48%	0.09	The USA
13	Univ Calif Davis	106	1.36%	0.17	The USA
14	INRA	98	1.26%	0.04	France
15	Univ Chinese Acad Sci	90	1.16%	0.04	China

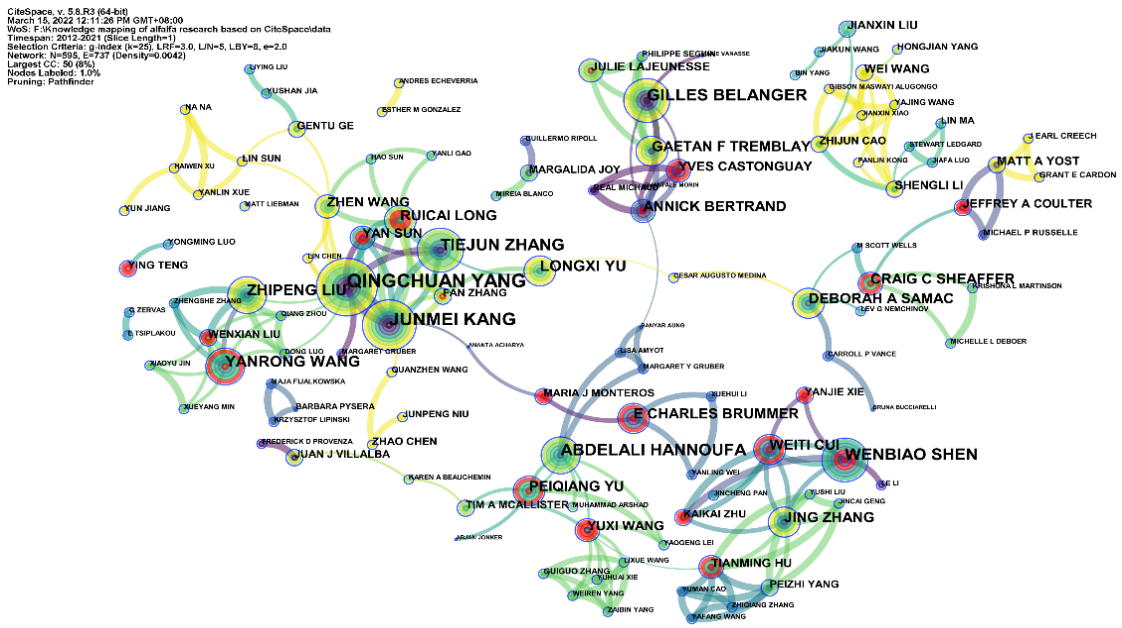

Figure 4. *Author collaboration network*

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Table 4. *Top 15 authors and co-cited authors from 2012 to 2021*

Rank	Author	Count	Centrality	Rank	Co-cited author	Count	Centrality
1	MARTHA P HAYNES	44	0	1	VAN SOEST PJ	1007	0.01
2	RICCARDO GIOVANELLI	42	0	2	AOAC	767	0.01
3	TAO SHAO	40	0	3	BRODERICK GA	362	0.03
4	QINGCHUAN YANG	36	0	4	AOAC International	352	0
5	JUNFENG LI	31	0	5	National Research Council	342	0.01
6	ZHIHAO DONG	31	0	6	SAS Institute	299	0.01
7	QING ZHANG	30	0	7	NRC	293	0.01
8	JUNMEI KANG	30	0	8	McDonald P	271	0.09
9	ZHU YU	27	0.01	9	Mertens DR	263	0.01
10	HISASHI KATONOGUCHI	27	0	10	Wang Y	227	0.04
11	TIEJUN ZHANG	25	0	11	MUCK RE	204	0.07
12	ABDELALI HANNOUFA	24	0	12	Beauchemin KA	203	0.05
13	WENBIAO SHEN	22	0	13	Allen MS	186	0.02
14	ELIZABETH A K ADAMS	22	0	14	BRADFORD MM	184	0.02
15	K A BEAUCHEMIN	22	0.01	15	KUNG L	182	0.03

Subject category distribution

Subject categories represent the highest level of the specialty (Cantillo et al., 2021). The subjects addressed in papers about alfalfa from 2012 to 2021 can be visualized in the form of co-occurring subject categories. As shown in *Figure 5* and *Table 5*, the most significant topics and relationships in alfalfa were identified, which provided scholars with a view of the subjects generally addressed in the field. Each category referred to a subject associated with the journals in the WoS database. 246 subjects were identified by CiteSpace, and the labels were written over the circles on the map. The size of each circle was proportional to the number of papers attributed to the respective category. The top 10 subject categories in the dataset were listed in *Table 5*, with the corresponding number of papers, the betweenness value and the year of the first occurrence in the dataset. The six highest-ranking categories were agriculture, plant science, environmental sciences & ecology, food science & technology, agronomy, and veterinary science. Of the top 20 categories, biochemistry & molecular biology had the maximum intermediate centrality value (0.22), which indicated its great influence on the dissemination of research in alfalfa.

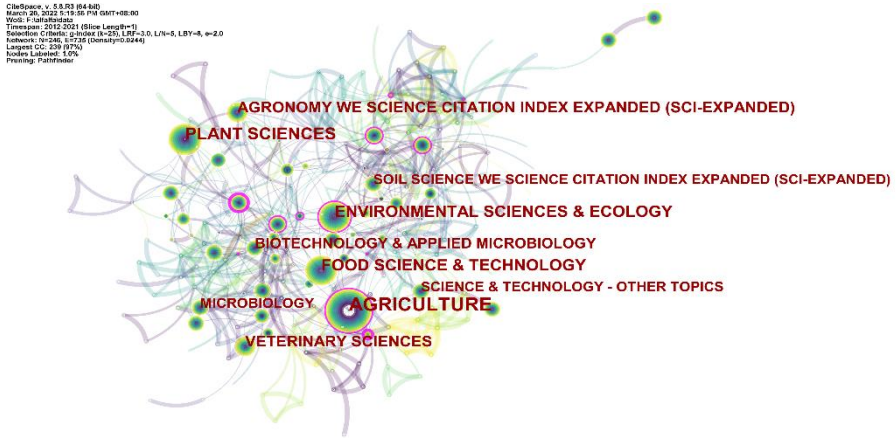

Figure 5. *Co-occurring subject categories during 2012–2021*

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Table 5. *Top 10 subject categories in the dataset from 2012 to 2021*

Rank	Frequency	Centrality	Year	WoS category	Proportion
1	3316	0.11	2012	Agriculture	20.83%
2	1036	0.02	2012	Plant Sciences	6.51%
3	905	0.18	2012	Environmental Sciences & Ecology	5.68%
4	711	0.01	2012	Food Science & Technology	4.47%
5	514	0.05	2012	Agronomy	3.23%
6	482	0.05	2012	Veterinary Sciences	3.03%
7	401	0.08	2012	Biotechnology & Applied Microbiology	2.52%
8	331	0.02	2012	Science & Technology - Other Topics	2.08%
9	330	0.01	2012	Microbiology	2.07%
10	330	0.01	2012	Soil Science	2.07%

From the perspective of the evolution of the number of papers in various research directions over time (*Fig. 6*), Agriculture had the highest overall number of papers and had increased year by year from 2012 to 2020. The number of papers in Plant Science and Environmental Science & Ecology increased slowly, while the number of papers in Food Science Technology and Agronomy changed little.

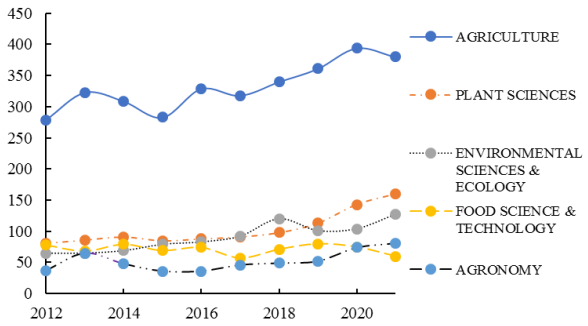

Figure 6. *The curve of the number of published papers in the main research directions of fecal microbiota transplantation over time*

Keyword co-occurrence analysis

Keywords are the essence and a general summary of a paper. The research priorities and directions in this area can therefore be derived from the analysis of the frequency of keyword occurrences (Hu et al., 2021). In the project interface of CiteSpace software, Time Slicing was selected 2012-2021, Years Per Slice selected 1 year, Node Types selected keywords, Top = 30 was selected for each time slice, and the keyword co-occurrence network knowledge map of alfalfa research papers was drawn. As shown in *Figure 7*, a total of 67 keyword nodes and 231 keywords were obtained. The research on alfalfa was scattered and the research direction was diversified. Keywords were indicated by small circular nodes, and their frequency was indicated by the size of the ring. The more times a keyword appeared, the larger its nodes were, indicating that it was a research hotspot in this field.

The top 15 high-frequency keywords from 2012 to 2021 were shown in *Table 6*. Except for the 'alfalfa' listed in the search criteria. The keywords with a high frequency

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of occurrence were growth (636), plant (447), quality (432), performance (407), elasticity (332), management (303), and nitrogen (295), respectively. Comprehensively considering the top 15 keyword information, it could be reflected that the research hotspots in the field of alfalfa in the past decade mainly focused on the factors affecting the growth and quality of alfalfa, the effects of alfalfa on soil, the application of alfalfa in silage, and the application of alfalfa in green manure.

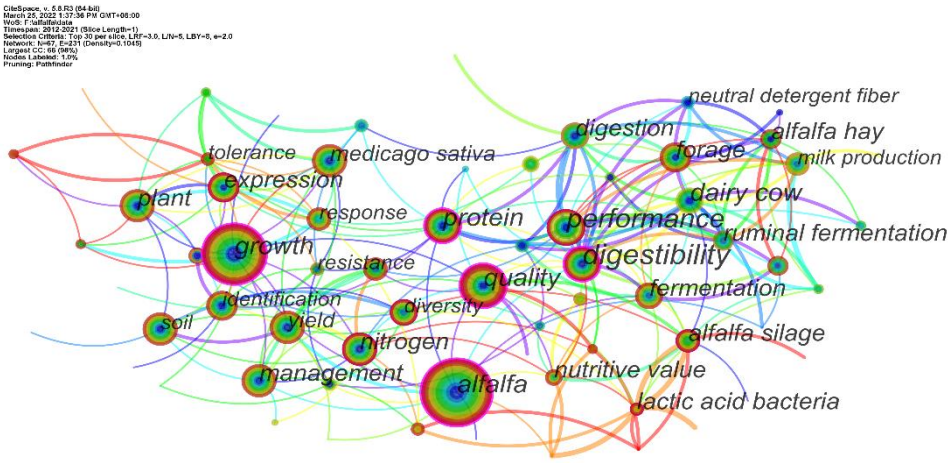

Figure 7. *Keyword co-occurrence network*

Table 6. *Top 15 high-frequency keywords from 2012 to 2021*

Rank	Keywords	Frequency	Centrality	Rank	Keywords	Frequency	Centrality
1	Alfalfa	908	0.2	9	Protein	290	0.27
2	Growth	636	0.21	10	Soil	274	0.07
3	Plant	447	0.06	11	Dairy cow	257	0.09
4	Quality	432	0.24	12	Expression	225	0.11
5	Performance	407	0.16	13	Identification	220	0.08
6	Digestibility	332	0.2	14	Diversity	214	0.11
7	Management	303	0.06	15	Fermentation	196	0.05
8	Nitrogen	295	0.11				

Burst keywords analysis

Burst detection quantifies the focus and emerging trends of research hotspots. The strength of burst keywords indicates the intensity of focus on a given field (Zhao, 2022). Top 21 Keywords with the Strongest Citation Bursts as shown in *Table 7*. The appearance of 'neutral detergent fiber' was the earliest and lasted for a long time in this decade, with the highest burst strength (25.909), indicating that alfalfa as a feed to study its quality characteristics was an important part of alfalfa research. Neutral detergent fiber, rumen, fiber and other words were all related to the study of alfalfa as livestock feed. These subsequent words such as cows, milk production and metabolism indicated that in the study of alfalfa as feed, most of the feeding objects were cows. The chemical components, lactic acid bacteria and other words in the late stage indicated that the research scope of alfalfa was extended to green manure and silage.

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Table 7. *Top 21 Keywords with the strongest citation bursts*

Keywords	Strength	Begin	End	2012-2021
Neutral detergent fiber	25.909	2012	2015	
Rumen	22.7838	2012	2014	
Fiber	16.1372	2012	2013	
Degradation	15.8088	2012	2013	
Population	9.6775	2012	2013	
Gene	9.5105	2012	2014	
Digestion	3.2521	2012	2014	
Gene expression	25.2975	2013	2016	
Resistance	12.5896	2013	2014	
Ruminal fermentation	12.4072	2013	2017	
Dairy cow	7.0213	2014	2016	
Milk production	3.7345	2014	2015	
Metabolism	23.5771	2015	2019	
Corn silage	16.1793	2015	2016	
Arabidopsis	24.5776	2016	2018	
Alfalfa hay	6.6969	2016	2018	
System	5.7611	2016	2018	
Lactic acid bacteria	25.0259	2018	2021	
Chemical composition	21.0517	2018	2021	
Dynamics	21.475	2019	2021	
Nutritive value	17.5355	2019	2021	

Discussion

The number of publications slowly increased from 2012 to 2021, which showed that there were more and more researchers on alfalfa all over the world. The top five subject categories were agriculture, plant science, environmental sciences & ecology, food science & technology, agronomy, and veterinary science. Most existing research had focused on the factors affecting the growth and quality of alfalfa, the influence of alfalfa on soil, the application of alfalfa in silage, and the application of alfalfa in green manure. Analysis of burst detection demonstrated the evolution of research hotspots. The hotspots of studies focused on feeding made from alfalfa, including 'neutral detergent fiber', 'rumen' and 'fiber'.

Alfalfa is a perennial high-quality legume forage with high crude protein, high grass yield, wide adaptability, vitamins and minerals, and is also the world's largest commercial legume. Alfalfa has strong adaptability and wide distribution and can grow generally under various environmental and soil conditions. We carefully reviewed the relevant papers according to high-frequency keywords, keyword emergent information, etc, and found that a large number of experts and scholars on alfalfa research mainly focused on the following three aspects:

(1) Studies on the influencing factors of alfalfa growth and quality. Alfalfa is a legume perennial herb. It is widely cultivated in many countries in the world due to its wide adaptability and high yield and is one of the forages with planting value

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worldwide. The breeding and cultivation technology of alfalfa is of great significance to the adaptability, yield and quality of alfalfa (Unal et al., 2023; Zhou et al., 2022). The nutritional components are different at different growth stages. To fully play its yield and quality advantages in production, the cutting stage should be from budding to early flowering (Eckberg et al., 2022). Planting density and row spacing allocation are also important factors affecting alfalfa yield, and these two factors greatly affect the photosynthetic utilization rate and dry matter content of the whole alfalfa population (Patel et al., 2021). Seed and seed production as an important means of production of alfalfa industrialization is particularly important. At present, alfalfa breeding is mainly in the direction of high yield, high quality, stress resistance and resistance to diseases and insect pests (Tucak et al., 2021). In addition, reasonable fertilization, reasonable cutting times, sulfur content and stubble height, inoculation of efficient rhizobia and other measures can also improve the yield and quality of alfalfa (Feng et al., 2022).

(2) Studies on alfalfa as silage. Alfalfa is a high-quality forage for ruminants due to its high protein content. Silage is one of the main processing and storage methods of alfalfa, but the soluble carbohydrate content of alfalfa is low, so it is difficult to silage. In recent years, to successfully process alfalfa into silage, scholars have done a lot of research. The effects of silage time, water content, additives and extrusion density on silage quality were mainly studied (Besharati et al., 2022). Studies have shown that in the process of alfalfa silage, the appropriate water content can rapidly reduce the pH value to the optimal level, make organic acids in the appropriate fermentation range, and reduce the protein degradation of silage raw materials (Guo et al., 2021; Sikora et al., 2021). Appropriate temperature is conducive to the rapid growth and reproduction of lactic acid bacteria, to achieve better silage quality (Zong et al., 2022). Appropriate density can promote the juice exudation and discharge the air in the cellar, which is conducive to the fermentation of lactic acid bacteria, thereby improving the quality of silage (Sun et al., 2021; Wang et al., 2018). Supplementary additives are an important means to solve the problem of alfalfa silage. In recent years, lactic acid bacteria additives have been widely used in alfalfa silage production. Adding lactic acid additive can rapidly reduce pH value, inhibit the growth of adverse microorganisms and improve the nutritional value of silage. The addition of lactic acid bacteria can also reduce protein and amino acid decomposition during silage, thereby reducing the formation of ammonia nitrogen and reducing dry matter loss.

(3) Studies on alfalfa as green manure. Alfalfa is a good cultivated green manure crop, which is rich in nitrogen and has a strong ability to enrich phosphorus and potassium (Akramovna et al., 2021). The green manure crop cultivation can improve soil structure, maintain soil temperature, and improve the microclimate (Xiao et al., 2022). Especially in orchards, alfalfa cultivation will eventually help improve fruit quality. If cultivated land depends on chemical fertilizer, it will lead to soil fertility decline, hardening and hardening, and then affect the yield and quality of crops. Alfalfa cultivation can provide nutrients, improve soil fertility, and improve soil structure (Gao et al., 2022). The action of alfalfa root system can maintain water and soil, increase the number of microorganisms, and then increase the content of organic matter. Generally, when the alfalfa grows to more than 30 cm, it can be cut, and the cut alfalfa returns to the soil as green manure. The study by Gao et al. (2022) showed that a proper combination of synthetic phosphate fertilizer and green manure could effectively maintain rice yield, improve phosphorus use efficiency and reduce phosphorus loss in paddy fields.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2103_19031916

Conclusions

The visualization analysis of alfalfa research papers in recent 10 years was carried out by the bibliometric method. The conclusions which may be drawn from this research are as follows:

(1) The overall number of alfalfa papers is gradually increasing, and global research in this field is gradually strengthening.

(2) At present, the United States has a high influence on alfalfa research. The number of researchers and institutions in this field in China is large, and the cooperation between countries is also close. In recent years, this field has become one of the hot topics for scientific research workers, but the exchanges and cooperation between institutions in this field need to be strengthened.

(3) The research on alfalfa mainly focuses on the factors affecting the growth and quality of alfalfa, the application of alfalfa in silage, and the application of alfalfa in green manure, showing an obvious trend of interdisciplinary integration.

Acknowledgements. This study was supported by the China Agriculture Research System of MOF and MARA (CARS-22), Bingtuan Science and Technology Program (2021CB022), the Finance Science and Technology Project of Alar City (2021NY07), the Key neighborhood Science and Technology Project of Xinjiang Construction Corps (2018AB037), President's Foundation Innovation Research Team Project of Tarim University (TDZKCX202203) and the Finance Science and Technology Project of Alar City (2022NY13). We also thank the editors and reviewers for their critical comments and constructive suggestions.

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