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Plant-Based Feed and Forage Research for Livestock: A Bibliometric Review

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Abstract: This bibliometric review research analyzes trends related to "Plant-Based Feed and Forage for Livestock," utilizing research data from 2013 to 2024. Eighty-two (82) English language journal articles indexed in Scopus were utilized as data. This study focuses on publications in agricultural and environmental sciences. The study aimed to identify all keywords, author keywords, authors, and countries related to research on plant-based feed and forage. It was calculated using VOSviewer to determine density, network, and overlay. This highlights the growing importance of sustainable alternative feed. This bibliometric review highlights the role of plant-based feed and forage in contributing to a sustainable livestock production system, supporting Sustainable Development Goal 2 (Zero Hunger) by enhancing food security through resilient and efficient resource feeding strategies. Shifting to resource-intensive conventional feeds that are environmentally friendly alternatives contributes to SDG 12 (Responsible Consumption and Production). Additionally, reducing greenhouse gas emissions through adaptation of plant-based feed for livestock production, aligned with SGD 13 (Climate Action), and promoting land use practices that reduce deforestation and preserve biodiversity, supports SDG 15 (Life on Land). Mapping the co-citation network and overlaying this research topic provides insights into the development and dissemination of new knowledge in agriculture. Analysis identifies emerging trends and gaps in current research, suggesting areas for future investigation. Overall, this bibliometric review provides a comprehensive overview of the diverse research landscape on plant-based feed and forage for livestock production, specifically for ruminant animals, in temperate and tropical regions. It emphasizes alignment between this research and sustainable goals.

Keywords: Plant-based feed; forage crops; bibliometric review; VOSviewer; sustainable livestock feed

1. Introduction

Sustainable agricultural practices have increasingly been a focus of the global livestock industry today, as it addresses environmental concerns and meets the growing demand for food, produced ethically. The shift prompted significant interest in using plant-based feed and forage for livestock production, which could be a promising solution to reduce the environmental impact of the traditional livestock feed system [1]. Conventional feed production relies heavily on grain and soy, which contribute to deforestation, biodiversity loss, and significant greenhouse gas emissions. In Brazil, mechanized soy farming in

Rondônia and Mato Grosso has led to deforestation, resulting in the release of up to 0.77 tonnes of CO_2 equivalents for every tonne of soy exported. Between 2010 and 2015, this totalled 223.46 million tonnes [2, 3]. Cereal grains such as wheat and barley contribute to soil disturbance and nitrous oxide emissions from fertilizers [4]. In South Asia, increasing CO_2 emissions from cereal farming endanger long-term productivity [3]. This result encouraged the researchers, policymakers, and industry stakeholders to explore plant-based alternatives to mitigate negative environmental impacts while maintaining animal productivity [1].

The potential of plant-based feed and forage research is increasingly recognized as a means to enhance sustainable livestock production. Alfalfa and clover are leguminous plants that contain a lot of crude protein (8.22%–22.19%), which is essential for animal growth and reproduction [5, 6]. Grasses provide a significant amount of crude fiber (32.06%–32.92%), which aids in digestion [7]. Mixed cropping increases neutral and acid detergent fiber, which is good for the health of the rumen [8]. These forages also provide macro minerals, such as Ca, Mg, K, and P, as well as micronutrients like Zn, Cu, Fe, and Mn [6, 9]. Legumes also contain condensed tannins that help animals utilize protein more efficiently and eliminate less nitrogen, which is beneficial for their health and the environment [10-11]. These essential nutrients improve livestock nutrition, enhance soil fertility, and promote biodiversity in the area. These leguminous plants are known for their nitrogen-fixing properties, which help enrich the soil's organic matter and reduce the need for synthetic fertilizers that can degrade soil health. Plant-based forage is a type of plant that serves as an efficient source of forage feed for livestock, requiring only a small amount of water to grow. In contrast, traditional grain-based feeds require more water, which can contribute to a more sustainable agricultural practice [12].

It has been shown that incorporating plant-based feed alternatives can improve the digestion process and reduce the incidence of diseases in livestock. Phytogenic compounds enhance mitochondrial function and energy biosynthesis, facilitating effective nutrient absorption [13]. Dietary fibers derived from plant by-products also affect protein bioavailability and hydrolysis, which are crucial for nutrient absorption [14]. Furthermore, the bioactive compounds in these feeds exhibit antimicrobial, antioxidant, and immunoregulatory characteristics that enhance immune responses and reduce oxidative stress [15, 16]. These substances help reduce detrimental intestinal microbes and promote gut health [16]. Importantly, phytogenic additives can mimic the effects of antibiotic growth promoters—now prohibited in numerous areas—without fostering antibiotic resistance [17, 18]. This study can serve as a basis for future research on exploring different forage species in terms of their nutrients, adaptability, and suitability for various climatic conditions, thereby informing sustainable farming practices. It was also highlighted that forage crops play a crucial role in reducing soil erosion, enhancing water retention, and promoting carbon sequestration, which is essential for combating climate change and fostering a resilient agricultural system. He further explained that plant-based feeds are being explored for their potential in reducing methane gas emission from ruminants and to further develop them as more environmentally friendly feed alternatives for livestock animals compared to traditional grain feed production in animal production systems [19]. Moreover, it has been observed that land planted with various forages for livestock has expanded significantly in recent decades. This may be because of the growing interest in sustainable livestock farming. Certain plant species are being studied for their potential adaptability and contribution to soil health conditions [20].

Plant-based feed and forage research is closely aligned with the objectives of organic farming and sustainable livestock production. Plant-based feeds and forage are produced without the use of synthetic fertilizers and pesticides to control pests or fertilize the soil, thereby reducing the ecological footprint in livestock production. Animal feed produced organically promotes sustainability by offering quantifiable financial and environmental advantages. Organic systems prevent pollution-causing synthetic inputs and lessen eutrophication and acidification per land unit [21, 22]. Forage legumes improve soil health by enhancing nitrogen fixation and carbon sequestration [23]. Livestock production accounts for only 18% of calories and 25% of protein, yet it consumes 70–80% of the world's agricultural land. Organic feed helps maximize land use by lowering dependency on feed that competes with food [24, 25]. Furthermore, organic methods enhance the management of water footprints [26]. These practices support a healthier ecosystem and meet the demand for sustainability in animal product production, contributing to advancements in achieving sustainable agricultural production globally [12]. Furthermore, plant-based feed and forage offer various environmental benefits, including sustainable intensification, improved food security, and reduced greenhouse gas emissions [27].

Improved forage corps integration in mixed production systems can contribute to the restoration of degraded land areas, enhance climate resilience, and reduce greenhouse gas emissions per unit of livestock products [28]. Forage production systems can accumulate soil carbon, and leguminous forages have a positive effect on soil nitrogen retention compared to cereal grain crops [29]. Nutritionally, forage crops are key determinants of livestock growth performance, reproduction, behavior patterns, productivity, and end-product quality [30]. Improved forage germplasm has shown significantly higher herbage yield productivity, and feeding regimes with improved leguminous forages have resulted in increased milk yield and dry matter intake in ruminant animals [31]. Specialized forage growing and livestock feeding activities can enhance smallholder welfare and farm income, contributing to the economic importance of livestock production [32]. The cool-season forage crops, such as fodder radish, offer a promising alternative for autumn and winter forages [33]. The Livestock Plus approach in livestock feed production, which includes sowing improved forages, can lead to the sustainable intensification of mixed systems, generating multiple benefits [28]. However, challenges that hinder livestock producers include a scarcity of quality feed, land tenure issues, limited access to resources, weak institutional frameworks, poor infrastructure, and environmental degradation [34]. Opportunities lie in the potential of improved forages to play a central role in sustainable intensification, which requires multidisciplinary approaches to quantify synergies and trade-offs [31]. Gene banking to conserve forage germplasm is facing challenges today; these challenges need to be addressed for immediate action to prevent loss and improve livestock systems [35]. Furthermore, research and development focused on maximizing the potential of plant-based feed and forage for sustainable livestock production.

This bibliometric review aims to analyze research trends related to plant-based feed and forage, utilizing VOSviewer as the tool for calculation. This is a quantitative research method used to evaluate the structure and development in a thematic area by examining Scopus publication data, citation patterns per author, and the network per author. The Scopus database is used to identify the most influential authors, institutions, and research topics related to the field of forage and pasture crop production. Additionally, this review will provide insights into how research on plant-based feed and forage aligns with broader sustainable agricultural goals in livestock production. This bibliometric review will contribute to the understanding of the scientific landscape surrounding plant-based feed and forage research, and this will offer a valuable insight into the progression of knowledge in this critical area of sustainable agriculture.

2. Materials and Methods

A bibliometric database of "Plant-Based Feed and Forage Research for Livestock" was constructed using the Scopus bibliographic database. A keyword search was performed to identify "Plant-Based Feed and Forage Research for Livestock" related studies published between 2013 and 2024, using the following flexible retrieval conditions: "plant-based feed" OR "plant protein" OR "alternative feed sources" OR "forage crops" OR "non-traditional feed" OR "fodder plants" AND "livestock nutrition" OR "animal nutrition" OR "ruminant feed" OR "herbivorous livestock" OR "livestock feeding systems" OR "feed efficiency" AND "sustainable feed" OR "agricultural sustainability" OR "livestock feed innovation" to locate publications that contained these words in their titles, abstracts, or keywords list. The results of the search in Scopus were filtered, yielding 82 records. Following the conventions used in other bibliometric studies, further analysis was restricted to the year range of 2013 to 2024, specifically the subject areas of Agricultural and Biological Sciences and Environmental Science. Furthermore, the document type was focused only on published articles, and the language used was English. The articles were analyzed and exported into CSV format, then imported into the bibliometric analysis tool VOSviewer, and several computations were performed. These computations involved identifying countries, authorship patterns, all keywords, and author keyword networks. VOSviewer version 1.6.20, released in October 2023 and designed by Ness Jan van Eck and Ludo Waltman, was used for co-occurrence maps and keyword analysis.

3. Results and Discussion

3.1 Results Based on VOSviewer Computations for All Keywords: Density, Network, and Overlay

VOSviewer computation for all keywords. The density shown in Figure 1 encompasses all keywords related to "forage" and "forage quality", their evolution, and interconnections, highlighting the key subjects in forage research. The density plot highlights the dominant role of forage and forage quality, and shows fitting clusters in crop productivity, forage types, nutrient value, environmental factors, and geographical relevance, particularly in China. In addition, the network map, presented in Figure 2, illustrates intersectional connections across research fields, demonstrating that forage studies encompass disciplines such as agriculture, environmental sciences, and animal nutrition. The specific clusters identified revolve around yield (e.g., intercropping, maize), nutritional quality (e.g., nitrogen, protein, legumes), and environmental challenges (e.g., climate change). In addition, as reflected in Figure 3, the overlay map illustrates longitudinal trends. Early publications (2019) focused on physiology and botanical aspects, while more recent articles (2020-2021) have addressed sustainability and agronomic innovations to meet global challenges. Targeting sustainability and agronomic innovations to address global challenges. Emerging interests include adapting forage systems to semi-arid regions, integrating sustainable practices, and enhancing resilience to climate variability. Throughout, the research remains interconnected across disciplines, bridging agronomy, ecology, and livestock nutrition to optimize forage yield and quality while tackling modern agricultural and environmental issues.

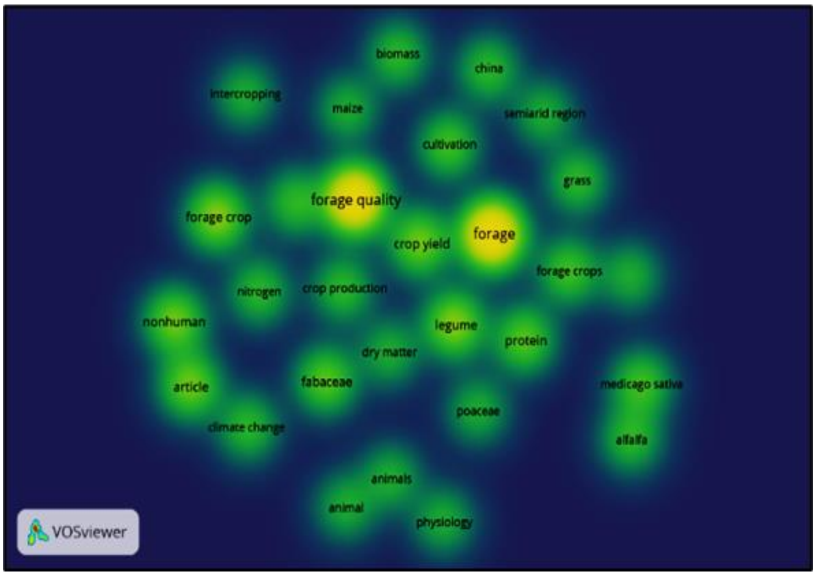

Figure 1. VOSviewer Computations for All Keywords Density.

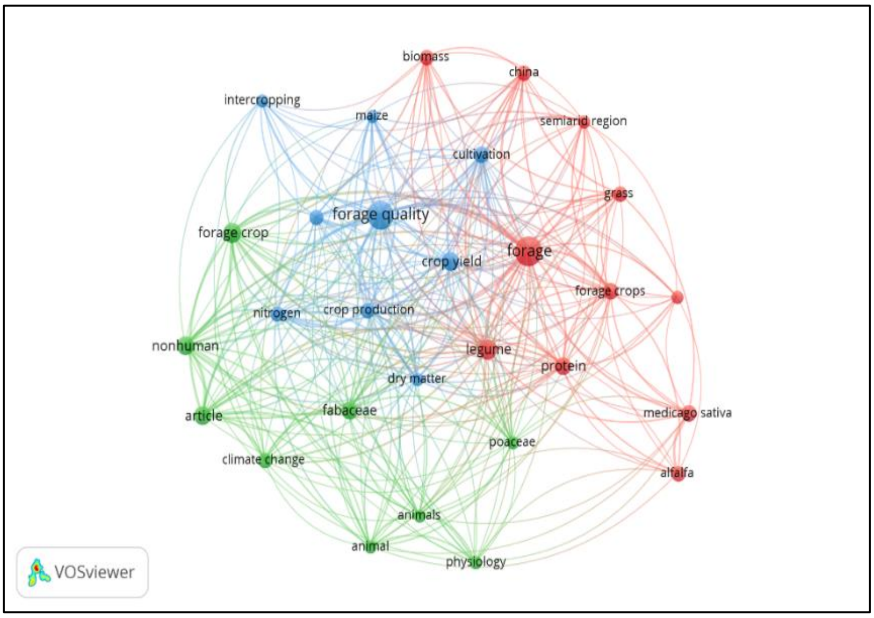

Figure 2. VOSviewer Computations for All Keywords Network.

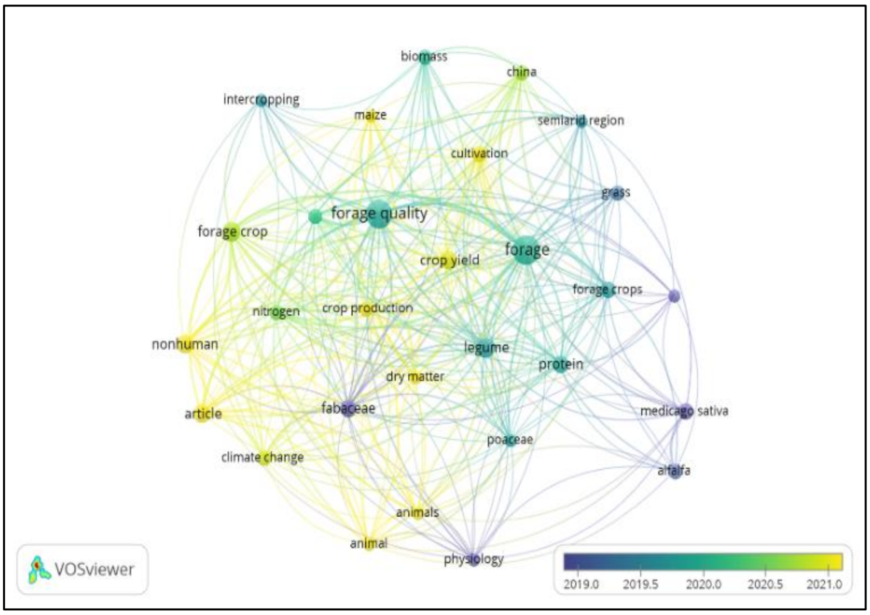

Figure 3. VOSviewer Computations for All Keywords Overlay.

3.2 Results Based on VOSviewer Computations for Authors Density, Network, and Overlay

The VOSviewer author visualizations highlight the density, network, and overlay of contributions and collaborations among researchers, focusing on figures like Devendra Singh Ginwal, R.K. Meena, Rakesh Kumar, Uttam Kumar, and Hardev Ram. As shown in Figure 4, the density map reveals high citation or activity frequency, with yellow gradients marking central authors and green to blue gradients representing decreasing influence. Figure 5 shows the network map, which features strong co-authorship connections, indicated by close positioning and thick connecting lines, suggesting frequent collaborations within small, focused groups. Authors like Ginwal and Meena appear central, reflecting their significant collaborative roles. Moreover, Figure 6 displays an overlay visualization that highlights recent contributions using a color gradient from blue (older activity) to yellow (recent publications), indicating these authors' ongoing engagement in their field. These maps collectively underline the interconnectedness of the authors' work, clustering them into research subgroups, while showcasing their influence through citation density and collaboration patterns. Such visualizations are valuable for identifying key contributors, understanding collaborative dynamics, and exploring potential partnerships in the research community. The study by Ginwal [36] aligns with VOSviewer bibliometric analyses, which provide empirical evidence to optimize intercropping ratios to enhance forage quality and nutrient yields. Frequent collaboration and citation in the author density map show influence in sustainable forage research. A tightly connected cluster among five authors was shown in the co-authorship network visualization, indicating an interdisciplinary synergy between them. Topical relevance was highlighted in overlay visualizations with the keyword "forage quality," which is trending in sustainable agriculture. These VOSviewer results strengthen the significance of the study, showing that the strategic collaboration between authors and the thematic focus of this research contribute to advancing livestock nutrition and resilient cropping systems. The research findings of these five authors also align with the Sustainable Development Goals. SDG 2 (Zero Hunger) promotes food security and improved nutrition, while SDG 12 (Responsible Consumption and Production) encourages resource-efficient feeding strategies. Additionally, it supports SDG 13 (Climate Action) through the use of a climate-resilient, organic, and legume-based feed production system, which reduces greenhouse gas emissions and enhances soil carbon sequestration. Lastly, through the protection of the ecosystem and biodiversity, it supports SDG 15 (Life on Land). The sustainable plant-based feed and forage production systems help reduce land degradation and promote biodiversity through diversified cropping and reduced chemical use.

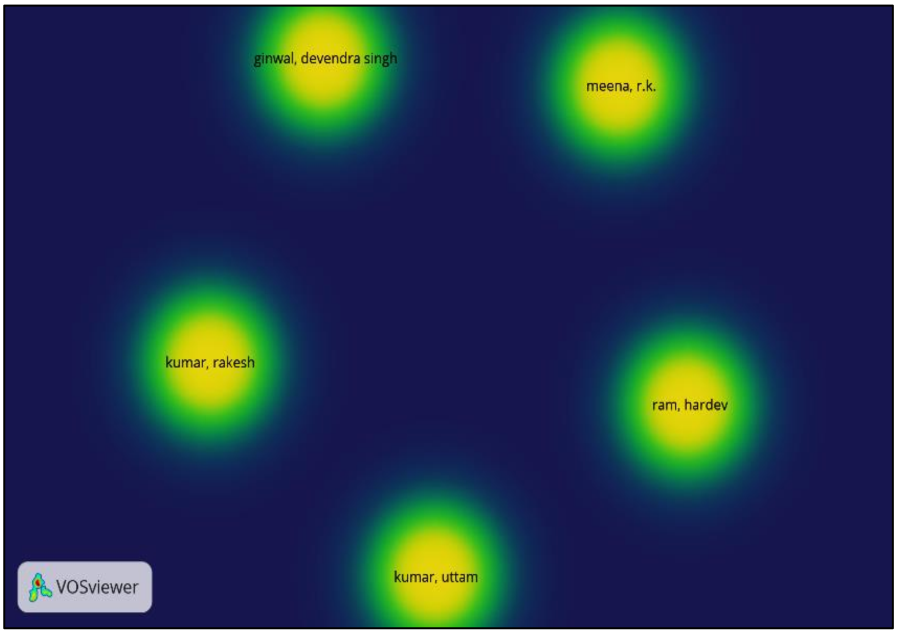

Figure 4. VOSviewer Computations for Authors Density.

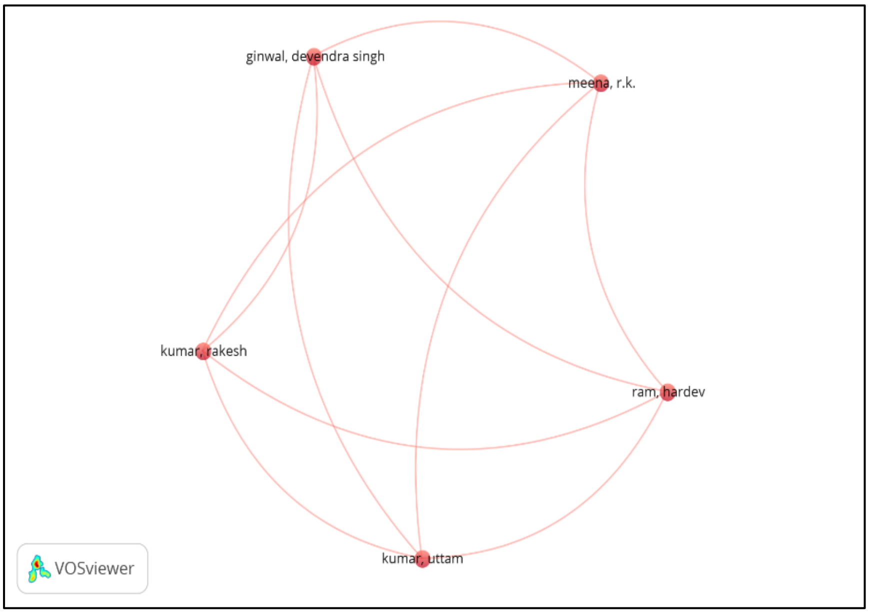

Figure 5. VOSviewer Computations for Authors Network.

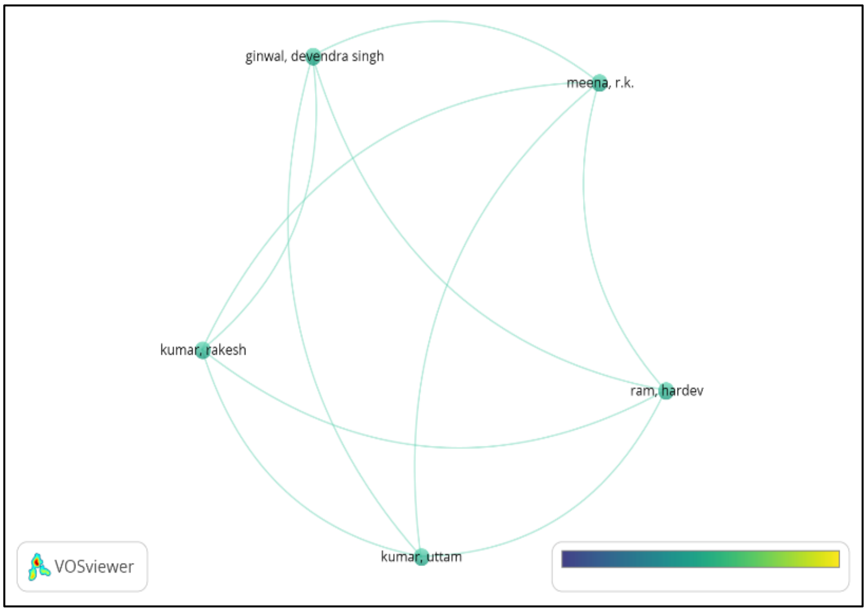

Figure 6. VOSviewer Computations for Authors Overlay.

3.3 Results Based on VOSviewer Computations for Authors' Keywords Density, Network, and Overlay

The VOSviewer visualizations for the author's keyword density, network, and overlay maps highlight the central themes, collaborations, and trends in forage research. Presented in **Figure 7** are the Author's visualizations, which reveal key contributors such as Devendra Singh Ginwal and R.K. Meena, whose prominence reflects frequent citations and collaborations, with interconnected clusters indicating strong co-authorship within focused research groups. Keyword density maps highlight terms such as "forage crop," "forage crops," and "forage quality," with "forage crop" exhibiting the highest prominence, indicating its central role in the research dataset. Furthermore, **Figure 8** shows the keyword network maps, which reveal limited connectivity between these terms, suggesting underexplored links between forage crop types and their quality. The overlay maps presented in Figure 9 showed that they trace the temporal evolution of research, showing that while "forage crop" is an established topic, "forage quality" has gained prominence more recently, highlighting a shift toward evaluating nutritional aspects. Weak links between terms suggest research gaps, offering opportunities to study the integration of crop productivity and forage quality more explicitly. Overall, the visualizations underscore trends in forage research while identifying key contributors, core terms, and potential areas for interdisciplinary or integrated studies. This analysis can guide future research, particularly in connecting forage crop studies with quality improvements for sustainable agriculture and animal nutrition.

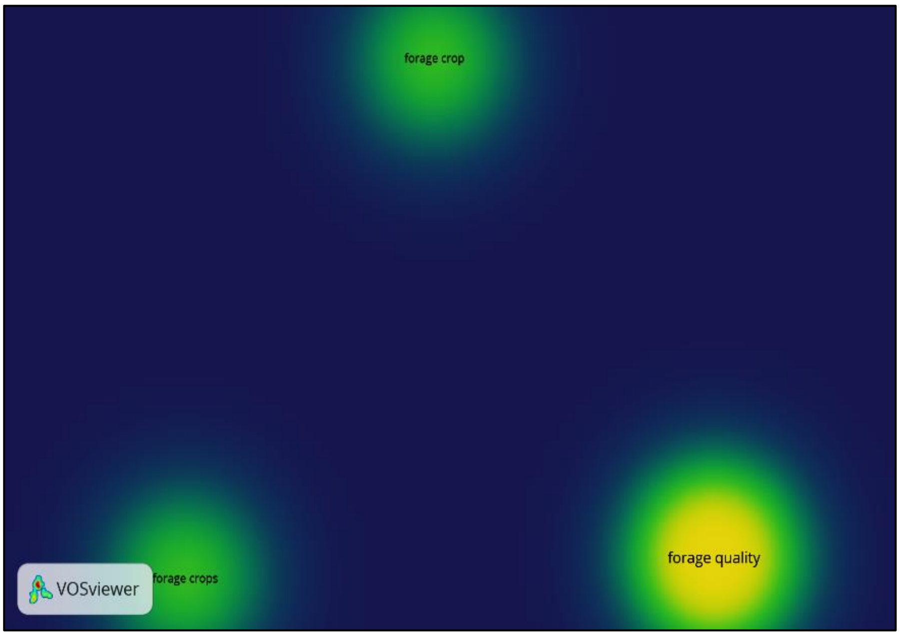

Figure 7. VOSviewer Computations for Authors' Keywords Density.

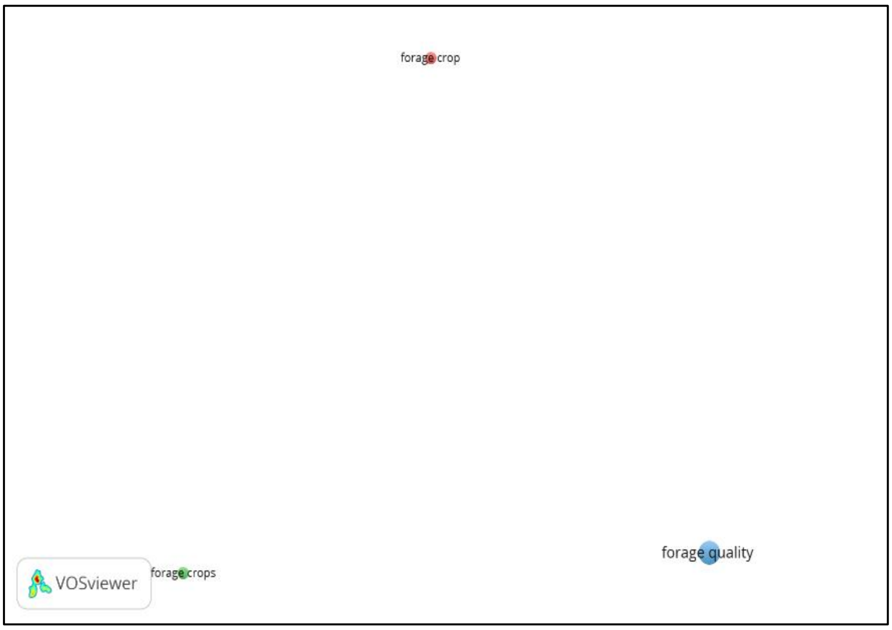

Figure 8. VOSviewer Computations for Authors' Keywords Network.

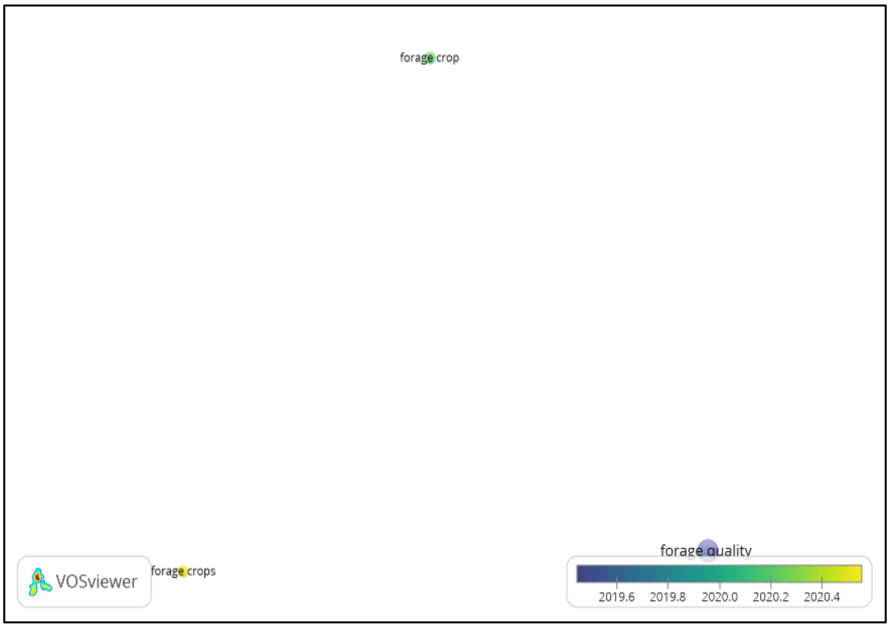

Figure 9. VOSviewer Computations for Authors Keywords Overlay.

Keywords and their number of occurrences are shown in Table 1. It shows that the most frequent keyword term was "forage quality" with 17 occurrences, followed by the terms "forage crop" and "forage crops" with 5 occurrences each.

Table 1. The ranking of the most frequently occurring keywords for the terms "Plant-based feed" and "Forage".

Keyword	Occurrences
Forage crop	5
Forage crops	5
Forage quality	17

3.4 Results Based on VOSviewer Computations for Countries Density, Network, and Overlay

The VOSviewer visualization highlights the prominence of the United States and China as leading contributors to the analyzed research dataset, with their influence depicted through node size and intensity in a density, network, and overlay map. As shown in **Figures 10, 11, and 12, the United States and China were countries that were both distinctly visible, indicating their significant involvement; yet,** the spatial separation between their nodes suggests limited direct collaboration or co-authorship. Color gradients reflect temporal trends, with activity spanning from 2019 to 2021, where the United States and China dominate individually but lack a strong interconnection. This separation highlights regional silos, potentially indicating missed opportunities for synergy between these global research leaders. The heatmap effect, transitioning from yellow (high intensity) to cooler colors (blue), further reinforces their substantial, yet isolated, contributions. Such a visualization underscores the need for fostering international cooperation, as bridging the collaboration gap between the United States and China could amplify innovation and accelerate progress in the studied field. This analysis provides strategic insights for policymakers and researchers, encouraging efforts to enhance global research networks and capitalize on the strengths of these two major players.

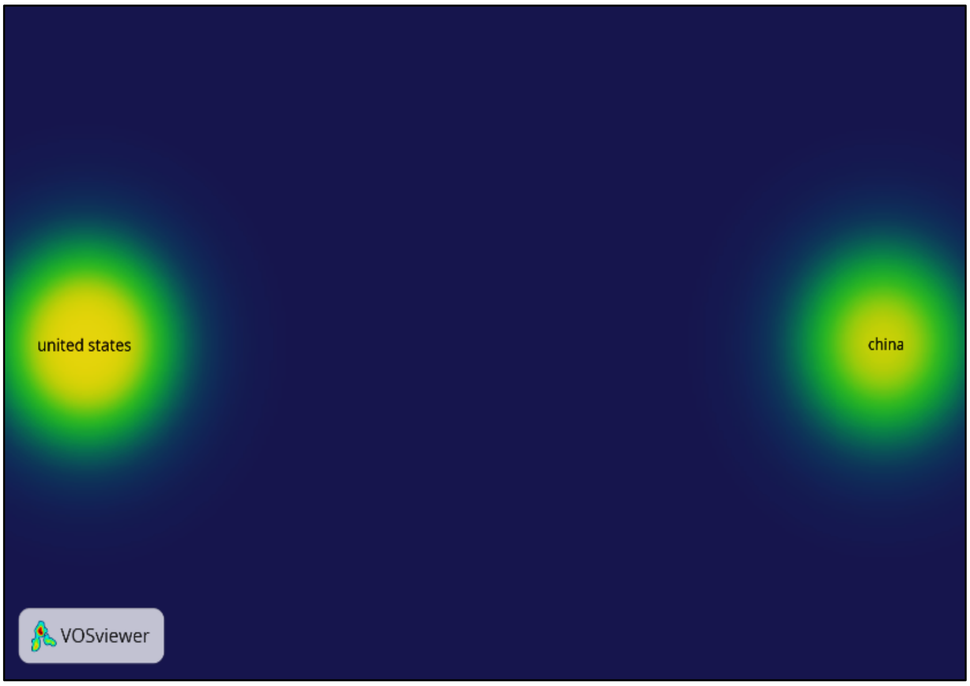

Figure 10. VOSviewer Computations for Countries Density.

Figure 11. VOSviewer Computations for Countries Network.

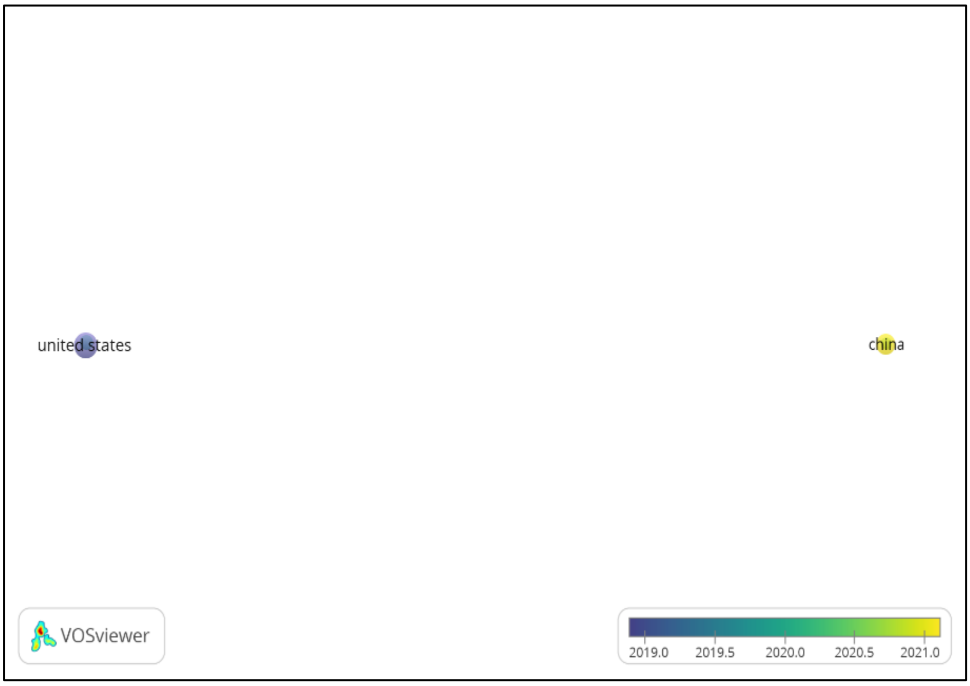

Figure 12. VOSviewer Computations for Countries Overlay.

Data on the countries, along with their corresponding documents and citations, is shown in Table 2. Among the four countries, the United States had the highest number of documents submitted (21 documents) with 387 citations, followed by China with 13 documents and 189 citations. Furthermore, Korea has 7 documents with 100 citations, while Pakistan has 5 documents with 41 citations, respectively.

Table 2. Countries with corresponding documents and citations

Country	Documents	Citations
United States	21	387
China	13	189
South Korea	7	100
Pakistan	5	41

3.5. Ratio of articles per year, by authors, by source, by affiliations, by country, by type, and by subject area.

The bibliometric analysis reveals several key trends in research output across various dimensions. The temporal analysis of documents by year reveals fluctuating research activity between 2013 and 2024, as illustrated in Figure 13, with significant peaks in 2014 and 2022, followed by a slight decline in 2023 and 2024. The peak in 2022 may reflect increased research funding or interest in specific topics, whereas the decline in 2024 might be attributed to incomplete data or shifts in focus. Figure 14 presents the analysis of documents per year by source, which shows that journals such as Crop and Pasture Science and Plants dominate specific years, indicating topical priorities in agricultural and environmental sciences. Understanding these journal-specific trends can help researchers target high-impact publications and identify thematic shifts within the field. Moreover, Figure 15 shows the documents authored by the author, revealing that a core group, led by Shen, Y., is responsible for a significant portion of the research output. The document-by-author ratio was based on output volumes, highlighting those who publish the most. Meanwhile, the data on VOSviewer covers computations on author density, network, and overly discussed influence, collaboration, and relevance, identifying who is central, cited, and active in the field. That is why Shen, Y. ranked highest in terms of document ratio, but in the VOSviewer maps, Ginwal, Meena, Kumar, and Ram appeared more central due to their greater influence and stronger networks, even though they are less prolific compared to Shen Y. This suggests the presence of collaborative networks that drive consistent contributions. Institutional analysis, as shown in Figure 16, revealed that leading affiliations, such as Lanzhou University and the USDA Agricultural Research Service, are major contributors. These institutions are complemented by others from South Korea, Saudi Arabia, and Australia, reflecting global collaboration and cooperation. The United States leads in research output, followed by China, underscoring its leadership in scientific contributions, likely supported by robust funding and infrastructure, as shown in Figure 17. A clear trend toward publishing research findings as peer-reviewed journal articles, as presented in Figure 18, reveals that 100% of the documents classified as "Articles" demonstrate a scholarly emphasis on maintaining academic rigor and disseminating findings to a broader audience. Collectively, Figure 19 presents the key highlights of the analysis, which focus on agricultural and environmental research, significant international collaboration, and the dominance of high-quality journal publications in advancing knowledge in this field.

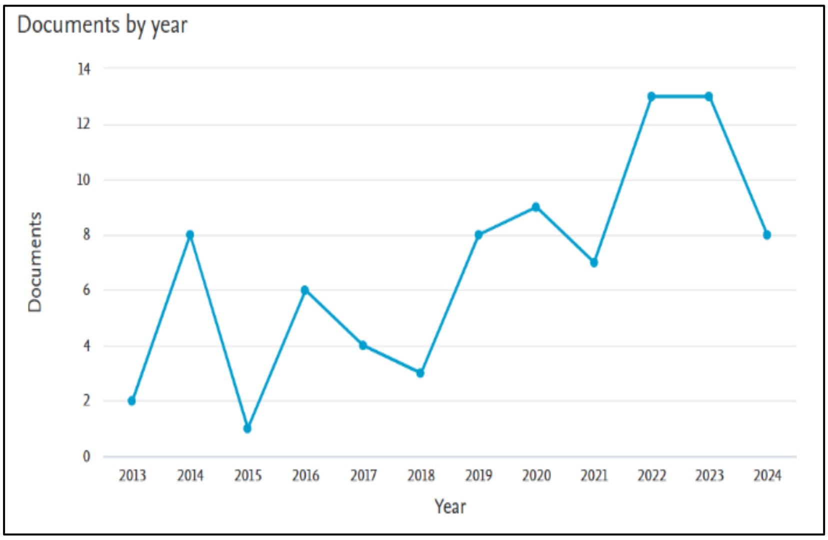

Figure 13. Ratio of articles per year.

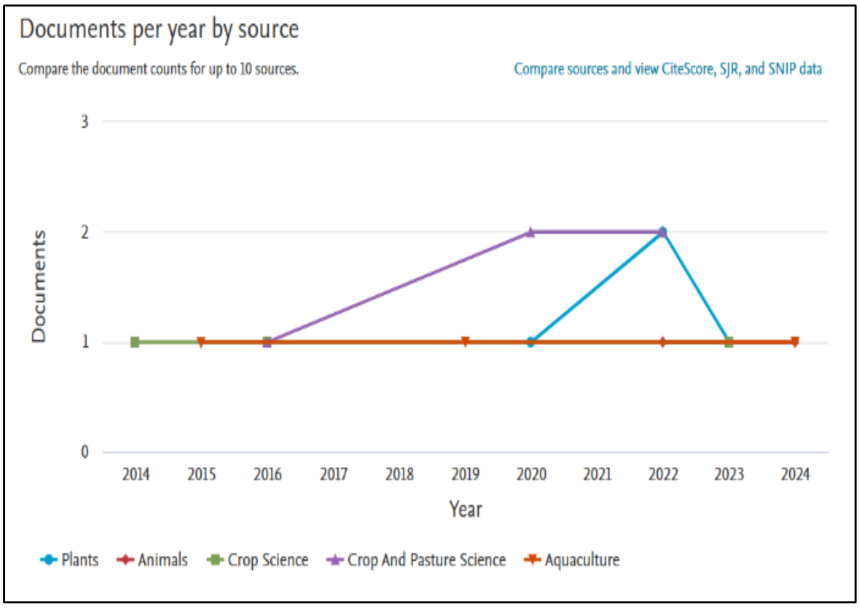

Figure 14. Ratio of articles by source.

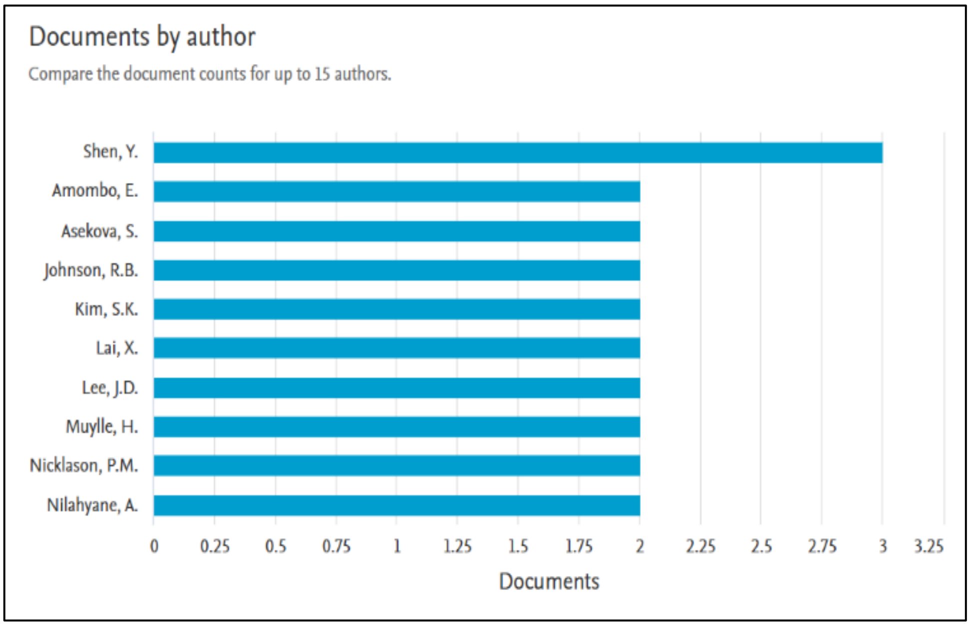

Figure 15. Ratio of articles by authors.

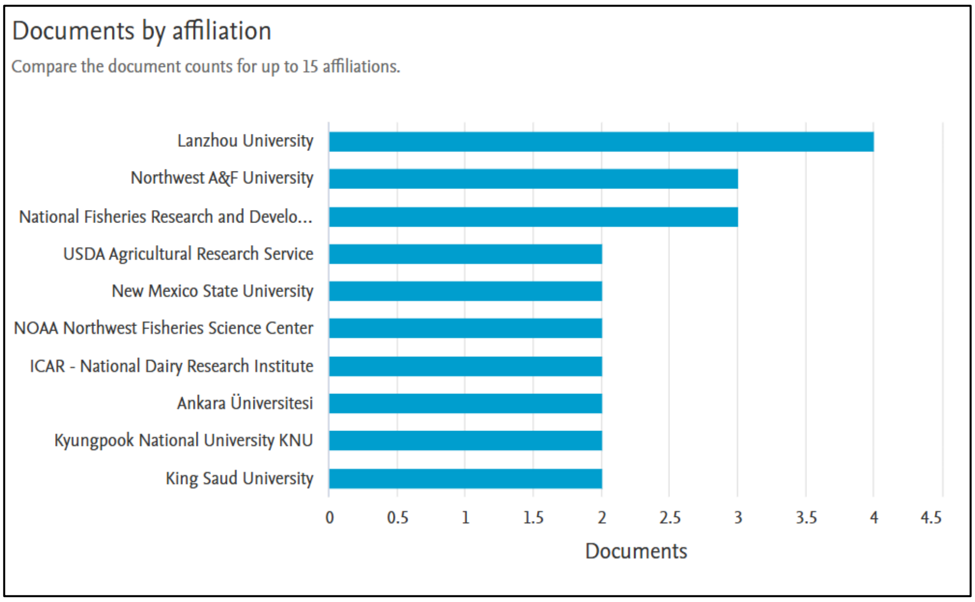

Figure 16. Ratio of articles by affiliations.

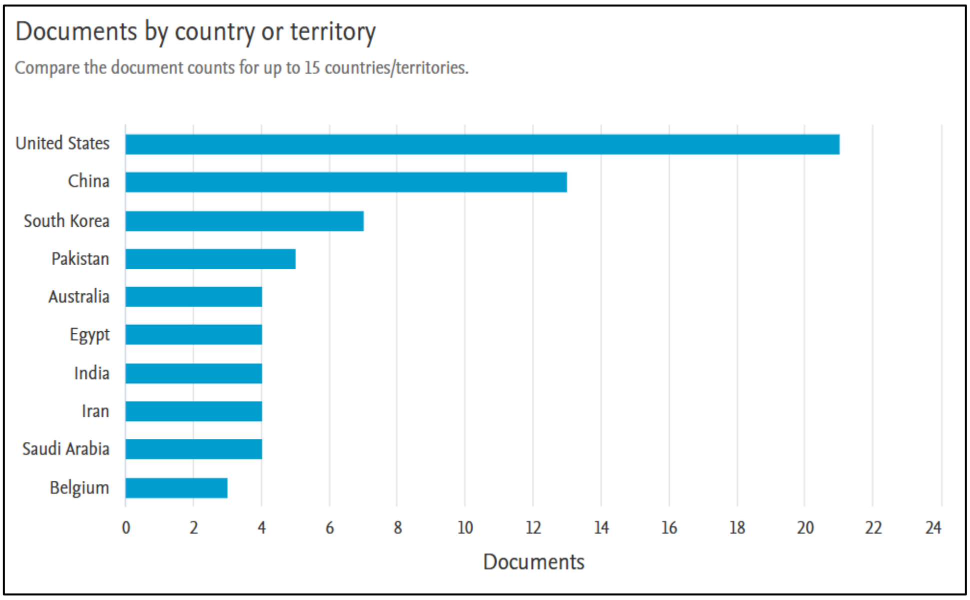

Figure 17. Ratio of articles by country.

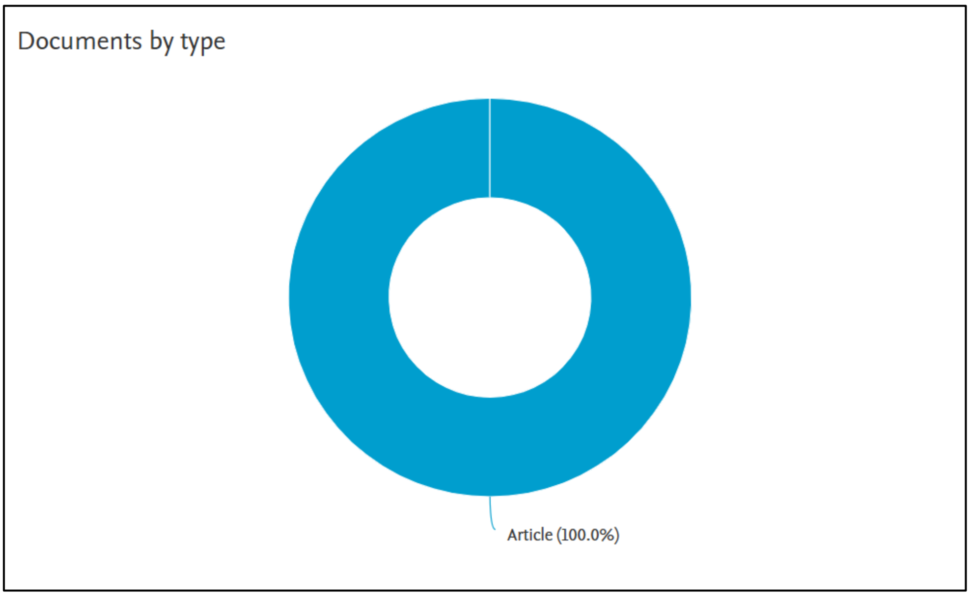

Figure 18. Ratio of articles by type.

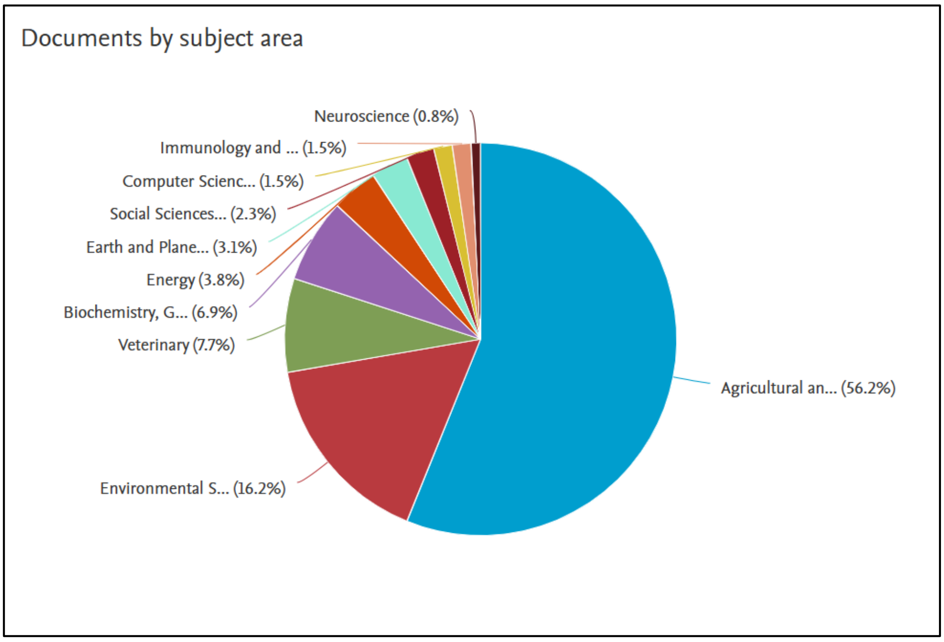

Figure 19. Ratio of articles by type.

4. Conclusions

The bibliometric review of plant-based feeds and forage research for livestock, gathered from 2013 to 2024, provides valuable insights into key trends, contributors, and thematic research development. This intensifies significant research endeavors that focus on the quality of forage, productivity, environmental sustainability, and other related aspects. VOSviewer visualizations reveal the robust interdisciplinary connections between agriculture, environmental science, and the field of animal production, addressing agricultural challenges such as climate change, crop resilience, and sustainability. Collaborative research by prominent authors such as Devendra Singh Ginwal and R.K. Meena was one of the key findings of this research. Forage crops and forage quality are the main highlights of the keyword analysis, which means there is an emerging interest in nutritional and sustainable practices in raising livestock. The findings suggest an opportunity for the deeper integration of crop production and forage quality in future research studies. The United States and China are the countries with the largest number of research studies related to plant-based feed and forage, highlighting the need for direct collaboration between these countries. Bridging the gap in collaboration between these two countries could foster innovation and thereby accelerate progress. Lanzhou University and the USDA Agricultural Research Service are the institutional leading contributors, demonstrating that robust infrastructure and international collaboration in advancing this field are very important. The analysis of research output over time shows that peaks occur in 2014 and 2022, corresponding to an increasing interest in the specific thematic area. Crop and Pasture Science journals dominate the publication outlets for research that emphasizes the importance of targeting platforms with significant impact. Overall, the results identify emerging trends, key contributors, and thematic priorities, which offer a future roadmap for research. To address the gap in collaboration between countries, it is essential to integrate the underexplored research area to enhance the global network further, optimizing forage research to support sustainable agricultural goals and livestock nutrition and production in a growing economy.

5. Acknowledgements

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