TÍTULO

EXPLORACIÓN DEL POTENCIAL DE SEMILLAS PROTEICAS EN LA ALIMENTACIÓN DE GANADO EN SISTEMAS DE PRODUCCIÓN ECOLÓGICA

AUTOR

Amado Kent Ruiz Gil

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Tutor	Dr. Juan Manuel Mancilla Leytón
Cotutora	Dra. Sara Muñoz Vallés
Instituciones	Universidad Internacional de Andalucía; Universidad Pablo de Olavide
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TRABAJO FIN DE MÁSTER

Exploración del potencial de semillas proteicas en la alimentación de ganado en sistemas de producción ecológica

Autor: Amado Kent Ruiz Gil

Tutor: Dr. Juan Manuel Mancilla Leytón
Cotutora: Dr. Sara Muñoz Vallés

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Resumen

El creciente consumo de proteínas animales, impulsado por el aumento de la población global y una mayor demanda de carne y productos lácteos, se proyecta que intensificará los impactos ambientales, particularmente en términos de emisiones de gases de efecto invernadero relacionadas con la producción ganadera. La producción de alimentos para animales representa el 45% de las emisiones del sector ganadero, lo que hace esencial un uso eficiente de los recursos alimenticios para garantizar la sostenibilidad. Las semillas ricas en proteínas, como guisantes, frijoles y lentejas, están emergiendo como alternativas viables a las fuentes tradicionales de alimento, como el maíz y la soja, que tienen un impacto ambiental significativo. Estas semillas, producidas de manera sostenible, representan una opción de menor impacto que contribuye a mejorar la salud del suelo y reducir las emisiones.

Este estudio lleva a cabo un análisis bibliométrico para examinar las tendencias de investigación sobre el uso de semillas ricas en proteínas en la alimentación animal, con un enfoque particular en los sistemas de producción orgánica. Dos búsquedas en la base de datos Scopus, una general y otra centrada en la producción orgánica/ecológica, identificaron 356 y 35 artículos, respectivamente. El análisis reveló tendencias clave, vacíos de conocimiento y trayectorias de investigación en este campo emergente. Los resultados destacan el potencial de estas semillas para mejorar la nutrición animal, al mismo tiempo que se promueven los principios de sostenibilidad y producción orgánica en la ganadería.

El estudio subraya la importancia de la colaboración interdisciplinaria y la innovación para desarrollar estrategias sostenibles en la producción ganadera. La incorporación de semillas ricas en proteínas en la dieta animal podría reducir de manera significativa la huella de carbono, contribuyendo a satisfacer la creciente demanda alimentaria global, al tiempo que se mitigan los efectos del cambio climático.

Exploration of the potential of protein-rich seeds in livestock feeding in organic production systems, a bibliometric analysis

Amado Kent Ruiz-Gil [a], Sara Muñoz-Vallés [b], Juan Manuel Mancilla-Leytón [c]*

[a] Máster en Agricultura y Ganadería Ecológicas, UNIA, Spain. ORCID: 0000-0002-0988-0898

[b] Escuela Técnica Superior de Ingeniería Agronómica (ETSIA), US, Spain ORCID: 0000-0003-3143-9510

[c] Escuela Técnica Superior de Ingeniería Agronómica (ETSIA), US, Spain ORCID: 0000-0002-9042-6683

* Corresponding author. Tel.: 954557063, *E-mail address:* jmancilla@us.es

Abstract

The growing demand for animal protein, driven by a rising global population and increased meat and dairy consumption, is expected to exacerbate environmental impacts, particularly greenhouse gas emissions from livestock production. Feed production accounts for 45% of livestock-related emissions, making the efficient use of feed resources essential for sustainability. Protein-rich seeds, such as peas, beans, and lentils, are emerging as viable alternatives to traditional feed sources like corn and soybeans, which have significant environmental footprints. These seeds, especially when produced sustainably, offer a lower-input, environmentally friendly option that can improve soil health and reduce emissions.

This study conducts a bibliometric analysis to explore research trends on the use of protein-rich seeds in livestock feed, with a focus on organic farming systems. Two searches in the Scopus database, a general search and an organic/ecologic search, identified 356 and 35 articles, respectively. The analysis revealed key trends, knowledge gaps, and research trajectories in this emerging field. The findings highlight the potential of protein-rich seeds to enhance animal nutrition while promoting sustainability and

organic principles in livestock farming.

The study underscores the importance of cross-disciplinary collaboration and innovation in developing sustainable livestock production strategies. Integrating protein-rich seeds into livestock diets could significantly reduce the carbon footprint of farming, aligning with global goals to meet growing nutritional demands while mitigating climate change impacts.

Introduction

Nutritionists advise that approximately one third of an adult human's daily protein intake should come from animal sources. In this regard, it is expected that the consumption of products of animal origin will continue growing towards 2050, due to an increase in the annual global consumption of meat, milk and other dairy products, as well as a growing human population, estimated to be greater than 9.5 billion in 2050 (Alexandratos & Bruinsma, 2012; Pingault et al., 2016; United Nations, 2019)

Feed constitutes 50-70% of the expenses involved in producing animal protein, and their production demands significant amounts of scarce natural resources, including water, land, fuel, and fertilizers (Flachowsky & Meyer, 2015). In this sense, the selection of raw materials for animal feeding not only affects the economy and viability of farms, but also the ways and dimension of the environmental impacts of livestock production *per se* as well as those of the input products on which it depends. In this sense, regarding only impacts enhancing global warming and climate change, 45% percent of the total greenhouse gas emissions from the livestock sector is attributed to feed production and processing, while other sources of emissions, such as enteric methane (35%), land-use change (9%), and manure gases (9.5%), largely depend on feed types (Makkar, 2016). Given the growing demand for animal feed, those impacts are expected to keep increasing unless a holistic and systemic approach is applied (Duluins & Baret, 2024). Efficient use of feed resources and the adoption of effective feeding strategies are essential for ensuring sustainability (Pulina et al., 2017). Essential innovations and practices in feed production and feeding encompass balanced and phased feeding strategies, enhancement of forage quality and utilization in diets, harvesting forages at their peak nutrient availability per unit of land, and reduction of grain usage (Parisi et al., 2020). Additional measures include the emergence of new business models for producing and using forages and silages on smallholder farms, strengthening seed development and distribution systems and incorporating underutilized local feed crops (Moorby & Fraser, 2021). Moreover, the collection of national-level feed availability data and the generation of accurate chemical composition and nutritional value data for feeds are crucial prerequisites for driving

innovation (Makkar, 2016).

Protein and energy are main elements on the composition of diets for animal feeding (McDonald et al., 2010). Several studies highlight that the use of protein-rich seeds for animal feeding (Moorby & Fraser, 2021; Parisi et al., 2020) can be part of the solution to reduce emissions from livestock production, in parallel to the adoption of more sustainable forms of agricultural production (de Oliveira Silva et al., 2017; Horrillo et al., 2020; Notenbaert et al., 2021). These seeds can provide a more sustainable source of protein for animal feeding in comparison to traditional options, such as corn, barley, wheat, and also soybean meal, since these other sources often require significant amounts of water, fertilizers, and pesticides, thus contributing to greenhouse gas emissions and environmental degradation (Chojnacka et al., 2021). Furthermore, conscious ways of producing these seeds, commonly legumes, can use lower inputs, improve soil health through crop rotation and enhance nitrogen fixation, making them a more sustainable option in many cases (Yanni et al., 2024). Thus, the use of well-known as well as emerging protein-rich seeds for animal feeding, alternative to soybean, such as peas, beans or lentils, particularly in the context of local and sustainable production as a part of a broader strategy, would be a solution to ameliorate the overall carbon footprint associated with livestock farming (Moorby & Fraser, 2021). In addition, protein-rich seeds, derived from diverse plant sources such as legumes, oilseeds, and pseudocereals, present a valuable opportunity to enrich livestock diets (Parisi et al., 2020), while adhering to organic principles. In the quest for sustainable and efficient livestock feeding practices, the integration of protein-rich seeds into organic production systems offers a promising avenue for enhancing animal nutrition and farm productivity (Díaz-Gaona et al., 2019).

In numerous scientific disciplines, there is a need to gain a comprehensive understanding of the literature (Freire & Nicol, 2019). However, in relatively new and merged fields like protein source feed in organic farming, the information is scattered across various sources, traditional review articles are scarce and provide only a partial view. In such cases, bibliometric analysis serves as a valuable complement to offer a more complete perspective (George et al., 2021; Pacheco et al., 2024; Zheng & Liu, 2022). This

type of analysis is a widely used and robust approach for examining and interpreting extensive collections of scientific data. It allows for the detailed exploration of the development and trends within a particular discipline, while also highlighting new and emerging areas within that field (Donthu et al., 2021).

This bibliometric analysis aims to compare the broader research trends on the use of protein-rich seeds in livestock feed with the more specialized focus on organic production systems, identifying key knowledge gaps, research trajectories, and future opportunities to enhance sustainable livestock nutrition.

Material and Methods

Bibliometric analysis is a rigorous method to explore and analyze large volumes of scientific data(Donthu et al., 2021). The difference with conventional reviews is the implementation of a repeatable, methodical, and clear procedure based on comprehensive literature searches of academic publications (Mancilla-Leytón et al., 2022).

A preliminary step was taken to provide an overview of the academic literature on the potential of plants, particularly seeds, as protein sources for livestock in organic farming. This involved an initial search across various databases (e.g., Scopus, Web of Science, and Google Scholar—the latter also including non-indexed documents). Specific keywords such as "protein", "livestock", "plant", and "seed" were used, both in English and their Spanish translations, along with different combinations of these terms. For the bibliometric analysis, data were subsequently extracted from Elsevier's Scopus database, limited to select only documents in English or Spanish language. A thorough ¨General¨ search was conducted in Scopus using [TITLE-ABS-KEY (protein AND seed AND feed AND livestock) AND PUBYEAR > 1970 AND PUBYEAR < 2024] as the search field. A total of 356 articles were identified in the search. A second ¨Organic/Ecologic¨ search was conducted in Scopus using [TITLE-ABS-KEY (protein AND seed AND feed AND livestock AND organic OR ecologic) AND PUBYEAR > 1970 AND PUBYEAR < 2024] as the search field. A total of 35 documents were retrieved. A specialized Scopus function was then used to gather data from these articles for a bibliometric analysis, covering aspects such as authorship, country of origin, field of study, and citation counts, among other categories. The data from this database was analyzed and processed using VOSviewer software (developed by Leiden University and CWTS) to uncover the general thematic relationships among the collected manuscripts (Donthu et al., 2021).

The size of each cluster was based on the number of keywords, their frequency of occurrence ($n \geq 10$ times for general search and $n \geq 3$ for the organic/ecologic), and their similarity index. Following the bibliometric analysis, a comprehensive review of the articles was conducted. This review facilitated the evaluation of the overall potential of species and seeds as protein sources for livestock in organic farming.

Results and Discussion

Basic bibliometric analysis

Documents per Year

The first document meeting the criteria for this review was published in 1971, covering data from 1971 to 2023. A total of 356 papers were identified that met the selection criteria for the general search. The compound annual growth rate (CAGR) during this period was 5.8%, indicating a clear upward trend in the number of publications, particularly in recent years (Figure 1). In the 21st century, the production of works incorporating the selected terms saw significant growth, rising from just 2 publications in 2001 to over 30 per year by 2023. This increase suggests a strong level of scientific activity, as the volume of published articles often correlates with research output and interest.

In contrast, when “Organic” was included in the search, fewer documents were found. However, there has been a notable increase in publications in this area during the 21st century, especially in the years leading up to 2023. The growing number of published papers and funded projects seems to align with the rising consumer and market interest in organic production, including organic livestock farming (Manuelian et al., 2020).

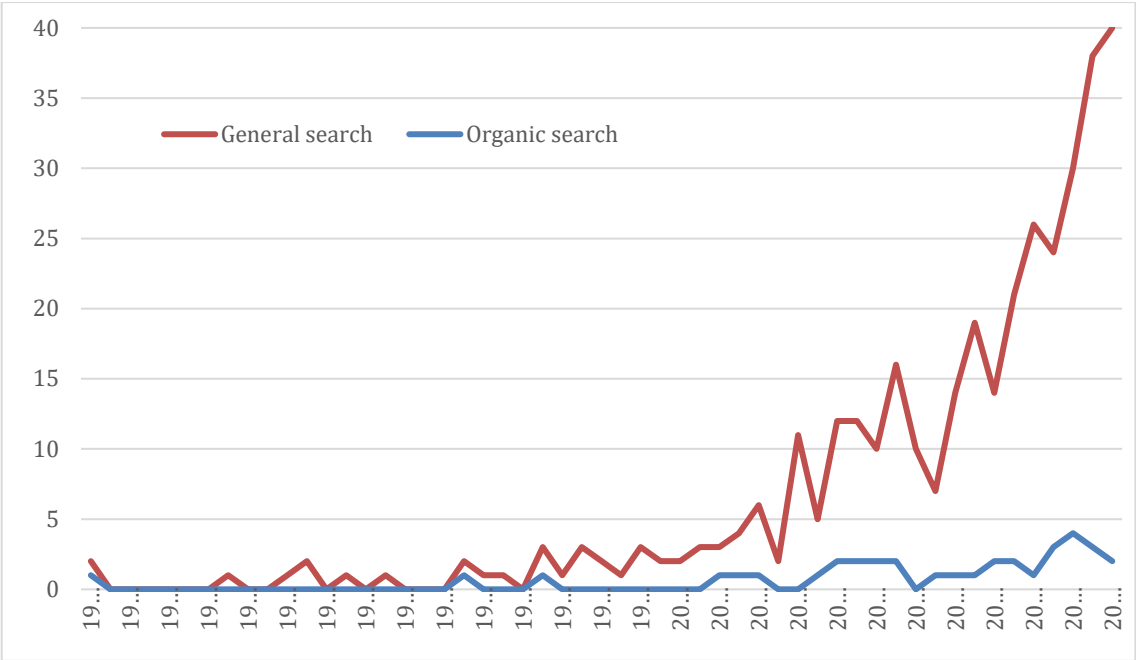


Figure 1. Number of documents published from 1971 to 2023, retrieved from Scopus General search (using keyword combination: protein + seed + feed + livestock) and Organic search (adding organic/ecologic).

Types of Documents

The majority of the documents obtained from general search were scientific articles, with 15% categorized as review articles. The remaining documents comprised books, book chapters, and conference papers. A similar trend was observed when "organic" was included in the search.

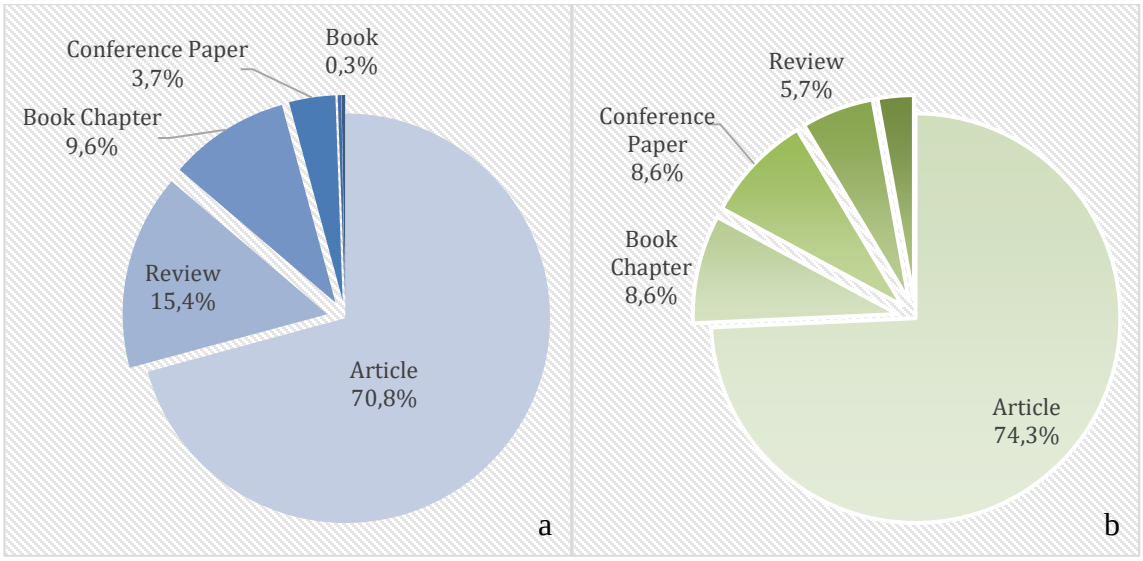


Figure 2. Type of the documents obtained from Scopus using the keywords: protein + seed + feed + livestock (2a) and adding "organic" (2b).

Authors

By analyzing the authors with the most documents included in the general search, along with their h-index (Figure 3), total number of publications, and citations in Scopus (Figure 4), 13 authors were selected. Table 1 provides details about their affiliations, countries, and the topics they most frequently contributed to in relation to the subject (general search).

The highest number of documents by a single author in our search was five. However, all selected authors have over 70 documents in Scopus, indicating that this is not their primary research focus.

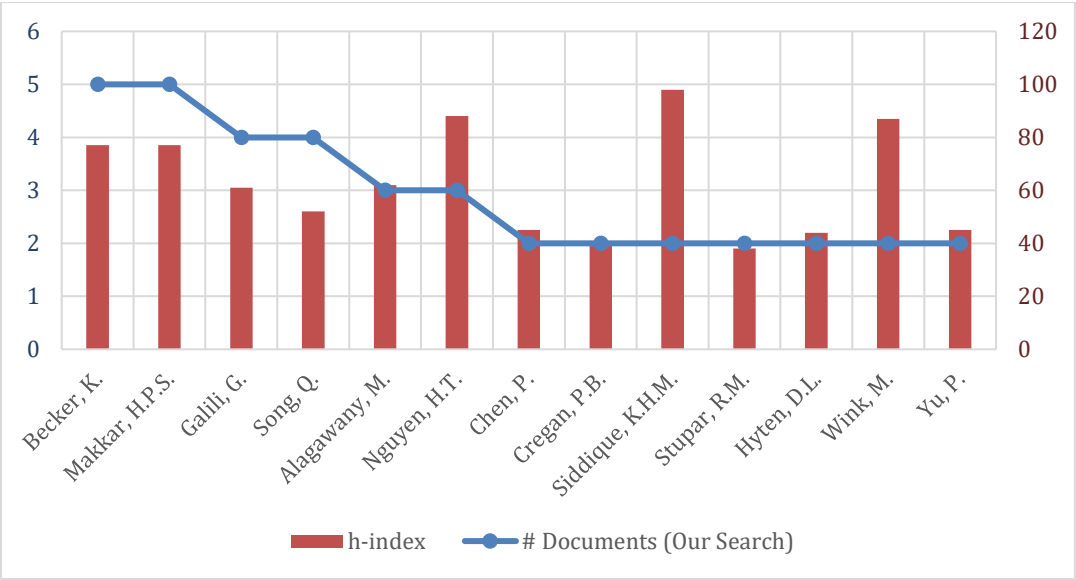


Figure 3. Number of documents for main authors (according to our search in Scopus using the combination of keywords: protein + seed + feed + livestock) and their h-index.

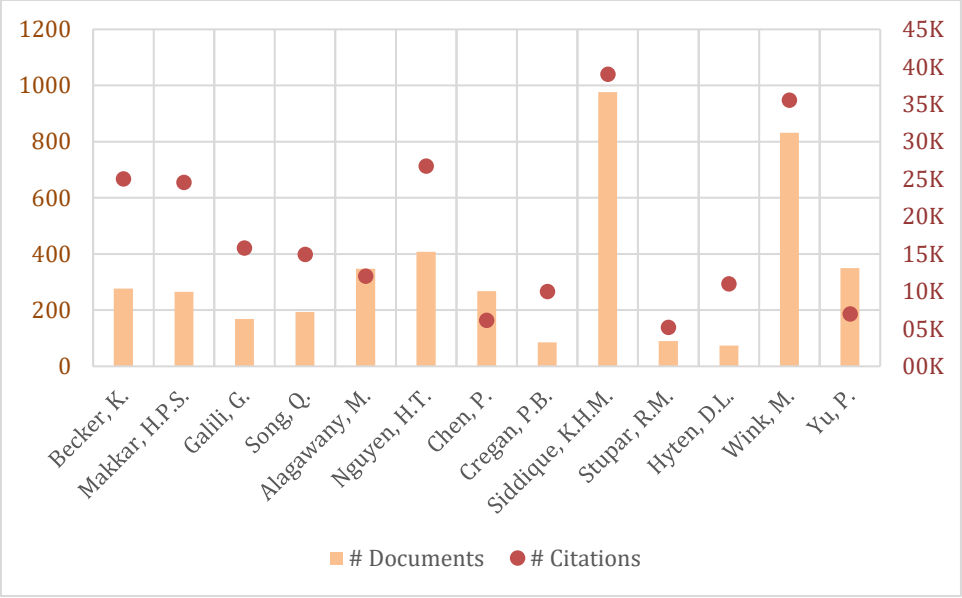


Figure 4. Number of documents and citations in general for selected main authors.

Most of the selected scientists are based in North America. Six are affiliated with U.S. institutions, representing three different universities and two locations of the Department of Agriculture's Agricultural Research Service (ARS). One researcher is

based at a Canadian university. Additionally, three authors are based in Europe, with two affiliated with German universities and one consultant (Makkar, H.P.S.) based in Austria, who previously worked at a German university. The remaining authors conduct their research in academic institutions in Israel, Australia, and Egypt.

In terms of the topics, they have contributed to most in recent years, research on seeds and genetics, along with related fields, dominates. This is followed by studies on digestibility, feed, and soybeans.

Table 1. Affiliation, country and most contributed topics of main authors from General Search.

Author	Affiliation	Country	Related Most contributed topics 2019-23
Becker, K.	Univ. Hohenheim	Germany	Digestibility; Soybean Meal; Jatropha Curcas
Makkar, H.P.S.	Sustainable Bioeconomy	Austria	Digestibility; Soybean Meal; Rangeland; Farm Animal; Food Supply
Galili, G.	Weizmann Institute of Science	Israel	Autophagy; Abiotic Stress; Arabidopsis; Gene Expression Profiling
Song, Q.	USDA ARS Beltsville	USA	QTL; Seeds; Genetics; Phaseolus; SNP
Alagawany, M.	Univ. Zagazig, Fac. of Agriculture	Egypt	Broiler; Feed Supplementation; Probiotic; Growth Performance
Nguyen, H.T.	Univ. of Missouri	USA	QTL; Seeds; Genetics; Cultivar; Soybean; Plant Diseases
Chen, P.	Univ. of Missouri	USA	QTL; Seeds; Genetics; Cultivar; Soybean
Cregan, P.B.	USDA ARS Washington	USA	QTL; Seeds; Genetics
Siddique, K.H.M.	Univ. of Western Australia	Australia	Water, Chickpea; Genetic Marker; Root System; Common Wheat
Stupar, R.M.	Univ. of Minnesota Twin Cities	USA	QTL; Seeds; Genetics; Soil Moisture
Hyten, D.L.	Univ. of Nebraska–Lincoln	USA	QTL; Seeds; Genetics, SNP
Wink, M.	Univ. Heidelberg	Germany	Medicinal Plant; Antiinfective Agent; Antioxidant Capacity
Yu, P.	Univ. of Saskatchewan	Canada	Rumen; Digestibility; Food Contamination; Cereal

Only three authors had more than one document in the Organic search, and two of them are from the same institution. Their affiliations, countries, and the topics they most frequently contributed to are shown in Table 2. Among the top authors from the General search, only Makkar, H.P.S. had a paper included in the Organic search.

Table 2. Affiliation, country and most contributed topics of main authors from Organic Search.

Author	Affiliation	Country	Related Most contributed topics 2019-23
Zollitsch, W.J.	BOKU Univ.	Austria	Greenhouse Gas; Environmental Impact; LCA; Rumen; Dairy Cows; Maize
Chiofalo, B.	Univ. degli Studi di Messina	Italy	Fatty Acids; Dairy Cows; Milk Lipids; Amaranth; Nutritive Value; Cereal
Gresta, F.	Univ. degli Studi di Messina	Italy	Fatty Acids; Dairy Cows; Milk Lipids; Amaranth; Nutritive Value; Cereal

Affiliations

The institutions (Figure 5) from General search align with the top authors mentioned, with the USA dominating the top five. The Indian Veterinary Research Institute stands out, contributing six documents, along with the Federal University of Technology Owerri in Nigeria, representing research from developing countries on the issue. The remaining institutions are academic or government organizations from Europe (the UK, the Netherlands, Germany) and Canada.

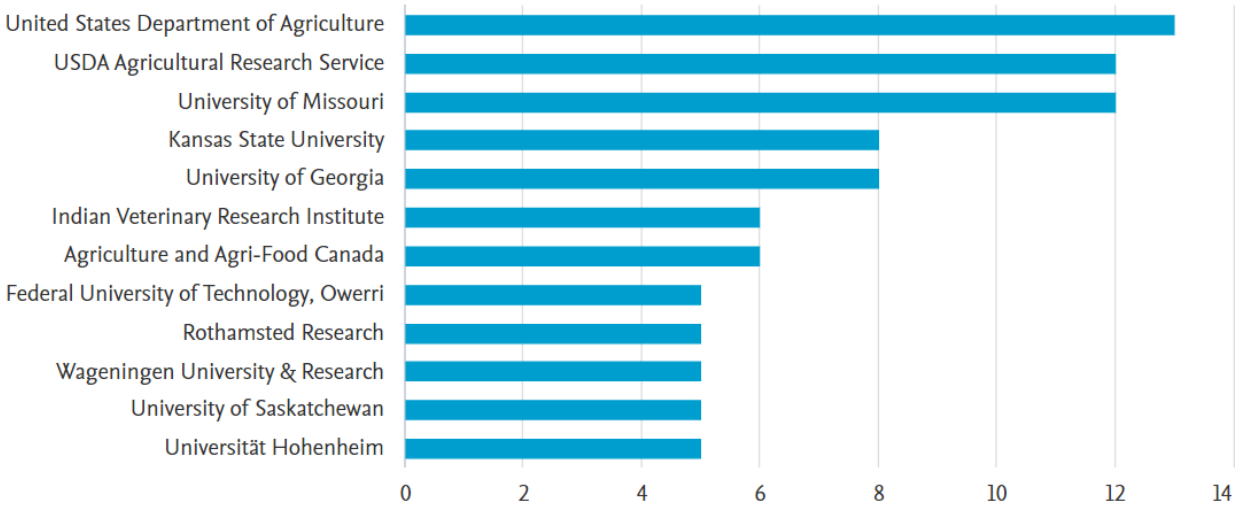
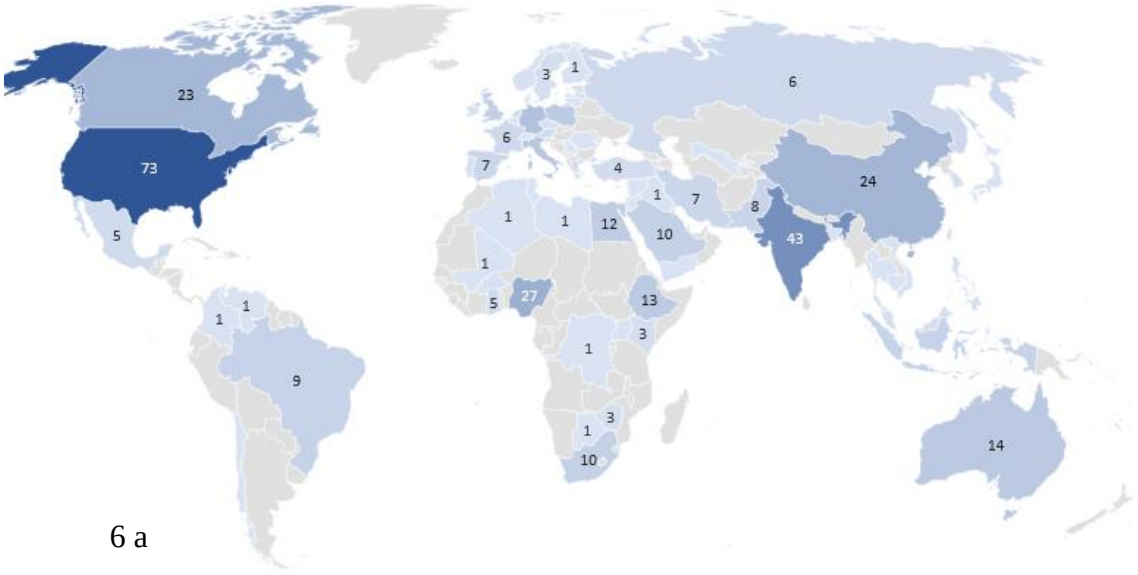


Figure 5. Number of documents submitted by the top 12 institutions, retrieved from Scopus search with keyword combination: protein + seed + feed + livestock.

In the organic search, the affiliations show a parallel with the most represented authors. Only four institutions are represented more than once: the two institutions mentioned in Table 2, along with Georg-August University of Göttingen (Germany) and Bahir Dar University (Ethiopia).

Countries

Authors affiliated with institutions in the United States and India have contributed the highest number of publications to General search documents (Figure 6a). Overall, 71 countries have participated in at least one publication during this period. In the Organic search, a total of 25 nations are represented (Figure 6b), with India and Germany leading the contributions. Germany, in particular, published the most scientific papers on organic livestock, according to a bibliometric analysis by Manuelian *et al*. (2020).



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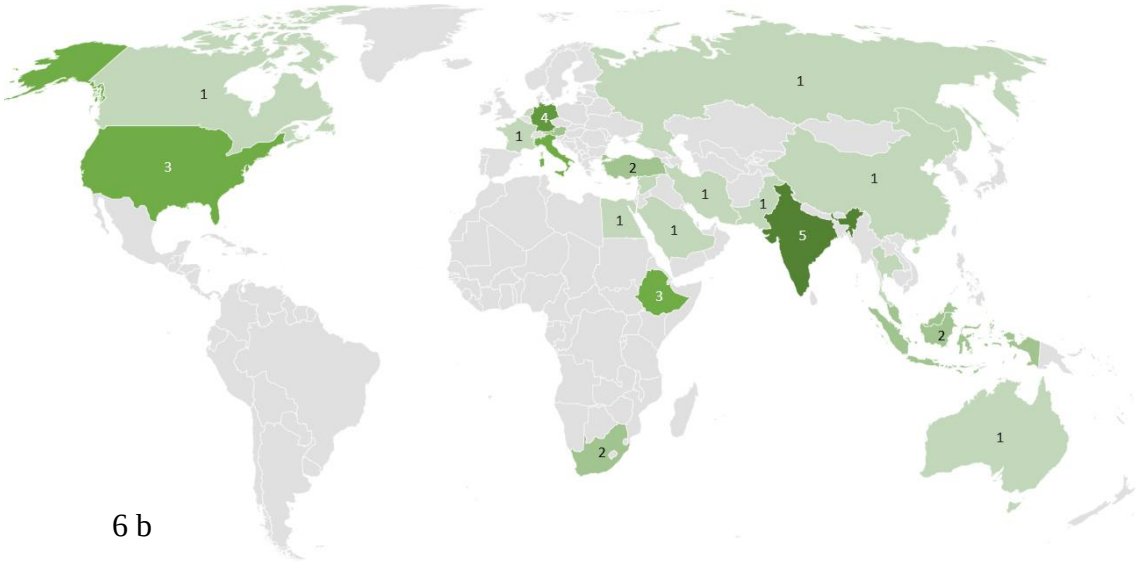

6 b

Figure 6. Map showing the countries and the number of documents in which researchers affiliated with institutions in those countries participated

(1971-2023). Data was obtained from a Scopus search using the following keyword combination: protein + seed + feed + livestock (6 a) and adding the term organic/ecologic to the search (6 b).

Funding

The primary funding organizations for the documents retrieved in the general search are presented in Table 3. The Department of Agriculture (USDA) from the USA provided the highest number of funded documents, accounting for eight publications.

The data reveals a prominent role for U.S. funding agencies in agricultural research, particularly the USDA and USB, reflecting the country's significant investment in this sector. The USDA, as the leading contributor, underscores its influence in shaping agricultural research globally, while the USB's funding of research suggests a strong private-sector interest in soy-related studies. Brazil's presence is also noteworthy, with two key funding public bodies, CAPES and CNPq, collectively contributing to 13 publications. This reflects Brazil's growing investment in higher education and scientific research, particularly in agriculture, which is a critical sector for the country's economy.

This distribution of funding highlights the essential role of national funding agencies in advancing agricultural science, while also showcasing the importance of cross-country collaborations in addressing global agricultural challenges.

Table 3. Main Funding Organizations and their countries for the General Search.

Department of Agriculture (USDA), **USA**	8
Coord. for the Improvement of Higher Education Personnel (CAPES), **Brazil**	7
United Soybean Board (USB), **USA**	7
National Council for Scientific & Technological Development (CNPq), **Brazil**	6
National Natural Science Foundation (NSFC), **China**	6
Biotechnology and Biological Sciences Research Council (BBSRC), **UK**	5
National Institute of Food and Agriculture (NIFA), **USA**	5
Indian Council of Agricultural Research (ICAR)	4

Given that funding data are not always available in research papers and considering

the few documents obtained in the Organic search, only 11 sponsors appeared among the 35 documents, each funding only one document and none of them were identified as main agents in the general search.

Subject area

Figure 7a shows the various subject areas of the documents obtained in the general search. The majority of the retrieved documents were classified under “Agricultural and Biological Sciences,” reflecting the central role of this field in studies related to seed proteins and their use in livestock feed. Other significant subject categories included “Biochemistry, Genetics, and Molecular Biology” and “Veterinary Sciences”; these fields are integral to understanding the biochemical composition of seed proteins and their impacts on animal health, growth, and nutrition. Documents classified under "Others" represent interdisciplinary or less traditional fields related to our search (Earth, Computer, Materials, Business-Economics, Physics, Neuroscience, or Social Sciences).

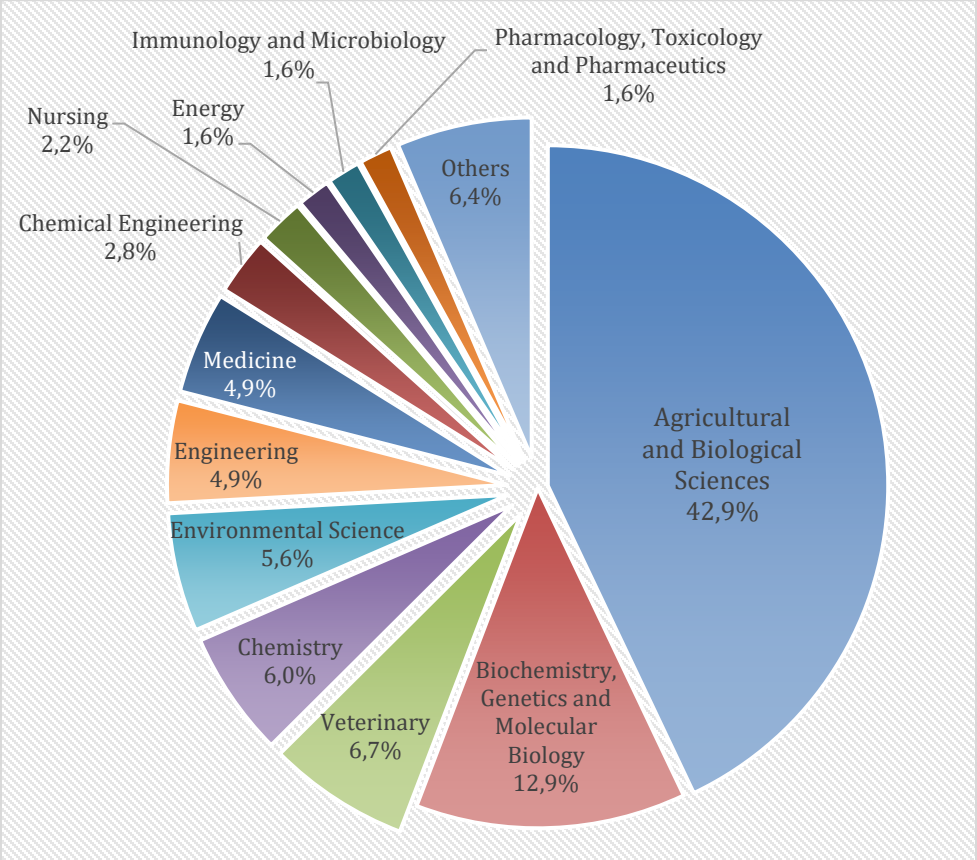

Figure 7a. Subjects of documents, in the General search retrieved from Scopus.

The trends in the subject areas are very similar when the search included "Organic" (Figure 7b).

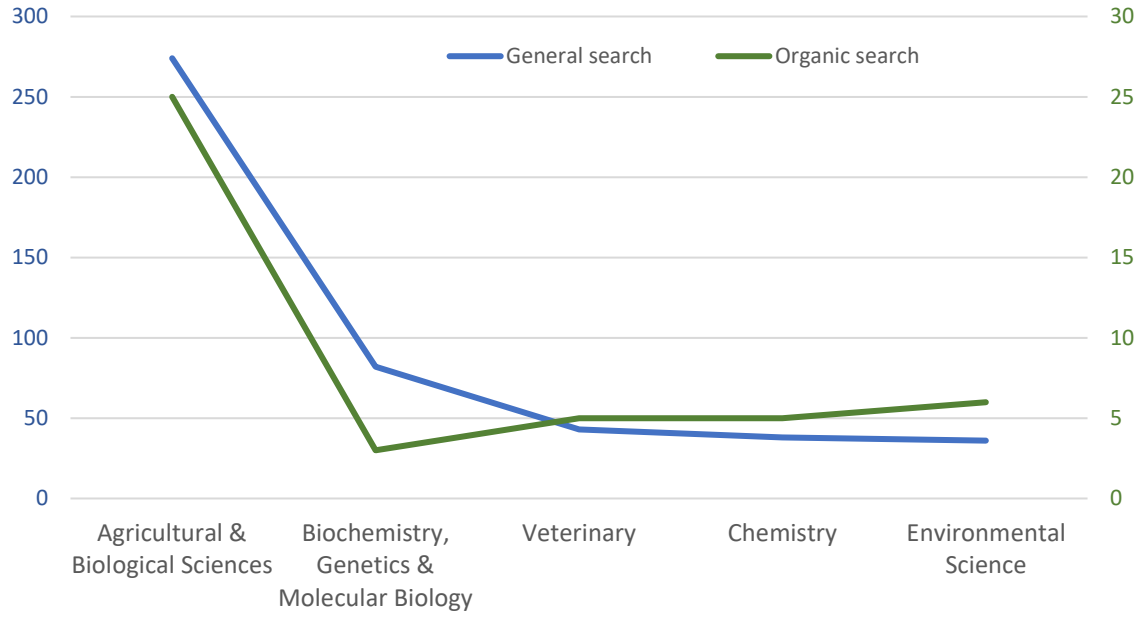

Figure 7b. Comparison of the subjects of documents from the General and Organic search.

The results of this Scopus search reveal a multidisciplinary approach to the study of seed-based proteins in livestock feed. The prominence of the "Agricultural and Biological Sciences" category reflects the central role of agriculture in researching alternative protein sources for animal feed, especially as global interest in sustainable food systems grows. In a bibliometric review of organic livestock production, the authors noted that research tends to focus more on feeding practices, particularly on forage and pasture, than on other topics (Manuelian et al., 2020). Research in this area is likely driven by the need to improve the nutritional quality of feed and enhance the efficiency of livestock production systems, as well as address food security concerns (Greenwood, 2021). The significant number of documents in "Biochemistry, Genetics and Molecular Biology" suggests that molecular approaches are becoming increasingly important in this field. Advances in genetic engineering, plant breeding, and protein characterization may provide new insights into optimizing feed formulations and developing novel protein sources,

which can support more sustainable livestock farming practices. The "Veterinary" and "Medicine" categories show that animal health and nutritional outcomes are key considerations when incorporating alternative proteins into livestock diets. Research in these fields could address the impact of new feed types on animal growth, disease resistance, and overall well-being, linking the nutritional properties of feed to livestock productivity and welfare (Schut *et al*., 2021; Sekaran *et al*., 2021).

Overall, the results point to a vibrant and multidisciplinary body of research exploring the potential of seed-based proteins for livestock feed. The wide distribution of documents across scientific disciplines underscores the complexity of this research area, which integrates biology, chemistry, environmental science, and animal health, among others. This interdisciplinary approach will likely be essential in advancing knowledge and innovation in sustainable livestock feed systems (Paul *et al*., 2020; van der Linden *et al*., 2020).

Sources

Figure 8 shows the distribution of the documents across different journals. *The Journal of Agricultural and Food Chemistry* was the most frequently cited source in General search, with 11 articles, highlighting its prominence in the field, particularly in the chemical composition analysis necessary for evaluating protein in livestock feed and seed composition. This was followed closely by *Animal Feed Science and Technology* and *Livestock Research for Rural Development*, each contributing 9 articles, and *Frontiers in Plant Science*, with 8 articles. Notably, the *Pakistan Journal of Nutrition* was also included, contributing 5 articles. A total of 142 journals were registered with at least one document for the General search, while 30 sources covered the Organic search.

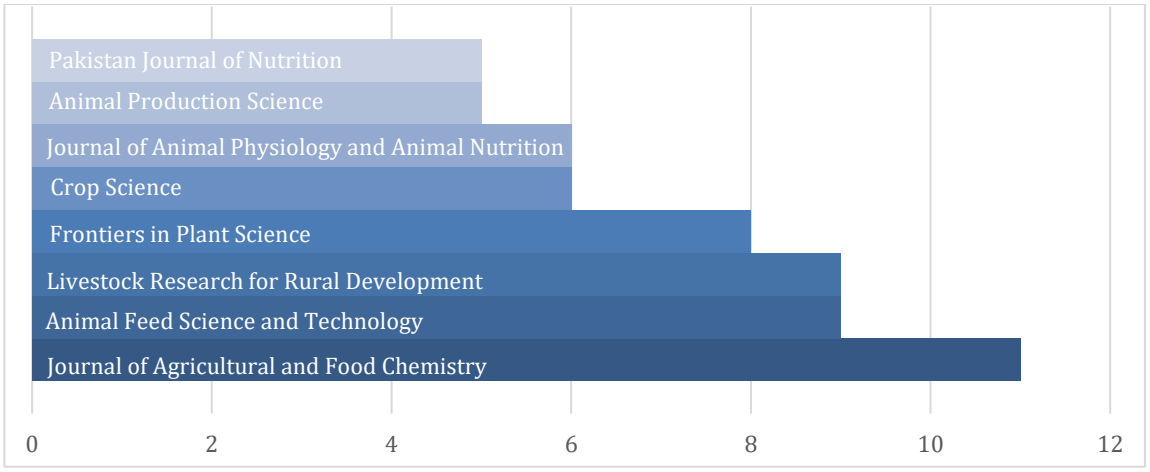

Figure 8. Journals by number of documents published in the period 1971-2023, related to the search retrieved from Scopus.

Top Documents

The documents most relevant to General search, as determined by the Scopus algorithm, are listed in Table 4. This table includes the top 20 documents, ranked by Scopus relevance, based on a search conducted from 1971 to 2023 using the keyword combination: "protein + seed + feed + livestock".

These articles provide key insights into the use of seeds as protein sources in livestock feed, covering a wide range of feed types, regional studies, and species: *Acacia nilotica*, *Hevea brasiliensis*, *Shorea robusta*, *Ximenia caffra*, *Sesamum indicum*, different species of *Lupinus*, *Brassica napus*, *Chenopodium quinoa*, *Jatropha curcas*, *Pisum sativum*, *Vicia faba*, *Albizia lebbeck*, and *Glycine max*. These species are evaluated for their nutritional benefits, as well as their limitations, such as the presence of anti-nutritional factors like tannins and phytic acid (Chivandi *et al*., 2012; Kumaresan *et al*., 1984; Negi, 1982; Nwokolo, 2017). A particularly prominent focus within these relevant documents is on soybeans, which feature in six of the top articles. Studies examine the biological mechanisms affecting soybean protein concentration and composition, the genetic enhancement of soybean seeds (such as low-phytic-acid mutants), and the development of high-protein feed products derived from non-genetically modified soybean varieties (Valliyodan & Nguyen, 2012; Wilcox & Shibles, 2001). Moreover, the

relationship between soybean seed quality attributes and their processing products is explored in depth, emphasizing soybeans' pivotal role in cattle nutrition (Niwińska *et al*., 2020).

Table 4. Top 20 documents by Scopus relevance, General search.

1st Author, Year	**Title**
Kumaresan, 1984	Biochemical evaluation of bagaruwa seeds (*Acacia nilotica*) for use as livestock feed
Nwokolo, 2017	Rubber seeds, oil and meal. Chapter in ”Non-Traditional Feeds for Use in Swine Production” (1992)
Negi, 1982	Tannins in sal seed (*Shorea robusta*) and sal seed meal limit their utilization as livestock feeds
Chivandi E, 2012	Red sour plum (*Ximenia caffra*) seed: A potential nonconventional energy and protein source for livestock feeds
Wilcox, 2001	Interrelationships among seed quality attributes in soybean
Valliyodan, 2012	Biological Mechanisms that Influence Soy Protein Concentration and Composition
Niwińska, 2020	Seeds of n-GM soybean varieties cultivated in poland and their processing products as high-protein feeds in cattle nutrition
Wadhwa, 2016	Application of Waste-Derived Proteins in the Animal Feed Industry
Kabinda, 2022	Significance of sesame (*Sesamum indicum L.*) as a feed resource towards small-ruminant animal production in Southern Africa: a review
Badigannavar, 2012	Improving the bioavailability of seed phosphorous in low phytic acid soybean mutants
Yuldasheva, 2023	Growth phases of autumn rapeseed effect of seedling thickness
Gaponov, 2021	The lupine significance for forage production: Lupin-and-rape concentrate as a source of valuable nutrients for animal feeding
Asher, 2020	The potential of quinoa (*Chenopodium quinoa*) cultivation in Israel as a dual-purpose crop for grain production and livestock feed
Nithiyanantham, 2012	Potential of *Jatropha curcas* as a biofuel, animal feed and health products
Aregheore, 1998	A review of implications of antiquality and toxic components in unconventional feedstuffs advocated for use in intensive animal production in Nigeria
Schumacher, 2011	Seed protein amino acid composition of important local grain legumes *Lupinus angustifolius L.*, *Lupinus luteus L.*, *Pisum sativum L.* and *Vicia faba L.*
Vianna, 2023	Soybean seed protein storage vacuoles for expression of recombinant molecules
Spaner, 2001	Pea and soybean performance in Newfoundland
Hassan, 2007	Nutritional evaluation of *Albizia lebbeck* (L.) pods as source of feeds for livestock
Makkar, 2008	Protein concentrate from *Jatropha curcas* screw-pressed seed cake and toxic and antinutritional factors in protein concentrate

Figure 9 illustrates the dispersion of the 20 most cited documents retrieved from General search, plotted against their respective years of publication.

The top documents by citation count in the Organic search are showed in Table 5. In contrast, the Scopus relevance-based ranking in Table 6 identifies Chivandi (2012) as the most relevant document, according to our terms for Organic search. This research on red sour plum seed as a non-conventional energy and protein source for livestock feeds appears on both search relevance tables. Notably, Schumacher (2011) appears in both tables, as well as in General search relevance table, indicating that their work on the amino acid composition of grain legumes is highly recognized.

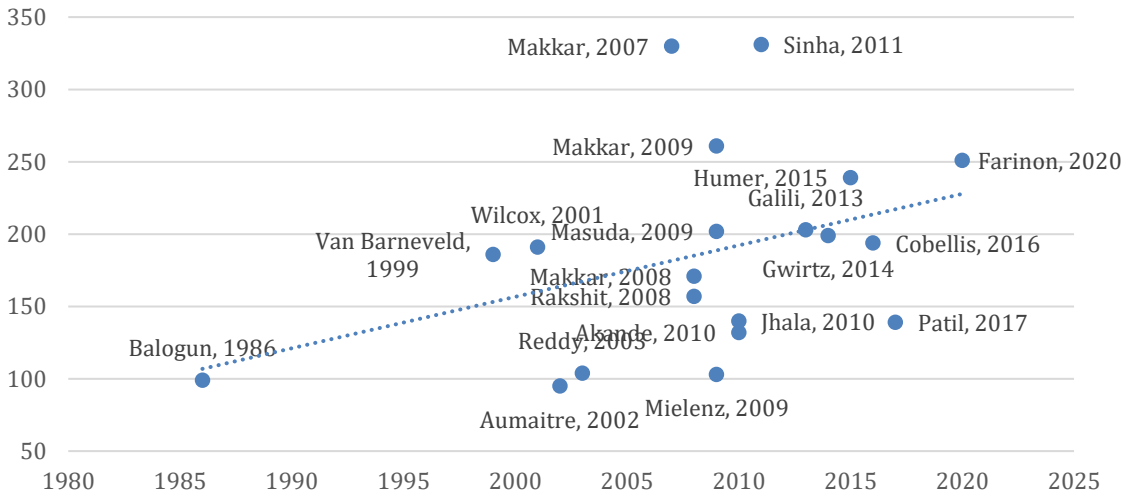

Figure 9. Distribution of 20 higher cited documents by year of publication, from the Scopus search, using keyword combination: protein + seed + feed + livestock, period 1971-2023.

Table 5. Top documents by citations, Organic search.

1st Author, Year	Title	Cites
Reddy, 2003	Crop management factors influencing yield and quality of crop residues	104
Mielenz, 2009	Fermentation of soybean hulls to ethanol while preserving protein value	103
Olukomaiya, 2019	Solid-state fermented plant protein sources in the diets of broiler chickens: A review	92
Howard, 2010	Reactive organic gas emissions from livestock feed contribute significantly to ozone production in central California	54
Schumacher, 2011	Seed protein amino acid composition of important local grain legumes *Lupinus angustifolius L.*, *Lupinus luteus L.*, *Pisum sativum L.* and *Vicia faba L.*	43
Downey, 1971	Agricultural and genetic potentials of cruciferous oilseed crops	41
Gresta, 2017	Seed yield, galactomannan content and quality traits of different guar (*Cyamopsis tetragonoloba* L.) genotypes	34
Makkar, 1990	Tannin levels and their degree of polymerisation and specific activity in some agro-industrial by-products	25
Gresta, 2010	Lupin seed for the crop-livestock food chain	24

Table 6. Top documents by relevance, Organic search.

1st Author, Year	Title	Cites
Chivandi E, 2012	Red sour plum (*Ximenia caffra*) seed: A potential nonconventional energy and protein source for livestock feeds	10
Schumacher, 2011	Seed protein amino acid composition of important local grain legumes *Lupinus angustifolius L.*, *Lupinus luteus L.*, *Pisum sativum L.* and *Vicia faba L.*	43
Wlcek, 2004	Sustainable pig nutrition in organic farming: By-products from food processing as a feed resource	11
Yeheyis, 2012	Sweet blue lupin *(Lupinus angustifolius* L.) seed as a substitute for concentrate mix supplement in the diets of yearling washera rams fed on natural pasture hay as basal diet in Ethiopia	10
Ingale, 2011	Amino acid profile of some new varieties of oil seeds	7

Keywords and Co-occurrence

Clusters

The Figure 10 illustrates the connections between the documents retrieved from the General search, based on the frequency of specific keywords. The resulting map highlights four clusters, each distinguished by a different color. At the center of the relationships between these documents, the keywords "protein" "seeds" and "animal feed"

are particularly prominent.

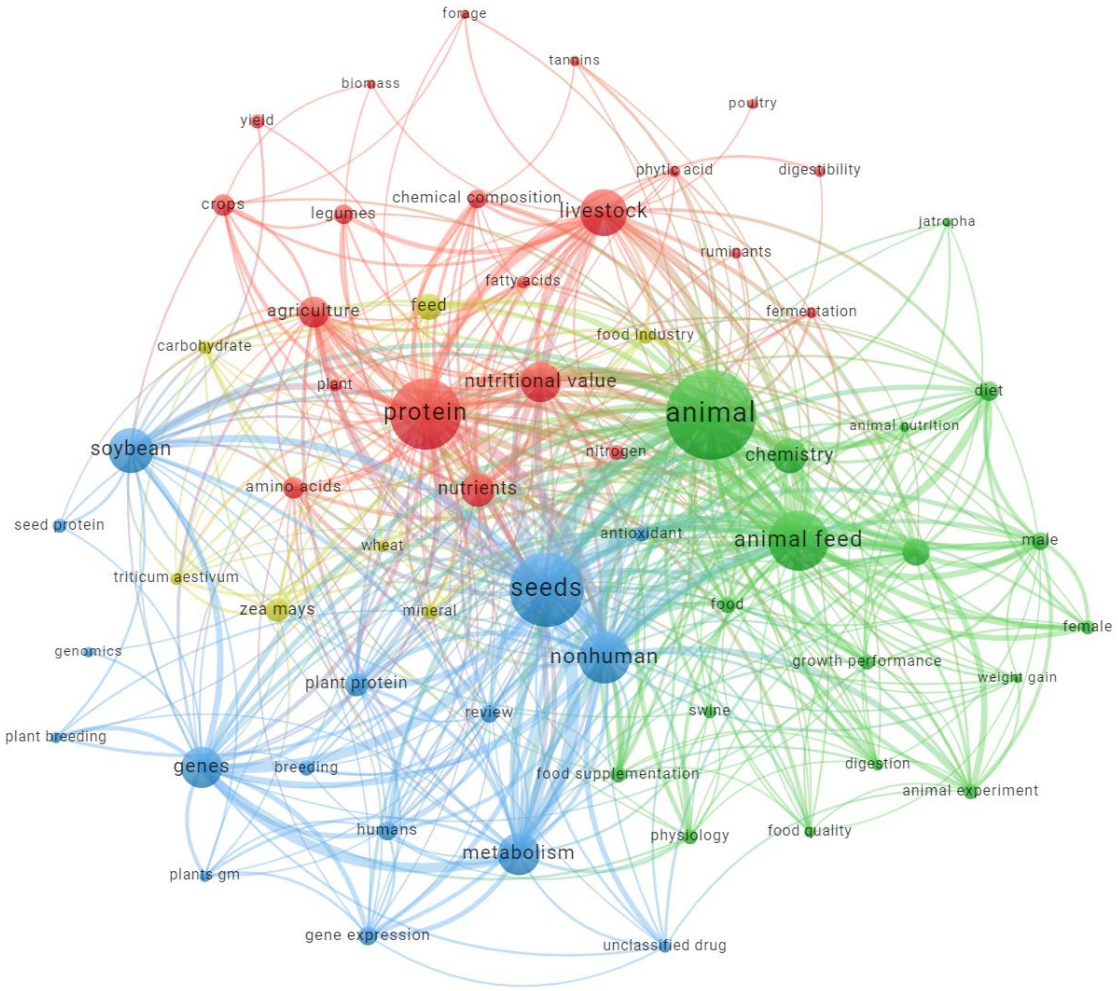

Figure 10. Clusters of keywords co-ocurrence (obtained using VOSviewer software) in documents, with a frequency equal or greater than 10, for Scopus search (356 documents), using keyword combination: protein + seed + feed + livestock, period 1971-2023.

The four groups distinguished by the software were organized into lists for comparison (Table 7). The four clusters group keywords around different themes related to agriculture, food science, and animal nutrition. Cluster 1 focuses on plant-based agricultural production, highlighting crops, livestock, and nutrients like protein, amino acids, and nitrogen, which are essential for agricultural yield and animal feed. Cluster 2 deals with animal-based research and nutrition, emphasizing controlled studies on animals, food quality, and factors like growth performance, physiology, and digestion.

Cluster 3 centers on plant science and genetic research, discussing plant breeding, gene expression, and plant proteins such as soybeans and wheat. Finally, Cluster 4 relates to animal food industry and components, with keywords like feed, *Zea mays*, mineral, and carbohydrate, indicating a focus on industrial processing and nutritional elements. Together, these clusters reflect an interdisciplinary focus on the intersection of plant and animal sciences, nutrition, and food production.

Table 7. Keywords identified in the General search documents, analyzed based on the clustering performed using VOSviewer. Terms included in these clusters had to appear at least ten times to be considered.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
protein	animal	seeds	feed
livestock	animal feed	nonhuman	zea mays
nutritional value	chemistry	soybean	food industry
nutrients	controlled study	metabolism	mineral
agriculture	diet	genes	carbohydrate
amino acids	male	plant protein	triticum aestivum
crops	food	gene expression	wheat
legumes	food supplementation	humans	
chemical composition	animal experiment	review	
nitrogen	growth performance	antioxidant	
yield	physiology	breeding	
fatty acids	female	seed protein	
plant	swine	unclassified drug	
digestibility	digestion	plant breeding	
fermentation	food quality	plants gm	
phytic acid	animal nutrition	genomics	
ruminants	jatropha		
poultry	weight gain		
tannins			
biomass			
forage			

The analysis of the Organic search using VOSviewer is depicted on Figure 11, resulting in four clusters but with lesser elements. The keywords "protein", "seeds", "feed" and "livestock" stand out as central to the connections between these 35 documents.

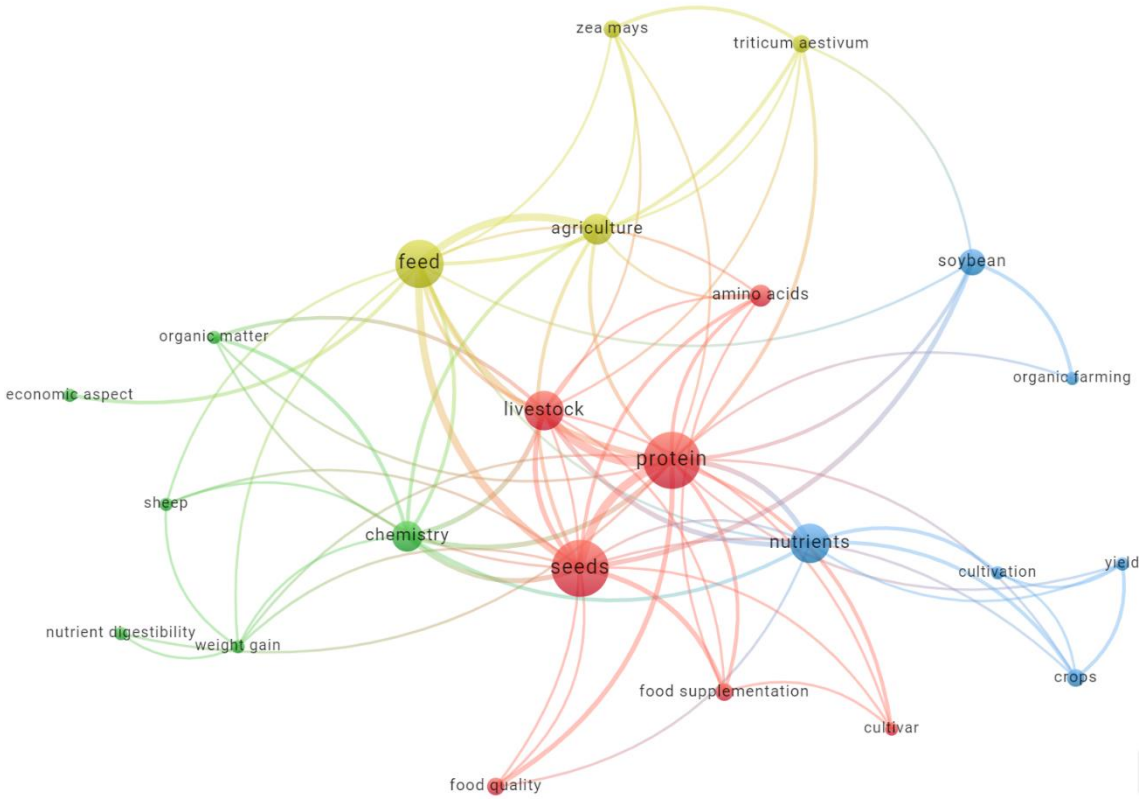

Figure 11. Clusters of keywords co-ocurrence (obtained using VOSviewer software) in documents, with a frequency equal or greater than 3, for Scopus search (35 documents), using keyword combination: protein + seed + feed + livestock + organic, period 1971-2023.

Table 8. Keywords identified in the Organic search documents, analyzed based on the clustering performed using VOSviewer. Terms included in these clusters had to appear at least three times to be considered.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
protein	chemistry	nutrients	feed
seeds	economic aspect	soybean	agriculture
livestock	nutrient digestibility	crops	triticum aestivum
amino acids	organic matter	cultivation	zea mays
food quality	sheep	organic farming	

food supplementation weight gain yield

cultivar

After adding "organic" to the search string, the resulting clusters show a more specific focus on organic farming and its associated aspects, leading to fewer documents and a refined clustering structure. Cluster 1 still highlights key components like protein, seeds, livestock, and amino acids, but the emphasis on food quality and supplementation suggests a more targeted exploration of organic agricultural products. Cluster 2 introduces "organic matter" and includes economic and nutrient digestibility aspects, reflecting the sustainability and efficiency of organic farming practices. In Cluster 3, the focus remains on nutrient-rich crops like soybeans but is now centered on "organic farming" and cultivation techniques, highlighting a shift towards organic crop production. Cluster 4 continues to emphasize large-scale agricultural elements like feed and major crops such as *Triticum aestivum* (wheat) and *Zea mays* (corn). The presence of fewer, more concentrated clusters illustrates a narrowing of scope towards organic practices, in contrast to the broader, conventional themes present in the original table.

Review of relevant papers in Organic search

The top relevant articles in the organic search provide insights into the potential of non-conventional seeds, legumes, and by-products as protein and energy sources for livestock feed, with an emphasis on sustainability and nutritional adequacy.

Schumacher *et al*. (2011) article is of big relevance to the topic of protein seed for livestock feeding in general (Table 4), even more in the organic animal production as this study emphasizes the value of legume proteins from species like *Lupinus angustifolius*, *Lupinus luteus*, *Pisum sativum*, and *Vicia faba* for livestock feed. These legumes are limited by the amino acid profiles, particularly tryptophan and sulfur-containing amino acids. The study underlines the need for further research and development in areas like selective breeding to enhance the amino acid composition, reducing dependence on high-quality components such as soybean meal. In a similar approach, although not explicitly stated as organic production-related research, the amino acid composition of lesser-known

oilseeds such as sunflower, safflower, and groundnut was evaluated (Ingale & Shrivastava, 2011). The study revealed a rich content of essential amino acids, including glutamic acid, aspartic acid, and methionine. These seeds demonstrated potential as energy and protein supplements in livestock feed, providing a sustainable alternative to traditional oilseed meals.

Nor focus on an organic farming but in a more practical context, sweet blue lupin (*Lupinus angustifolius*) was tested as a substitute for conventional concentrate feed in sheep diets in Ethiopia (Yeheyi *et al*., 2012). The study demonstrated that lupin seed could replace commercial concentrates without negatively affecting the animals' weight gain, with no significant differences in growth between lupin-based and conventional feed treatments. It underscores the potential for integrating local legume crops into livestock nutrition systems, improving feed security in regions with limited access to traditional feed inputs.

Ximenia caffra seed, also known as red sour plum seed, was identified as a potential non-conventional feed source based on its composition, suggests its suitability as a protein (18.3% crude protein) and energy supplement (32.1 MJ kg-1). Moreover, the presence of key amino acids such as glutamic acid and a low phytate-phosphate content enhances its nutritional profile (Chivandi *et al*., 2012). Another option for protein rich feed is the use of by-products from food processing. Its potential as a nutrient source for organic pig farming was explored in Austria (Wlcek & Zollitsch, 2004). By-products such as wheat and rye bran, feed-grade potatoes, and whey were found to offer substantial amounts of metabolizable energy. However, the availability of high-protein by-products was limited, covering only 4-5% of the protein and lysine requirements of pigs in organic systems. This study shows that organic by-products can provide energy and reduce waste, but they fall short in meeting protein demands, necessitating additional protein-rich feed components or innovative recycling of organic waste.

In general, these studies highlight the growing interest in alternative and underutilized feed sources, ranging from non-conventional seeds like *Ximenia caffra* and

lupins to by-products from food processing and lesser-known oil seeds. While these alternatives offer considerable potential in providing energy and protein for livestock, challenges remain, particularly in optimizing amino acid profiles and ensuring sufficient protein content. Research into selective breeding, improved processing techniques, and regional adaptation will be crucial in fully realizing the potential of these resources in sustainable livestock feeding systems.

Conclusions

The bibliometric analysis highlighted a growing scientific interest in this field, with significant contributions from researchers in the U.S., Europe, and developing countries, especially in the context of sustainable and organic farming. The study revealed knowledge gaps and research trajectories, emphasizing the importance of cross-disciplinary collaboration in addressing the challenges of sustainable livestock production. Additionally, the inclusion of protein-rich seeds in organic farming systems could enhance animal nutrition while aligning with organic and sustainable agricultural principles. This analysis underscores the critical role of innovation and systemic approaches to reduce the environmental impact of livestock farming while meeting the nutritional needs of a growing global population.

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