






## Bibliometric Analysis of Trends and Future Research Directions in Protected Fat Supplementation in Ruminant Nutrition

Budi Wardiman<sup>1</sup>, Asmuddin Natsir<sup>2\*</sup>, Syahriani Syahrir<sup>2</sup>

<sup>1</sup> Department of Agricultural Science, Hasanuddin University, Makassar 90245, Indonesia

<sup>2</sup> Department of Nutrition and Animal Feed, Faculty of Animal Husbandry, Hasanuddin University, Makassar 90245, Indonesia

Corresponding Author Email: [asmuddin\\_natsir@unhas.ac.id](mailto:asmuddin_natsir@unhas.ac.id)

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### ABSTRACT

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*bibliometric analysis, VOSviewer, co-occurrence analysis, citation analysis, co-occurrence analysis, science mapping, rumen protected fat, rumen inert fat*

Rumen protected fat (RPF) has garnered significant attention in livestock nutrition research. The present study aimed to perform a bibliometric analysis on RPF research in ruminant nutrition to evaluate global research patterns and future trends. This study represents the first bibliometric analysis on this topic using data from Scopus database to examine publications from 1991 to July 2024. The bibliometric analysis was done using Scopus Bibliometrix and VOSviewer. We identified 148 relevant articles, with a noticeable increase in publications starting around 2006, peaking notably in 2019 and 2020. The Journal of Dairy Science emerged as the leading publisher in this field. M. Kreuzer was identified as the most prolific author. Cluster analysis revealed five main thematic areas: (1) dairy cow and physiology; (2) meat production and performance; (3) rumen fermentation and digestibility; (4) buffalo-specific studies; and (5) forage management. Notably, the application of RPF in large ruminants primarily focused on milk production and quality, while in small ruminants, it mainly addressed performance, carcass traits, and meat quality. Future research should explore under-studied areas such as meat quality, genetic expression, and performance in large ruminants, and on milk quality and production in small ruminants.

## 1. INTRODUCTION

Supplementing fat in the diet of ruminant animals plays a crucial role in enhancing their nutritional intake and overall health. Fat serves as a concentrated source of energy, containing more than double the energy per gram compared to carbohydrates and proteins. This high energy density makes fat an efficient choice for boosting productivity in ruminants, whether it's increasing milk yield in dairy cows or promoting weight gain in beef cattle. In addition to its energy benefits, fat also supplies essential fatty acids such as omega-3 and omega-6. These fatty acids are essential for maintaining normal cellular function and supporting a healthy immune system in ruminants. Moreover, certain fats aid in the absorption of fat-soluble vitamins like A, D, E, and K, thereby enhancing overall nutrient utilization from the diet [1].

Furthermore, a well-balanced diet enriched with appropriate fats can contribute to improved physical condition and reproductive performance in livestock. However, it is important to carefully select the type and amount of fat supplementation, as excessive amounts or improper types of fats can disrupt rumen function and overall digestion. Excessive amounts of fat can disrupt the microbial balance in the rumen. Ruminants rely on a complex ecosystem of microorganisms to digest fibrous feeds efficiently. High levels of fat can inhibit the growth of these microbes, leading to decreased fiber digestion and potentially causing digestive

upset [2, 3].

Therefore, rumen protected fat (RPF) was developed to address these challenges by protecting fatty acids from degradation in the rumen. The primary benefit of using RPF is the improvement in milk production in dairy cows. By providing RPF, essential fatty acids such as conjugated linoleic acid (CLA), Omega-3, and Omega-6 can reach the small intestine without being oxidized or degraded in the rumen [4]. This contributes to enhancing the quality and quantity of milk produced and improves feed efficiency because more energy can be utilized by the animals [5].

Moreover, RPF can also influence reproductive health and metabolism in animals. Its use has been shown to ruminal function [6], increase fertility [7-9], improve body condition [10, 11], and optimize animal weight and growth [12]. Therefore, RPF not only enhances production and animal health but also optimizes feed resource utilization and increases production efficiency in modern agriculture [13].

However, the future direction and patterns of research on rumen protected fat (RPF) from its inception to the present remain unclear. A bibliometric analysis is essential to fill this knowledge gap. Employing a comprehensive keyword approach focused on RPF, this study aims to explore various facets of research in this area. It will investigate global trends and future directions, offering insights into where the field is heading. By integrating bibliometric analysis and content analysis, and utilizing visualization tools such as VOSviewer

and Bibliometrix, the study seeks to provide a deeper and more comprehensive understanding of RPF research [14, 15].

Bibliometric analysis involves quantitative methods to analyze patterns of publication, citation, collaboration, and impact within a specific field or topic. It allows researchers to map out the intellectual structure of a field, identify influential authors and journals, trace the evolution of research themes over time, and uncover emerging trends. By systematically analyzing metadata from scholarly publications, bibliometric analysis provides empirical insights into the growth, development, and impact of research literature [16].

In the context of RPF research, bibliometric analysis can help identify key contributors, influential research topics, prominent journals, and collaborative networks. It enables researchers to assess the global dissemination of knowledge, benchmark research outputs across countries or institutions, and highlight gaps or areas ripe for further investigation. Overall, bibliometric analysis enhances the rigor and depth of research by offering a data-driven perspective on the evolving landscape of scholarly work in the field of rumen protected fat.

To address this, the authors have formulated three specific research questions. The first question seeks to delineate clusters of research articles within the field of rumen protected fat (RPF) using bibliometric methods such as cluster analysis. This approach aims to uncover groups of publications sharing common themes, keywords, or citation patterns, thereby offering insights into the primary areas of focus and specialization within RPF research. The second question aims to identify new and emerging research topics within RPF through bibliometric analysis. By tracking recent publications and analyzing keyword trends, the study endeavors to highlight innovative areas of exploration and development. This investigation will illuminate evolving interests and potential future directions in RPF research. The third research question looks ahead by projecting future trends in RPF research. Through synthesizing findings from bibliometric analysis and interpreting patterns in publication growth, citation impact, and international collaboration. The study aims to forecast forthcoming developments and research trajectories in the field. This forward-looking perspective will help anticipate the future direction of RPF research, including potential challenges and opportunities.

## 2. MATERIALS AND METHOD

### 2.1 Data retrieval

The method employed in this research is bibliometric analysis through mapping metadata from scientific journals focusing on Rumen Protected Fat (RPF) research obtained from the Scopus database. Bibliometric analysis was chosen due to its cost-effectiveness within library science research. This study used data accessed through Scopus's subscription service, which is managed by Elsevier. Scopus offers a comprehensive and continuously updated repository of over 77.8 million core records, providing researchers with access to diverse, high-quality scientific publications and powerful analytical tools [17, 18]. Web of Science and Scopus are the two primary databases for bibliometric analyses. Comparative studies have shown that Scopus generally offers broader journal coverage than Web of Science, which is known for its

more selective journal inclusion [19, 20]. Scopus is one of the largest curated databases, encompassing scientific journals, books, and conference proceedings, selected and continuously reevaluated. Its platform features Search for document and author queries, Discover for identifying collaborators and analyzing research metrics, and Analyse for tracking citations and assessing data by various criteria. Scopus data typically includes 43 fields, such as source title, abstract, and author keywords [17]. Scopus is a reputable international indexing institution, regularly supervising the indexation of journals and books every 3 to 6 months to ensure adherence to ethical publication standards. Journals or books found in violation of these ethical rules may be discontinued from indexing [21].

The search was conducted across all available fields, including titles, abstracts, and keywords, to maximize the scope of data collection. This study gathered data using the advanced search feature on the Scopus website by inserting specific keywords: title-abs-key (rumen protected fat) or title-abs-key (rumen bypass fat) or title-abs-key (rumen protected fatty acids) or title-abs-key (rumen inert fat) or title-abs-key (rumen inert fatty acids) and (limit-to (language, "english")). There was no restriction on the range of years to ensure a comprehensive dataset. This search yielded 148 articles. The search revealed that research on RPF began in 1991 and has fluctuated in volume up to July 2024. Data were collected by selecting criteria from Scopus, including citation information, bibliographical details, and abstracts & keywords. After choosing these criteria, the data were downloaded as CSV file. The CSV file was transferred to VOSViewer software for further analysis.

### 2.2 Bibliometric analysis mapping and visualization

The bibliometric analysis utilized VOSviewer, a widely recognized software for visualizing and analyzing bibliometric data. VOSviewer is adept at creating visual representations of scholarly networks, identifying research trends, and exploring relationships among research papers, authors, keywords, and journals. Prior to employing VOSviewer, data from the Scopus database underwent organization and cleaning to ensure compatibility with the software. This process included extracting key metadata such as publication title, authors, publication year, source, keywords, and citation counts [22].

VOSviewer allows for straightforward import of bibliometric data prepared in CSV and Excel formats. It seamlessly handled both bibliographic and citation data, enabling the construction of bibliometric networks based on relationships among various entities within the datasets. Co-occurrence networks were particularly analyzed, where the strength of connections between papers was determined by the number of common references they shared [23].

Analytical functions in VOSviewer, including cluster analysis, provided deeper insights into the bibliometric data by identifying closely related groups of research papers. The findings from VOSviewer analysis were instrumental in identifying country-wise contributions to published documents and total citations, facilitating meaningful conclusions and insights into trends, key research themes, and collaboration patterns related to the study topic. VOSviewer was pivotal in visualizing and analyzing bibliometric data related to rumen protected fat, offering a comprehensive exploration of the research landscape in these areas [22].

### 3. RESULTS AND DISCUSSION

#### 3.1 Descriptive analysis

##### 3.1.1 Publication trend

Based on the bibliometric analysis conducted on research related to rumen protected fat from 1991 to July 2024, a total of 148 articles have been published. The first documented publication on rumen protected fat dates back to 1991. The highest number of publications occurred in 2015 and 2019, 2020, with 11 articles, followed by 10 articles in 2000 and 2017. Initially, from 1991 to 2003, there was a period of stagnation in publications, notably with only one article published in each 2004 and 2005 (Figure 1). Subsequently, a trend emerged showing an increasing number of publications from 2006 onwards.

This upward trend suggests a growing interest and research focus on rumen protected fat over the years, reflecting evolving scientific inquiries and advancements in the field. Factors contributing to this trend could include emerging technologies, agricultural practices, and the recognition of the nutritional benefits of rumen protected fat in livestock production. The peaks in publication numbers in recent years, particularly in 2019 and 2020, may indicate heightened research activity, possibly driven by technological innovations, market demands, or specific research funding initiatives aimed at addressing agricultural sustainability and animal nutrition challenges. Overall, the bibliometric analysis reveals a dynamic landscape of research on rumen protected fat, underscoring its importance in the context of livestock nutrition and agricultural productivity.

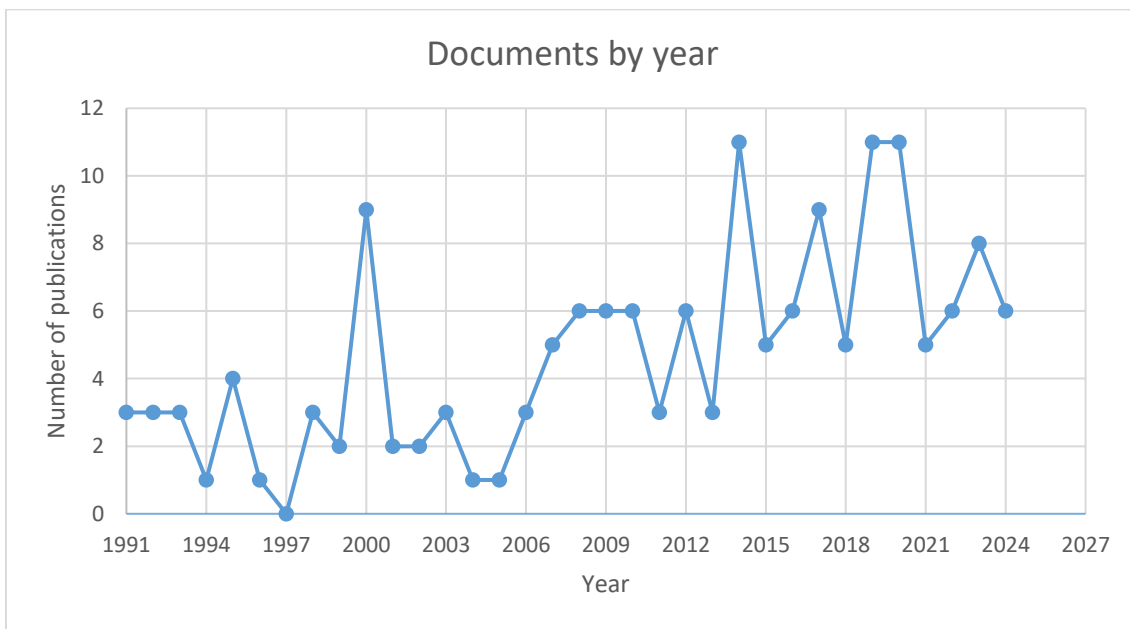


Figure 1. Documents per year on rumen protected fat research

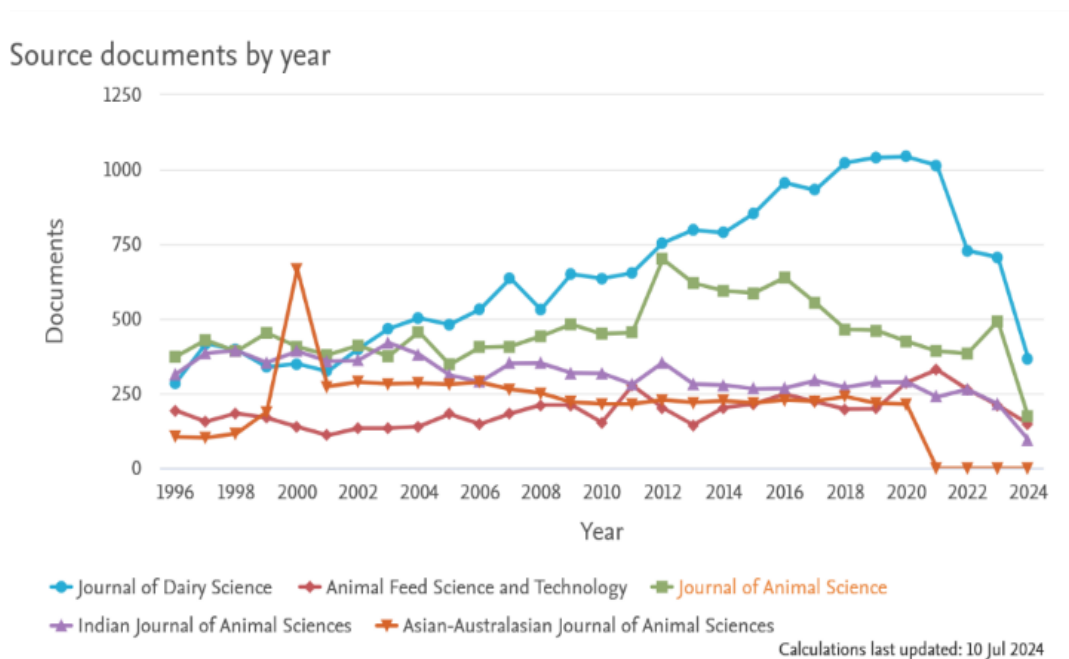


Figure 2. Documents per year by journals on rumen protected fat

### 3.1.2 Journals

In the bibliometric analysis of publications related to rumen protected fat from 1991 to July 2024, the distribution across journals indicates that the Journal of Dairy Science has published the highest number of articles on this topic, totalling 18 articles (Figure 2). Following this journal, the next significant contributors include Animal Science and Feed Technology, Indian Journal of Animal Science, Journal of Animal Science, Asian Australasian Journal of Animal Sciences, and Professional Animal Scientist.

This distribution highlights the prominence of specific journals in disseminating research findings on rumen protected fat. Journals such as the Journal of Dairy Science, known for its focus on dairy-related research, likely attract studies that explore the effects of rumen protected fat on milk production and animal health. The Journal of Dairy Science's emphasis on dairy-related research aligns well with studies exploring how rumen protected fat influences milk production and the quality of dairy products. The significant presence of articles in this journal suggests a focused interest in understanding the physiological responses of dairy cows to rumen protected fat supplementation, thereby contributing to advancements in dairy nutrition and management practices.

Similarly, Journals like Animal Science and Feed Technology, Indian Journal of Animal Science, Journal of Animal Science, Asian Australasian Journal of Animal Sciences, and Professional Animal Scientist also play crucial roles in disseminating research outcomes, catering to broader aspects of animal science and agriculture where rumen protected fat finds application. Together, these findings

illustrate a comprehensive view of how research in this field evolves and contributes to the understanding and application of rumen protected fat in livestock production systems worldwide. The varied representation across these journals underscores the interdisciplinary nature of research on rumen protected fat, spanning areas such as animal nutrition, feed technology, and agricultural sciences. This diversity in publication venues reflects the global interest and ongoing research efforts aimed at understanding the benefits and applications of rumen protected fat in livestock management and production systems.

### 3.1.3 The most relevant authors on rumen protected fat

Based on the bibliometric analysis of authors contributing to research on rumen protected fat, Kreuzer M. emerges as the most prolific author with a total of 9 articles published on this topic. Following Kreuzer M., notable contributors include Bhatt, R.S. with 7 articles Berchielli, T.T., Machmuller, A., Messana, J.D., and Canesin, R.C., each having authored 6 articles (Figure 3). These researchers are prominent figures within the field of ruminant nutrition, showcasing their substantial contributions to advancing knowledge on the utilization and effects of rumen protected fat in animal diets. These researchers have significantly influenced the literature on rumen protected fat through their extensive publications, covering various aspects such as the impact on animal performance, nutrient utilization, and metabolic responses. Their collective efforts contribute to shaping the understanding of how rumen protected fat can be effectively used to enhance livestock productivity and health.

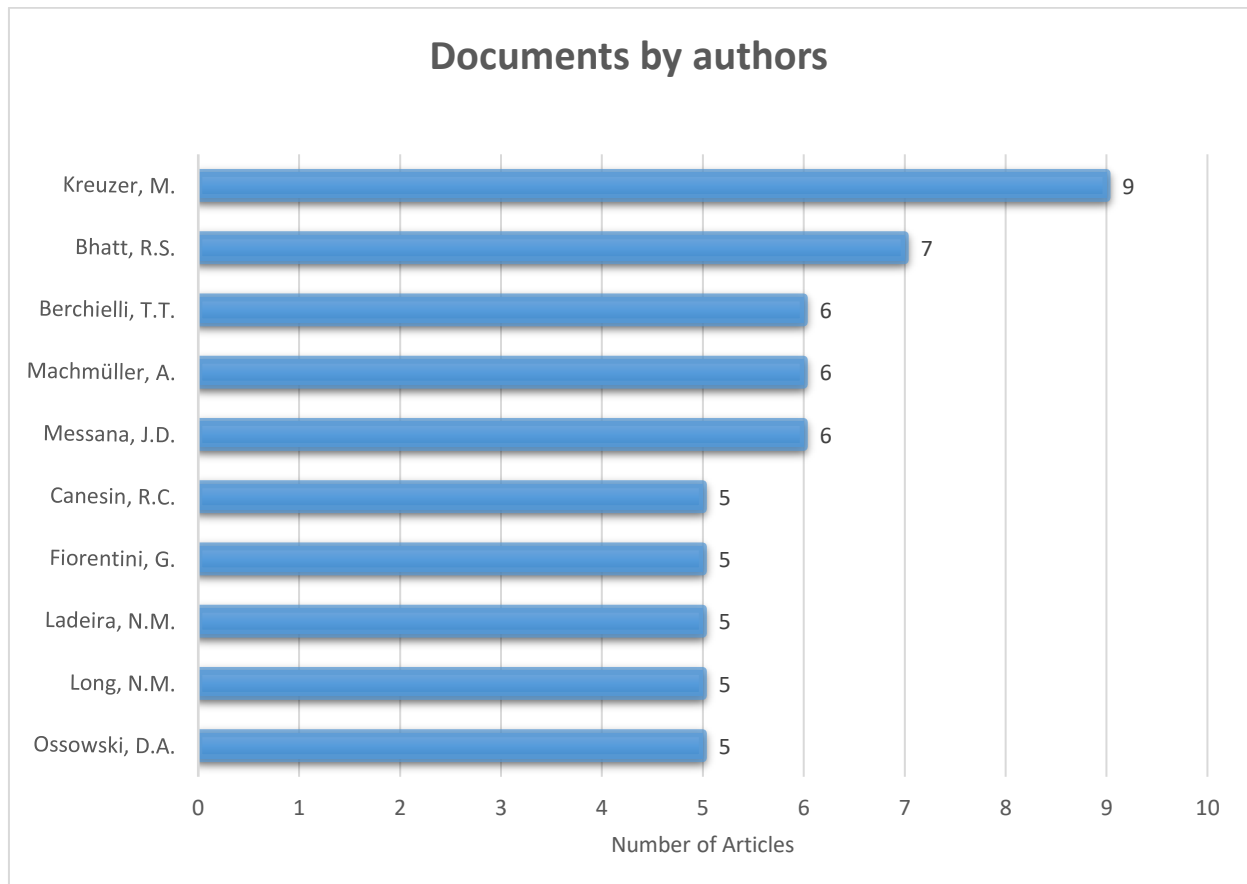
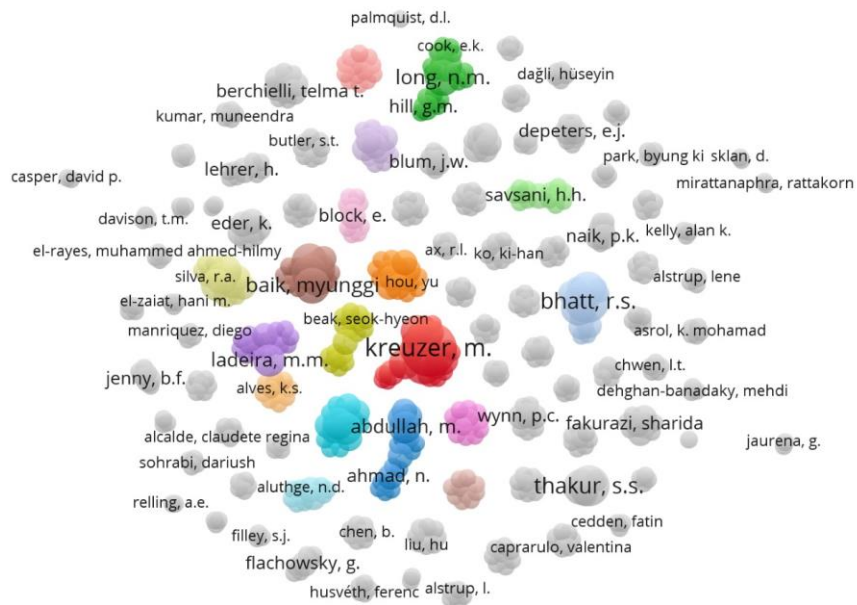


Figure 3. The most relevant author on rumen protected fat

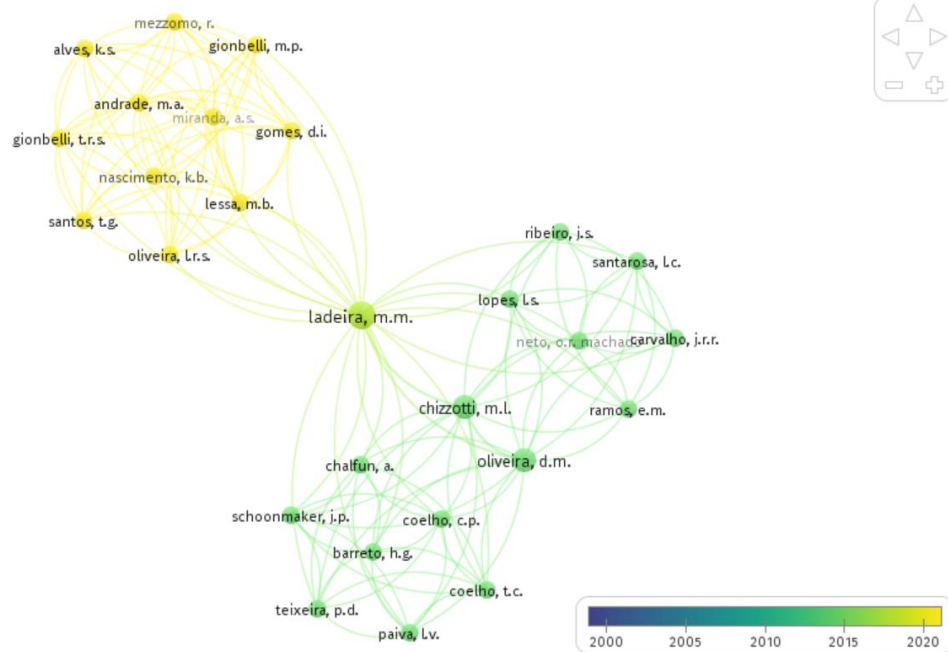


**Figure 4.** VOSviewer-screenshot figure citation analysis between mostly publishing author

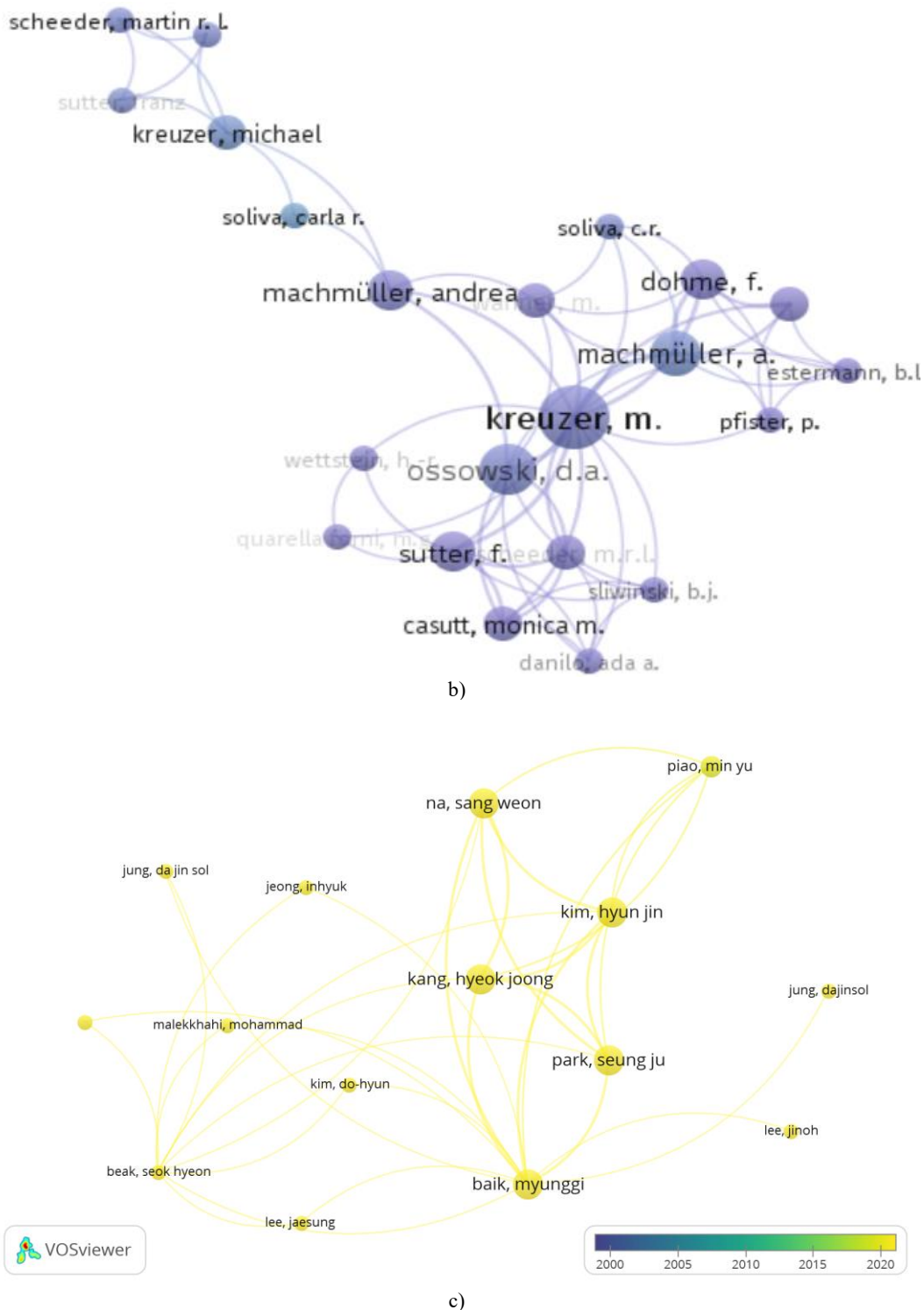
Based on the overlay visualization for co-authorship (Figure 4), it is evident that there is a lack of strong links or correlations among authors in research related to rumen protected fat. Therefore, it is crucial for future research on rumen protected fat to encourage greater international collaboration among authors from various countries and institutions. This collaborative approach is expected to yield broader and more comprehensive research outcomes. International collaboration in research offers several advantages. It allows researchers to leverage diverse expertise, methodologies, and resources available across different regions and institutions. By pooling together knowledge and resources, international collaborations can facilitate more

extensive data collection, larger sample sizes, and validation across different geographical and environmental contexts. This approach not only enhances the reliability and generalizability of research findings but also promotes the adoption of best practices and standards in scientific inquiry.

Based on the overlay visualization for co-authorship, the analysis reveals 95 clusters, each representing groups of authors with significant collaborative links (Figure 5). Among these clusters, Cluster 1, Cluster 2, and Cluster 3 stand out with the highest number of total items, indicating robust collaboration among authors within each cluster-27, 22, and 20 items respectively.



a)



**Figure 5.** Three clusters with the most items. a) Cluster 1, b) Cluster 2, c) Cluster 3

Cluster 1 prominently features Ladeira as the primary collaborator within the cluster, indicating a high degree of co-authorship among researchers involved in recent studies on rumen protected fat, generally after 2015 (Figure 5(a)). This cluster likely represents contemporary research efforts, reflecting current trends and advancements in the field. Cluster 2, dominated by Kreuzer and Long, is notable for its historical significance, particularly around the year 2000 (Figure 5(b)). Articles from this cluster serve as foundational works and references in the study of rumen protected fat, highlighting early contributions that laid the groundwork for subsequent research. Cluster 3, also influenced by Long, shows a substantial number of collaborative publications (Figure 5(c)).

While not as historical as Cluster 2, it indicates ongoing collaboration among researchers exploring various aspects of rumen protected fat.

The overlay visualization provides insights into the temporal dynamics and collaborative patterns among authors in the field of rumen protected fat research. It illustrates both the historical roots and current developments, underscoring how collaboration evolves over time to advance understanding and application in ruminant nutrition and agricultural sciences.

### 3.1.4 Country of the corresponding authors

Examining the data on the occurrence rate of publications related to rumen protected fat research across different

geographical regions provides valuable insights into the global landscape of studies in this field. The United States emerges as the country with the highest scientific productivity in this domain, with a total of 40 documents (Figure 6). This significant output underscores the United States' leadership in advancing research and knowledge in ruminant nutrition, particularly concerning the utilization and effects of rumen protected fat in livestock diets.

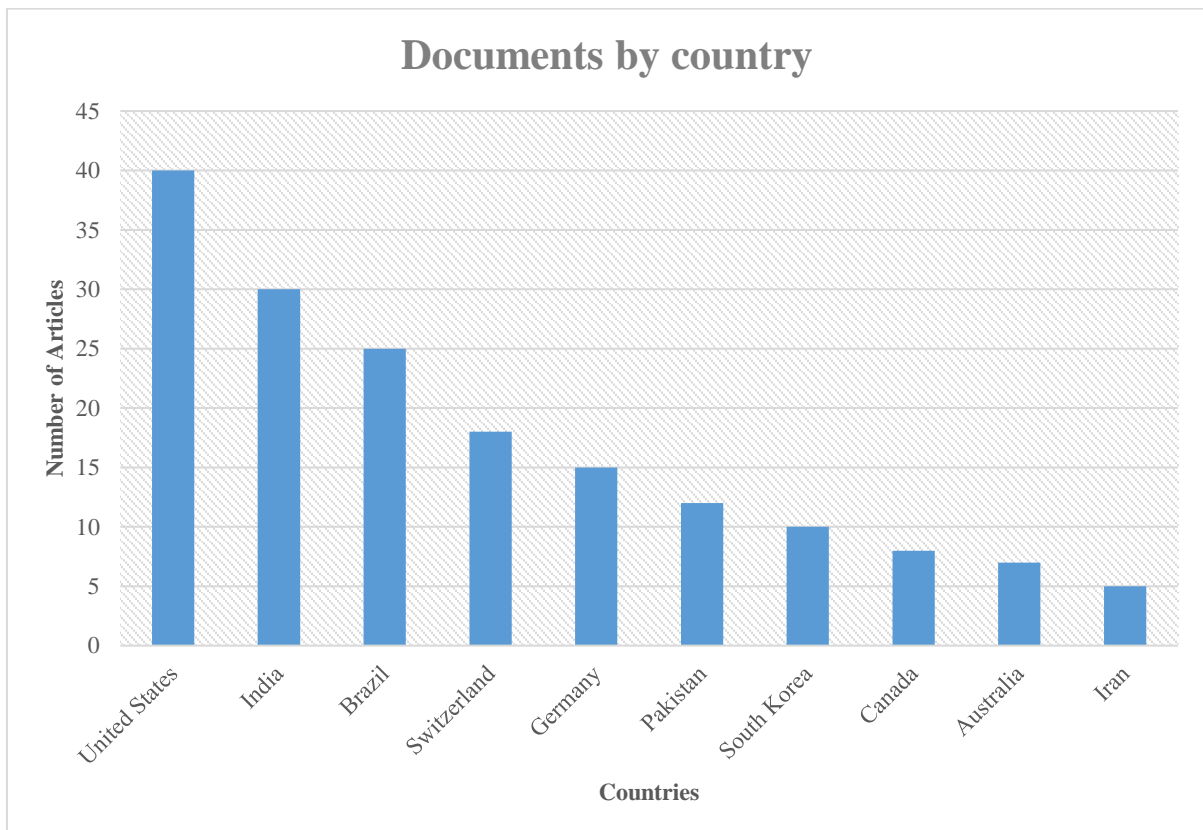
The high scientific productivity of the United States in the field of rumen protected fat research reflects its strong agricultural industry, particularly in ruminant livestock farming. The country's leadership in scientific publications on rumen protected fat can be seen as linearly related to its productive livestock industry for several reasons. Firstly, the United States has a well-established infrastructure supporting agricultural research and development, including extensive university networks, research institutions like USDA (United States Department of Agriculture), and private sector involvement in livestock nutrition and management. This infrastructure facilitates rigorous scientific inquiry into topics such as rumen protected fat, where advancements can directly impact livestock productivity and health.

Secondly, the United States ranks among the top producers of dairy and beef globally, with a sophisticated livestock sector that demands continuous innovation in feed and nutrition strategies to optimize production efficiency and animal health. Research on rumen protected fat directly addresses these demands by exploring its benefits in enhancing nutrient utilization, improving milk and meat quality, and supporting overall animal performance. Thirdly, the scientific output in rumen protected fat research reflects ongoing efforts to

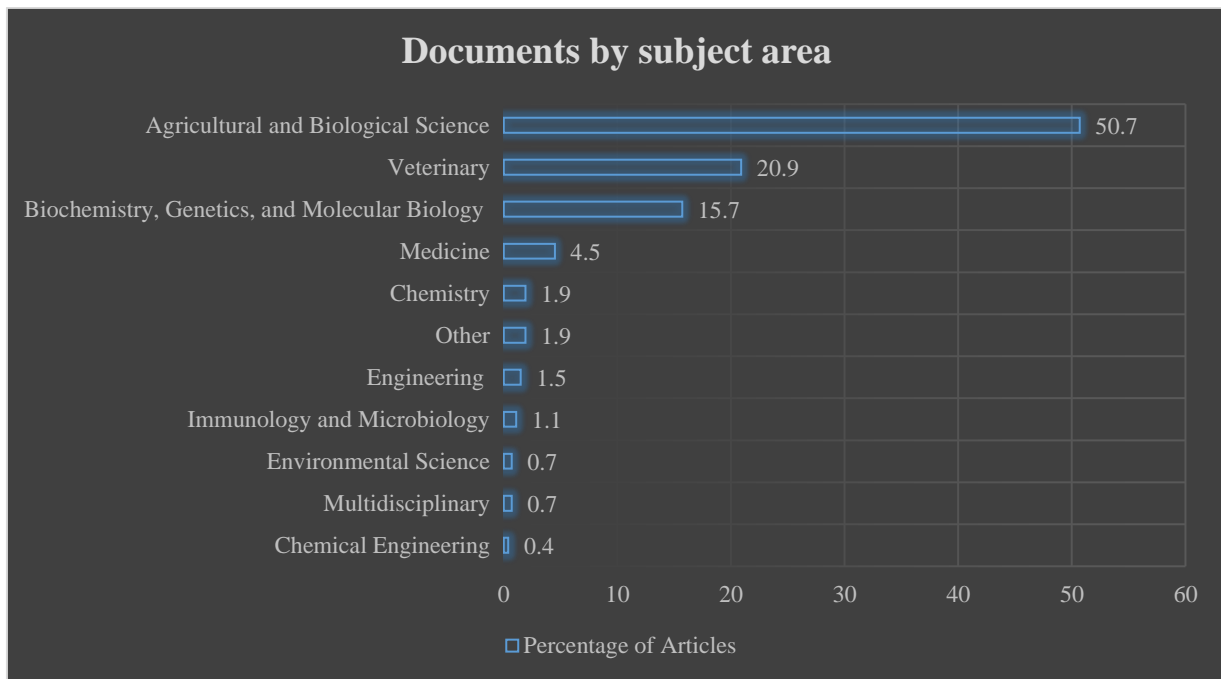
address challenges in livestock nutrition, sustainability, and economic efficiency within the U.S. agricultural sector. This alignment between research productivity and industrial needs fosters a cycle of innovation and application, where insights gained from scientific studies inform practical solutions and improvements in livestock management practices.

India, Brazil, and Switzerland, as mentioned in the data, also show notable contributions to rumen protected fat research. India, with its diverse agricultural landscape and substantial livestock sector, follows the United States in publication output. This indicates a growing interest and investment in improving livestock nutrition and productivity through research initiatives. Brazil, known for its extensive cattle industry and agricultural research institutions, contributes significantly to global research on rumen protected fat. The country's focus on tropical livestock systems and sustainable agricultural practices underscores its relevance in advancing knowledge in ruminant nutrition. Switzerland, despite its smaller size compared to the other countries mentioned above, shows a noteworthy presence in rumen protected fat research. The country's strong research infrastructure and focus on precision agriculture and animal health contribute to its contributions in this field.

The geographical distribution of publications on rumen protected fat research reflects the global scale of interest and investment in improving livestock nutrition and productivity. Countries like the United States, India, Brazil, and Switzerland play pivotal roles in advancing scientific understanding and practical applications that benefit the livestock industry worldwide.



**Figure 6.** The countries of the corresponding authors that publish scientific studies about rumen protected fat



**Figure 7.** The most relevant subject area related rumen protected fat

### 3.1.5 The most relevant subject area related rumen protected fat

Agriculture and Biological Sciences, Veterinary, and Biochemistry, Genetics, and Molecular Biology play pivotal roles in the dissemination of research on rumen protected fat, collectively contributing significantly to the body of knowledge in this field. Agriculture and Biological Sciences journal stands out as the leading publisher in rumen protected fat research, accounting for approximately half of the total publications on this topic recorded in Scopus, totalling 136 articles (Figure 7). This journal's extensive coverage reflects its focus on agricultural sciences, encompassing studies that explore the application and impact of rumen protected fat on livestock nutrition and production.

Veterinary journals, which include studies on rumen protected fat, contribute significantly as well, with 56 documents published. These journals provide essential insights into the veterinary aspects of rumen protected fat supplementation, such as its effects on animal health, metabolism, and disease resistance, thus bridging the gap between animal science and veterinary medicine. Biochemistry, Genetics, and Molecular Biology journals also play a crucial role, publishing 42 documents, accounting for approximately 15.7% of the total publications. These journals highlight research focusing on the biochemical mechanisms underlying the utilization of rumen protected fat by ruminants, genetic factors influencing fat metabolism, and molecular pathways involved in nutrient absorption and utilization.

### 3.2 Global research pattern

The Development Map of rumen protected fat research was conducted using VOSviewer 1.6.16. In selecting the type of data, researchers used "create a map based text data". Then, in the data source, we used "read data from reference manager files" with supported file types CSV. Next, for the counting method, they employed "Binary counting" with a minimum number of occurrences of the term set to 5 and the number of terms to be selected set to 158 (see Figure 7).

The clustering analysis of research on rumen protected fat identified 145 items distributed across 5 clusters. Cluster 1 comprises 53 items, Cluster 2 contains 43 items, Cluster 3 includes 20 items, Cluster 4 consists of 15 items, and Cluster 5 comprises 14 items. Cluster analysis in VOSviewer groups together research papers based on similarities in their bibliometric characteristics, such as shared keywords, co-citation patterns, or co-authorship relationships. Each cluster represents a distinct thematic focus within the field of rumen protected fat research. The varying sizes of the clusters indicate different levels of research emphasis or publication volume on specific aspects or subtopics related to rumen protected fat. This clustering approach helps researchers and analysts to identify prominent themes, trends, and research directions within the literature, providing insights into the distribution and interrelationships of research topics and contributing to a comprehensive understanding of the field.

Cluster 1, rumen protected fat research depicts a focus on dairy cow nutrition and related physiological parameters. This cluster encompasses studies that explore various aspects of nutrition and physiological performance in dairy cows supplemented with rumen protected fat (RPF). Terms such as blood components, body condition, conjugated fatty acids, milk production, and milk composition highlight the attention given to RPF's influence on cow health and milk production. Additionally, parameters like fat-corrected milk (FCM), glucose metabolism, insulin, and specific fatty acids such as palmitic and linoleic acids indicate research aimed at understanding how RPF affects energy metabolism and milk nutrient composition. This cluster reflects a multidisciplinary approach in RPF research, integrating nutrition, physiology, metabolism, and production management to enhance dairy cow performance and health in modern agricultural contexts.

Cluster 2, rumen protected fat research reveals a focused exploration on meat production and growth performance in livestock. This cluster encapsulates studies examining factors such as feed conversion efficiency, genetic expressions, and the quality of meat derived from animals supplemented with rumen protected fat. Terms related to carcass traits, fatty acid



composition, and feed ingredients like soybean meal and soybean oil underscore the emphasis on improving meat quality and nutritional outcomes. Additionally, factors such as age, initial body weight, and growth rates highlight the ongoing efforts to optimize growth performance in cattle and sheep through dietary interventions with rumen protected fat. This cluster reflects a critical intersection between nutritional science, genetic research, and meat production practices, aiming to enhance both the efficiency and quality of meat production in agricultural systems.

Cluster 3 of rumens protected fat research focuses on terms related to rumen fermentation, digestibility, and specific feed ingredients. This cluster includes keywords such as acetate, ADF (acid detergent fiber), apparent digestibility, coconut oil, fermentation processes in the rumen, studies on sheep, and various oilseeds like linseed, rapeseed, and sunflower seed. Additionally, terms such as methane production and methane release highlight research into environmental impacts and efficiency in ruminant digestion. The inclusion of "In vitro" indicates studies using simulated environments to assess rumen processes outside of live animals. Cluster 3 underscores investigations into dietary components, digestion dynamics, and environmental considerations associated with rumen protected fat, crucial for optimizing ruminant nutrition and sustainability in agriculture.

Cluster 4 in the VOSviewer analysis of rumen protected fat research primarily focuses on studies involving buffalo (*Bubalus bubalis*) as the primary livestock species. This cluster includes terms such as bypass fat, concentrate mixtures, Neutral Detergent Fiber (NDF), cholesterol concentration, dry matter intake (DM intake), lactose, milk fat percentage, nutrient digestibility, nutrient utilization, serum triglycerides, and wheat straw. These keywords indicate a significant emphasis on understanding the nutritional requirements, feed efficiency, and metabolic responses specific to buffalo when supplemented with rumen protected fat.

Cluster 5 of rumens protected fat research focuses on terms related to forage management, rumen fermentation dynamics, and dietary components. This cluster includes keywords such

as alfalfa hay, blood metabolites, corn silage, crude protein, dry matter basis, high-fat diets, rumen pH, supplemental fat, total volatile fatty acids (VFAs), and volatile fatty acids. These terms indicate a focus on studies investigating the effects of rumen protected fat supplementation on forage utilization, rumen fermentation characteristics, and metabolic responses in ruminants.

The co-occurrence analysis, visualized in five clusters, reveals distinct research focus. It is evident that the application of RPF in large ruminants predominantly emphasizes milk production and quality, reflecting a strong interest in improving dairy cow performance and health [24-31]. In contrast, research on small ruminants primarily focuses on performance, carcass traits, and meat quality, indicating a different set of priorities for enhancing meat production [32-36]. These findings suggest that future research should address under-explored areas: large ruminant studies could delve into meat quality, genetic expression, and performance, while small ruminant research should prioritize milk quality and production. This focused approach will help in addressing existing gaps and advancing the understanding of RPF's impact across various livestock species.

### 3.3 Future works and directions

Based on the overlay visualization findings (Figure 8), it is evident that "RPF supplementation" (Figure 9(a)) and "inert fat" (Figure 9(b)) are commonly used terms in rumen protected fat research. "Inert fat" is predominantly found in articles published before 2010, whereas "RPF supplementation" appears more frequently in recent publications. Several strong links associated with both terms include "Milk," "Milk production," "dairy cow," "weight," "age," "average daily gain," and "ether" indicate that research on rumen protected fat (RPF) is predominantly focused on evaluating its effectiveness in enhancing various aspects of dairy cow performance and health. This observation provides a plausible explanation for the higher number of publications in the Journal of Dairy Science compared to other journals (see Figure 3).

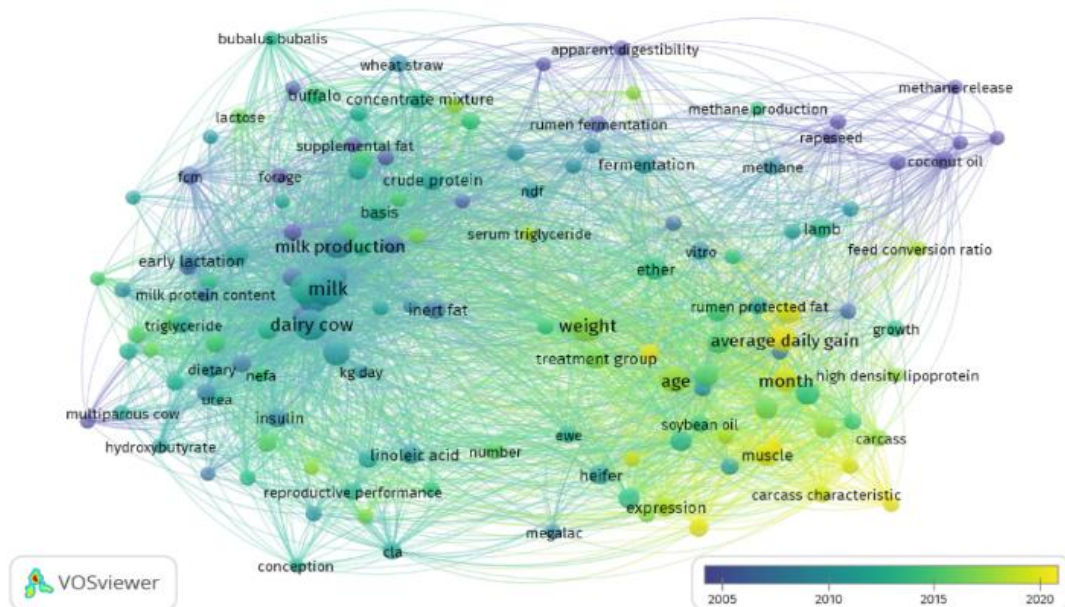
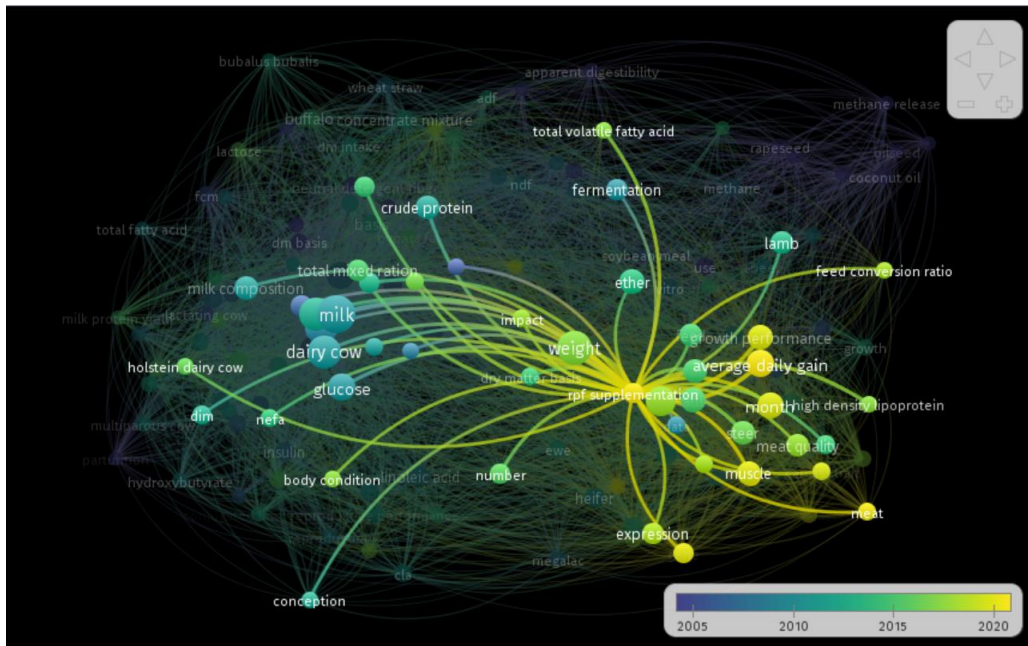
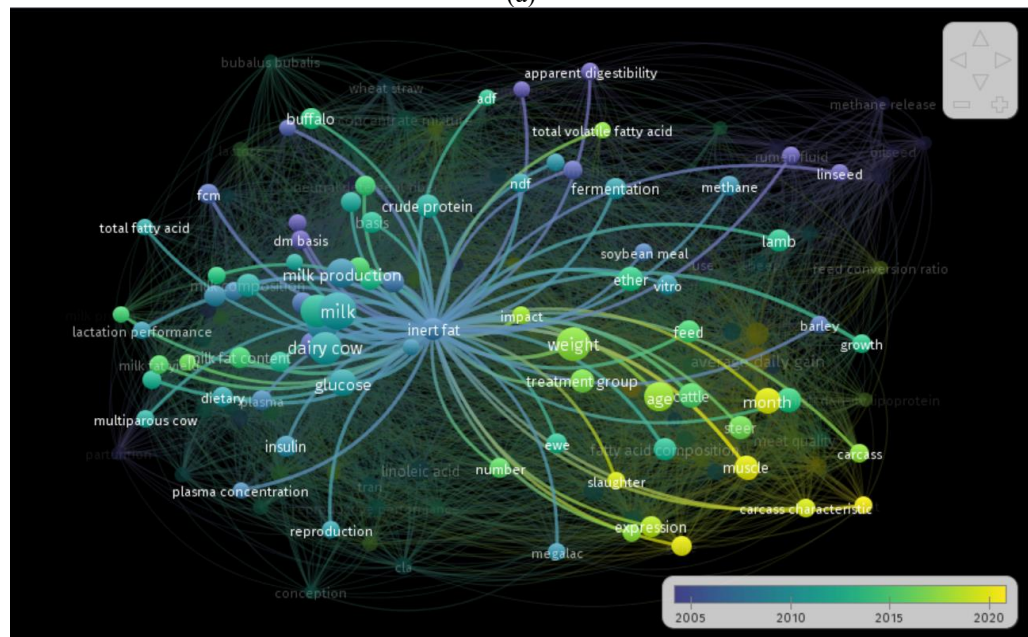


Figure 8. Overlay visualization from co-occurrence analysis



(a)



(b)

**Figure 9.** Overlay visualization of potential future research. Two terms that are commonly used in rumen protected fat research; a) RPF supplementation, b) Inert fat

Conversely, weaker links include terms such as "total volatile fatty acid," "fermentation," "lamb," "feed conversion ratio," "conception," "body condition," "NEFA," and "high density lipoprotein." These terms are dispersed across 5 clusters, marked by smaller nodes, indicating that they have not been extensively researched and present opportunities for further investigation. The presence of smaller nodes suggests areas where research is less developed or less focused, highlighting potential avenues for new studies and advancements in understanding the impacts and mechanisms of inert fat and RPF supplementation in ruminant nutrition and health.

Several terms that are currently widely associated but have not been extensively researched in the context of rumen protected fat (RPF) include "meat," "muscle," "carcass characteristics," "gene expression," "growth performance," "body condition," "blood parameters," "total volatile fatty

acid," "reproduction," and "plasma concentration." Specific livestock species such as "lamb," "ewe," "buffalo," "steer," and others are also underrepresented in this topic.

Research in these areas remains relatively limited, presenting opportunities for further investigation into how RPF supplementation influences meat quality, muscle development, carcass traits, gene expression patterns related to nutrient metabolism, growth performance metrics, body condition scoring, blood biochemical parameters, volatile fatty acid profiles, reproductive outcomes, and plasma concentrations in various livestock species. These gaps in knowledge highlight potential avenues for expanding understanding and optimizing the application of RPF in livestock nutrition and management practices, particularly in relation to broader physiological and performance-related aspects beyond dairy cattle.

#### 4. CONCLUSIONS

Based on the bibliometric analysis conducted on research related to rumen protected fat (RPF) from 1991 to July 2024, a total of 148 articles have been published, indicating a relatively modest volume of research in this field. The distribution of publications fluctuated over time, with notable peaks in 2019 and 2020 where 11 articles were published, highlighting varying levels of research activity. In terms of journal contributions, the Journal of Dairy Science emerged as the leading publisher with 18 articles on RPF, followed by significant contributions from journals like Animal Science and Feed Technology, Indian Journal of Animal Science, Journal of Animal Science, and Asian Australasian Journal of Animal Sciences.

Among the researchers, Kreuzer M. has published the highest number of articles (9), followed closely by Bhatt, R.S. produced 7 articles, Berchielli, T.T., Machmuller, A., Messana, J.D., and Canesin, R.C., each with 6 articles. These authors have significantly shaped the literature on RPF, focusing on various aspects of ruminant nutrition and agricultural sciences. Geographically, the United States leads in scientific productivity in RPF research, followed by India, Brazil, and Switzerland. These countries contribute substantially to advancing knowledge in livestock nutrition, reflecting their robust agricultural sectors and research infrastructure.

In terms of subject areas, RPF research predominantly focuses on dairy cows, as indicated by keywords such as "Milk," "Milk production," "dairy cow," "weight," "age," "average daily gain," and "ether." However, there remains limited research on topics like "total volatile fatty acid," "fermentation," "lamb," "feed conversion ratio," "conception," "body condition," "NEFA," and "high density lipoprotein," presenting opportunities for future studies. Moreover, terms such as "meat," "muscle," "carcass characteristics," "gene expression," "growth performance," "body condition," "blood parameters," "total volatile fatty acid," "reproduction," and "plasma concentration" are associated but underexplored in the context of RPF. This indicates potential areas for new research initiatives aimed at broadening our understanding of RPF's effects across different livestock species and physiological parameters.

Research on rumen protected fat has shown steady growth, it remains relatively underexplored in certain aspects. The findings underscore opportunities for innovative research to expand knowledge gaps, particularly in less studied areas, thereby enhancing the application and impact of RPF in livestock nutrition and agricultural practices globally.

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