

A meta-analysis of forage feed impacts on milk production and quality in dairy goats

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ABSTRACT

Dairy goats are a strategic commodity in sustainable farming systems. However, the presence of antinutritional compounds in forage can affect nutrient effectiveness and lactation performance. This study aimed to conduct a meta-analysis and systematic review of the scientific literature evaluation the effects of forage on the quantity and quality of goat milk. Data were obtained from the Scopus and Semantic Scholar databases through keyword searches "dairy," "goat," and "forage," as well as snowballing methods on relevant references. Of the 333 identified articles, 157 studies met the inclusion criteria and were analyzed bibliometrically using VOSviewer. The results indicate that this topic is multidisciplinary and rapidly developing, with three main focuses: basic nutrition, rumen fermentation, and functional milk quality. Keyword cluster identification shows the potential integration of topics between forage quality, rumen microbiota, and milk nutritional value. Countries such as Spain, Indonesia, and Brazil are major contributors to related publications. This study highlights research gaps, particularly in environmental aspects such as methane emissions, as well as the direct link between feed and human health through goat milk. Recommendations are directed towards integrative research approaches that connect nutritional aspects, microbiota, and the functional impact of milks on consumer health.

Introduction

Dairy goats have become a strategic alternative in the provision of animal milk. Particularly in areas with land limitations and extreme climates that are less supportive of dairy cattle farming. Goat milk has nutritional advantages such as higher protein and fat content that are easier to digest. The content of medium-chain fatty acids, as well as its hypoallergenic potential, makes it an attractive option for individuals with lactose intolerance (Kaskous and Pfaffl, 2025).

The quality and quantity of goat milk highly depend on several factors. Feed not only affects milk, including fat, protein, lactose, and fatty acid profiles. Studies on feed nutrients have become a rapidly growing field of research in line with the increasing demand for high-quality and functional dairy products. Previous research has shown that improving feed quality, such as using high-nutrient forage like alfalfa, wildrye, and corn silage, significantly increases fat and protein levels in goat milk as well as the expression of genes related to fatty acid synthesis in mammary gland tissue (Zhang *et al.*, 2015). The provision of pasture-based feed has also been shown to increase the levels of vitamins A, D3, Omega-3 fatty acids, and CLA in milk (Pajor *et al.*, 2014).

Recent findings strengthen the importance of exploring local-based alternative feed ingredients. For example, feed supplementation with olive pomace shows an increase in milk fat content, offering a sustainable approach to utilizing agro-industrial waste (Mohamed *et al.*, 2024). The use of omega-3-rich feed supplements such as flaxseed and fish oil can alter the fatty acid profile of milk to be healthier without affecting the taste or sensory characteristics of goat milk products (Moya *et al.*, 2023).

The addition of functional ingredients such as stevia pomace has also been proven to enhance productivity and technological quality of goat milk, demonstrating the potential of herbal additives in improving production efficiency (Sufyanova *et al.*, 2023). Recent research is also beginning to explore the relationship between feed and the presence of bioactive compounds in milk such as CLA, polyunsaturated fatty acids (PUFA), and other anti-inflammatory compounds (Delgadillo-Puga *et al.*, 2020).

Although various studies have been conducted, there has yet

to be a systematic approach that comprehensively maps the correlation between feed type and the characteristics of goat milk from a multidisciplinary perspective. Existing challenges include the integration of findings from rumen microbiome research, gene expression related to lipid metabolism, and the influence of feed on functional components of milk such as CLA, fat-soluble vitamins, and bioactive peptides. Therefore, this study focused on conducting a systematic literature review to synthesise current knowledge, map research gaps, and provide recommendations for future research directions that can drive innovation in more sustainable goat milk production systems, adaptive to local resources, and with high nutritional value.

Materials and methods

Data collection

Data collection in this study was conducted through a systematic search using two main scientific databases, namely Semantic Scholar and Scopus, enhanced by a snowballing method on the reference lists of relevant articles selected from 2005 to 2025. The keywords used in the search were: "dairy" AND "goat" AND "forage" designed to obtain literature exploring the relationship between types of forage and the production performance of goat milk. The selection of these two databases considers multidisciplinary coverage and regular updates on high-quality scientific literature. This approach allows for the identification of contemporary research trends related to the effects of various types of forage on the quality and quantity of goat milk. The combination of database search methods and subsequent reference searches in this study ensures that the literature review is conducted comprehensively and includes the most relevant recent studies on the relationship between forage and goat milk production.

Study Selection

Articles obtained from the initial search were filtered in layers to de-

termine their suitability against the established inclusion criteria. This selection process aims to ensure that only relevant, high-quality, and accountable literature is used as analysis material in the study. The inclusion criteria used include: (1) studies that explicitly focus on the three main components, namely dairy, goat, and forage; (2) research that examines the relationship between the type or quality of feed (especially forage) with the quantity and/or quality parameters of goat milk; (3) articles that have been officially published through a peer review process in scientific journals or conference Proceedings; (4) articles that are not written in English are also included if they have an abstract in English and a high relevance to the study focus; (5) results of conference proceedings that have been officially published, as well as (6) technical reports and scientific books from credible institutions are also included to enrich the understanding of partial and historical context.

Studies related to this trend involve exploring types of local forage and tropical feed that can enhance the efficiency of sustainable milk production (Doyon *et al.*, 2024; Kiura *et al.*, 2024). Although the number of publications is not massive, the scientific relevance and thematic diversity of the identified studies reflect the importance of interdisciplinary research in understanding and developing adaptive and highly nutritious feed-based goat milk production systems.

Bibliometric

Understanding the scientific landscape of this research examines the relationship between feed and the quality and quantity of goat milk. Using bibliometric analysis based on citation data extracted from two main databases, namely Semantic Scholar and Scopus. This analysis includes several key aspects, such as the identification of important keywords, quantification of publication trends per year, citation patterns among articles, and collaborative networks among researchers or institutions. This process aims to reveal the dynamics of research development in the field of nutrition and feeding of dairy goats quantitatively and visually.

One focus of this analysis is keyword co-occurrence mapping, which can provide an overview of dominant topics, such as "forage quality", "milk yield", "goat nutrition", and "rumen fermentation", that frequently appear in the literature. The use of precise keywords also aims to enhance the accuracy and precision of literature searches, ensuring that only truly relevant publications are analyzed further. Local citations are analyzed to assess how often an article is referenced by other studies in the selected data scopus. This helps identify studies that serve as core references or foundational literature in specific subtopics. Meanwhile, global citations reflect the general influence of a publication in the broader scientific community, as measured in large index databases such as Scopus or Semantic Scholar.

For citation data processing and visualization of the relationship networks among publications, the author uses VOSviewer software, which is widely known in bibliometric studies for its ability to map relationships among topics, authors, and institutions. This program allows for density mapping-based visualization and co-authorship networks, thus capable of identifying collaboration centers and emerging main research trends (Altay and Bahm, 2024; Zheng *et al.*, 2025). This method not only maps existing literature but also identifies research gaps, such as the lack of systematic studies on tropical local feed and its impact on bioactive compounds in milk. The bibliometric results will be used as a basis for formulating recommendations for future research agendas that are more focused and evidence-based.

Results

The scientific literature used in this study was obtained from two main databases, namely Semantic Scholar (n = 310) and Scopus (n = 23), resulting in a total of 333 articles that were successfully collected in the initial stage. After the filtering process based on the established inclusion

and exclusion criteria on the relationship between feed and goat milk production, types of official scientific publications, and readability in English, the number of articles that met the criteria and were selected for in-depth analysis was 157 articles (Fig 1). This process reflects a high level of relevance and specificity of the topic, considering that only about 47% of the initial articles matched the focus of the study.

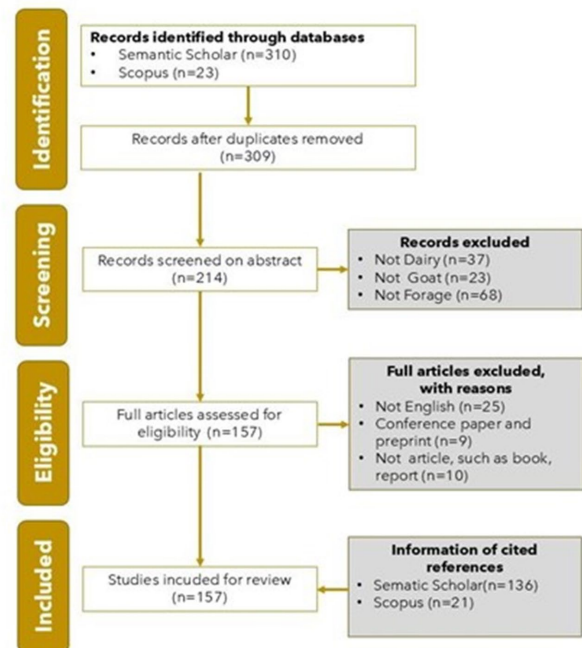


Fig 1. Schematic workflow of review.

Analysis of annual publication trends shows that from 2005 to March 2025, the 157 articles are spread across 151 scientific journals. This indicates an increase in interest and diversification of topics in scientific studies regarding the relationship between forage and the quality and quantity of goat milk. The frequency of publications spread evenly across more than 150 journals also shows that this issue is interdisciplinary, covering fields such as livestock nutrition, milk production, forage agronomy, rumen microbiology, as well as public health and functional foods. Although the topics of goat milk and feed are quite specific, they have gained attention in the global scientific realm, particularly related to food security challenges, the utilization of local feed, and the development of functional dairy products.

Discussion

Visualization of bar chart showing the top ten academic and research institution affiliations with the most scientific publications related to the topics "Dairy", and "Forage". The chart 1 shows that renowned research centers in the field of small ruminant livestock are spread globally, with a strong concentration in the United States, Southern Europe, Southeast Asia, and Latin America. Langston University, USA, occupies the top position with six publications, demonstrating its historical role as a global center of excellence in research and development of dairy goat production systems. This university has an active Goat Research Extension program and is often referenced in feed innovation, management, and dairy goat genetics (Sahlu *et al.*, 1992). Europe has three dominant affiliations from Spain: Universitat Autònoma de Barcelona, Cordoba University, and Universidad de Sevilla, each making significant contributions with five to three publications. Southern Europe is actively researching the relationship between Mediterranean-based forage feeding systems and milk quality, including its on human health and the environment (Gallardo and Teixeira, 2023).

Andalus University, Diponegoro University, and Bogor Agriculture

University from Indonesia show that Southeast Asia, particularly Indonesia, is beginning to play an important role in tropical dairy goat research. Common research topics include the use of local feeds such as lamtoro, indigofera, or fermented tropical forages during the dry season to improve milk production efficiency. Universidade Federal da Paraíba, Brazil, demonstrates active involvement from Latin America in developing goat farming systems that are adaptive to semi-arid climates. Their studies often focus on the effectiveness of mineral supplements and fermented forages on production performance during the dry season or natural feed shortages. Chungnam National University, Korea, with two publications, indicates the potential for new research from the East Asia region in utilizing biotechnology and nutrigenomic approaches in goat milk production.

Based on the data of the number of publications and the distribution map of countries with the highest contributions in the research, it is dominated by the Southern European region, Southeast Asia, and South America. Spain occupies the top position with 22 publications, showing its dominant role in research on goat milk and Mediterranean feeding systems (Fig. 2). The main focus of research from this country is on feed manipulation, improving milk fatty acid profiles, and the sustainability of grass-based farming systems. In second place, Indonesia with 21 publications shows significant growth in tropical goat farming research. Institutions such as Andalas University, IPB, and Diponegoro University conduct much research on the efficiency of local forage use, handling dry seasons, and the utilization of natural minerals.

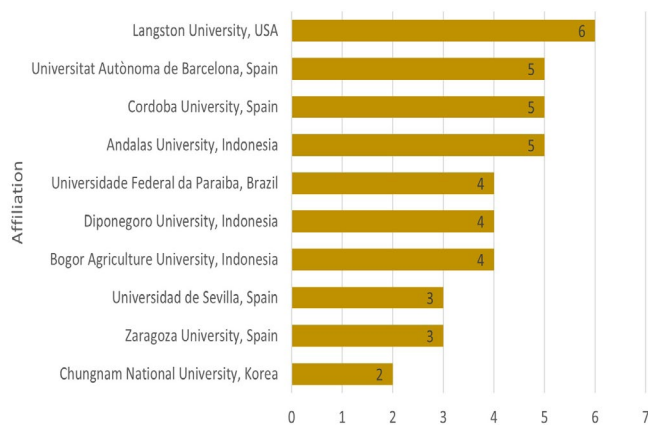


Fig 2. Top ten affiliated academic and research.

Brazil, with 19 publications, demonstrates strength in developing adaptive farming systems in semi-arid regions, with a strong emphasis on feed supplementation and local fermentation technology. The United States, although quantitatively in fourth place with 9 publications, has a significant influence through institutions such as Langston University, which focuses on goat milk nutrition and energy metabolism efficiency. Other countries such as Mexico, Italy, Mesir, Korea, Iran, Turkey, Canada, France and Thailand each contribute 3-6 publications. These countries have diverse research focuses, ranging from the nutritional value of pro-

cessed products like Italy and France, biotechnology of metabolism in Korea and Iran, to the adaptation of farming to extreme climates in Turkey and Mesir. Global research has moved towards a more contextual approach, in accordance with the agroecological conditions of each country. Spain, Indonesia, and Brazil stand out as major research centers with distinctive local advantages. To enhance relevance and impact, future research is advised to integrate nutrition approaches, environmental mitigation, and the enhancement of the functional value of dairy products. Cross-country collaboration is also highly potential to strengthen global scientific contributions in the field of small ruminant farming.

Table 1 shows the article with the highest number of citations was written by Tedeschi *et al.* (2010) with a total of 224 citations and an average of 14.55 citations per year. This article contains a fundamental study of the nutritional model or system management in small ruminants which is the main reference in many further studies. Next by Min *et al.* (2005) with 177 citations with 11.12 citations/year this article strengthens its status as a classic work, especially in the study of functional feed plants such as the use of tannins in goat feed. Meanwhile, Bouattour *et al.* (2008) and Connor *et al.* (2009) also show long-term influence in the academic community, each with more than 100 citations and stable annual citation rates.

More recent articles such as the work of Cabiddu *et al.* (2019) managed to obtain 70 citations in just a few years with an average of 11.33 citations per year, indicating that the topics discussed around Mediterranean forages and milk fatty acid quality are very relevant to current research trends. Likewise, the article by Sujani and Seresinhe (2015) with 107 citations, 10.41 citations per year shows that research from tropical regions on feed efficiency and adaptation of goats to extreme climate conditions is now receiving widespread attention. Several other articles, such as those by Chilliard *et al.* (2012) and Min *et al.* (2007), despite having lower citations per year, still show important contributions in more technical areas such as lipid metabolism or biochemical characteristics of goat milk. This list helps in identifying the most impactful research directions and focuses. Classic articles remain the main references in building theoretical and methodological foundations, while articles with high citation rates per year indicate new trends and rapidly developing topics. Therefore, for researchers who want to compile a literature review, research proposal, or scientific publication in this field, the combination of these two types of articles is very strategic to be used as the main reference.

Network visualization groups various topics based on the relationships of keywords that appear together in scientific literature. The color and position of the nodes reflect clusters or major topics in research, while the lines indicate relationships or co-occurrence between topics (Fig. 3). The yellow cluster (Nutrition-Cattle-Feed Supplementation) focuses on nutrition, feed supplements, and micro needs such as vitamins and minerals. Keywords such as "nutrition", "cattle", "feed supplement" and "animal health" indicate a great deal of attention to the quality and efficiency of nutrition livestock production, particularly cow and dairy goats. The main keywords in the Red Cluster include: evaluation, growth, milk protein, availability, dry season, dairy goat, rumen function, sup-

Table 1. Articles with the highest number of citations.

Author	Year	DOI	Total Citations	Total Citation per Year
Tedeschi <i>et al.</i>	2010	https://doi.org/10.1016/j.smallrumres.2009.12.041	224	14.55
Min <i>et al.</i>	2005	https://doi.org/10.3168/jds.S0022-0302(05)72937-4	177	11.12
Bouattour <i>et al.</i>	2008	https://doi.org/10.3168/jds.2007-0753	133	9.18
Connor <i>et al.</i>	2009	https://doi.org/10.1017/S1751731109991285	114	7.26
Sujani and Seresinhe	2015	https://doi.org/10.3923/ajas.2015.85.99	107	10.41
Chilliard <i>et al.</i>	2012	https://doi.org/10.1533/9781845691073.2.281	98	5.73
Taboada <i>et al.</i>	2011	https://doi.org/10.2136/2011.soilmanagement.c20	91	4.07
Min <i>et al.</i>	2007	https://doi.org/10.1017/S0022029906002378	87	3.06
Póti <i>et al.</i>	2015	http://dx.doi.org/10.4067/S0718-58392015000200017	80	7.9
Cabiddu <i>et al.</i>	2019	https://doi.org/10.3390/ani9100771	70	11.33

plementation level, linear increase, and animal feed. The evaluation of growth and livestock production in this cluster in many studies discusses the influence of the type and level of feed supplementation on growth, milk production, and other performance parameters. Keywords such as "growth," "evaluation," and "animal feed" indicate a strong focus on livestock productivity results (Bovolenta *et al.*, 2009). The presence of the term "dry season" indicates attention to production challenges during periods of forage scarcity, especially in tropical regions. This is closely related to alternative feed supplementation strategies when fresh forage is limited.

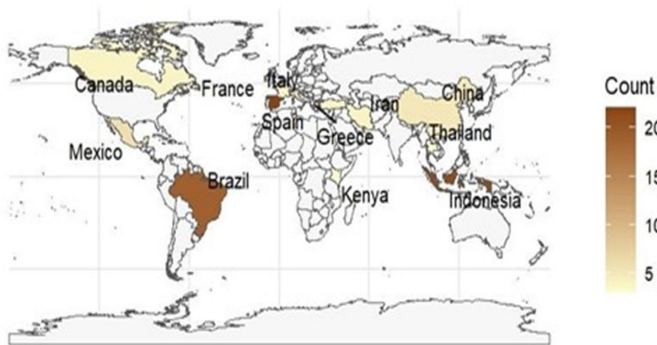


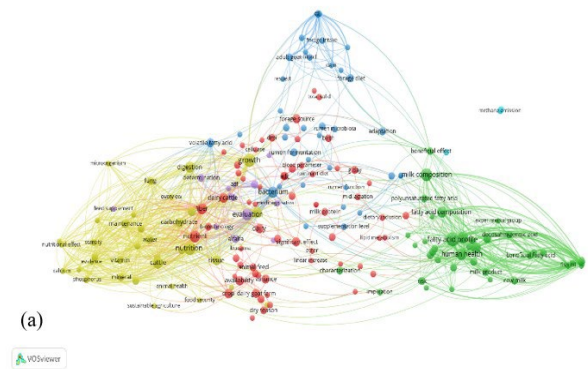
Fig. 3. Map of distribution of countries with the highest contributions.

Keywords "dairy goat," "rumen function," and "milk protein" indicate a specific focus on dairy goats, including the impact of feed on milk composition and digestive efficiency. This is important because the digestive system of goats differs from that of cattle and requires a specific feeding approach. This indicates quantitative studies that analyze how variations in dosage or levels of supplementation affect productivity parameters, an approach often used in experimental feed studies. The Blue Cluster such as Forage, Fermentation, and Microbiota centers on "forage diet," "rumen fermentation," and "goat feed." This highlights the importance of the type of forage feed and its impact on rumen microbiota health and digestive efficiency, especially in dairy goats (Fonteles *et al.*, 2016). The Green Cluster Fatty Acid Profile, Human Health, and Milk. Quality with keywords such as "fatty acid profile," "human health", and "milk product" indicates a major focus on the nutritional quality of milk and its impact on human health (Gallardo and Teixeira, 2023).

Some keywords such as "methane emission" appear separate and less connected with other clusters, indicating that the relationship between greenhouse gas emissions and dairy goat feed has not been deeply explored. This is an opportunity for integrative research that links nutrition, rumen fermentation, and environmental impact. The weak connection between the cluster's "nutrition" and "human health" also suggests that few studies directly trace the relationship between dairy goat nutrition and its impact on milk quality for human consumption, particularly from the aspect of functional health. A publication strategy that could be implemented is by integrating clusters: Research linking forage diet, fatty acid profile, and milk output to human health will bridge the green and blue clusters Focusing on environmental topics, namely through research on methane emission mitigation via manipulation of dairy goat feed, is a new topic with minimal exploration, suitable for publication in sustainability or animal nutrition-themed journals. Exploring species variation where studies are currently dominated by dairy cattle, thus specific research on dairy goats with a metabolomic or microbiome approach will be highly sought after (Cristobal-Carballo *et al.*, 2021).

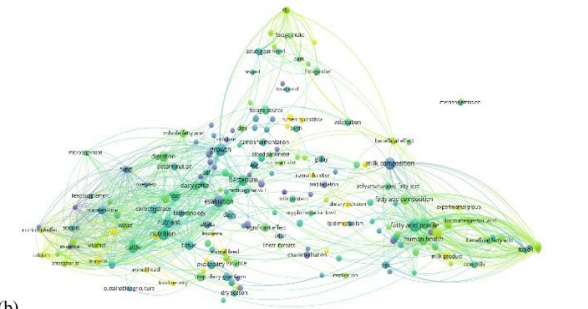
The nutrition and animal health cluster on the left with keywords such as nutrition, cattle, mineral, vitamin, feed supplement, and sustainable agriculture shows a classic and long-term focus on improving basic nutrition in ruminant farming systems, including dairy goats. The dominance of dark colors in this cluster indicates that this topic has long been a research focus but remains relevant. Previous studies highlight the

importance of supplements such as phosphorus and calcium in animal productivity and digestive efficiency (Safdar and Kor, 2014). The forage and rumen fermentation cluster at the top with keywords such as forage diet, rumen fermentation, microbiota, and adaptation signify increasing attention to rumen fermentation dynamics and the effects of forage types on ruminant physiological function. This cluster has a dominant bright green color, indicating that this topic is a relatively new and rapidly developing research area. Recent studies confirm that types of greens such as legumes and corn silage can significantly affect rumen microbiota composition and methane emissions (Cristobal-Carballo *et al.*, 2021).



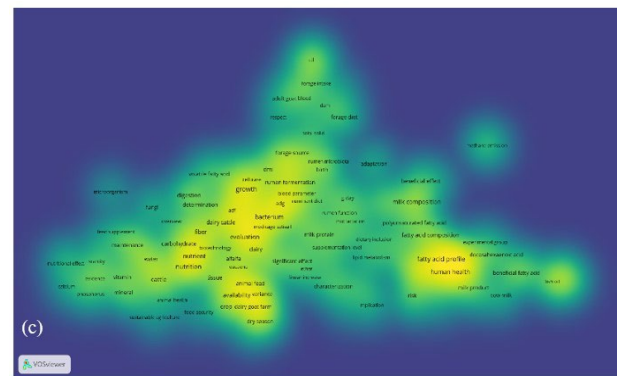
(a)

VOSviewer



(b)

VOSviewer



(c)

VOSviewer

Fig 4. Vosviewer for the keywords a). Forage quality, milk yield, goat nutrition and rumen fermentation". b) and c) The yellow and green Simage indicates the year of journal was published.

The cluster of milk quality and human health on the right with keywords such as fatty acid profile, human health, milk composition, and docosahexaenoic acid shows the modern research direction linking livestock feed with the nutritional quality of milk and its health benefits. This cluster is very new temporally, as indicated by the bright green color. Many studies now highlight the potential of feed modification to enrich milk with healthy fatty acids such as omega-3 (Gallardo and Teixeira, 2023). The focus on rumen fermentation, methane emissions, and milk quality (fatty acid profile) is a cutting-edge topic that deserves further exploration. This could be a great opportunity for publication with high competitiveness, especially in journals in the fields of animal nutrition, sustainability, and functional foods. The isolation of keywords such as methane emission standing alone indicates the still minimal integration between rumen fermentation studies and the impact of feed on the environment. This

could be a direction for future interdisciplinary research. Research should be directed towards integrating forage quality, microbiota adaptation, and milk functional value to bridge the old and new clusters, thereby increasing the chances of significant and globally relevant scientific contributions.

The densest zone marked by a bright yellow color represents the latest hot topics, with several keywords such as "fatty acid profile," "human health," and "milk composition" indicating that the relationship between fatty acid composition in milk and its implications for human health is a very active research topic. Recent research focuses on feeding strategies to increase the unsaturated fatty acid content in goat and cow milk to provide functional benefits for consumers (Gallardo and Teixeira, 2023). The intermediate zone, namely nutrition and production evaluation, dominated by keywords such as "nutrition," "growth," "cattle," and "evaluation," indicates an old focus that remains significant. Nutritional Basics and Livestock Performance Evaluation. This includes studies regarding mineral needs, fiber, and feed efficiency. Recent studies also discuss how trace minerals such as zinc and selenium affect reproductive performance and the immune system (Zuma, 2022). Keywords such as "methane emission," "fish oil," and "microorganism" are on the periphery and appear rarely, indicating that environmental aspects and emission mitigation strategies have not become mainstream research. This is an important potential research gap considering the increasing demand for sustainable livestock systems. Studies on lipid-based feed integration to reduce biohydrogenation and methane emissions are beginning to be reported, but are still few (Sterk, 2011).

Research on the composition of milk fatty acids and their impact on human health is a global scientific focus, particularly related to optimizing livestock diets to improve the nutritional quality of dairy products. The expansion of studies towards mitigating environmental impacts such as methane emissions and exploring rumen microbiota opens new contribution opportunities in the sustainable livestock research ecosystem. Research recommendations can be made by integrating approaches to nutrition, rumen metabolism, and milk product quality for interdisciplinary publication in journals in the fields of livestock nutrition, public health, or the environment.

Conclusion

Studies on forage feed and goat milk production show a rapidly evolving, multidisciplinary, and globally relevant research trend, with major contributions from Spain, Indonesia, and Brazil. Topic mapping reveals three main focuses: basic nutrition, rumen fermentation, and functional milk quality, as well as research gaps in environmental fields such as methane emissions. Classic and recent articles serve as important references, indicating the need for integrative research linking nutrition, microbiota, and environmental impacts. Cross-country and cross-disciplinary collaboration is key to strengthening sustainable and highly nutritious goat farming systems.

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Conflict of interest

The authors have no conflict of interest to declare.

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