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Research Article

Silage Studies Published in DergiPark Infrastructure: A Bibliometric Analysis

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Abstract

This study aims to analyze the thematic and methodological trends in silage research published in DergiPark, focusing on the most frequently discussed topics: silage quality, fermentation processes, and the use of additives. By systematically analyzing publication patterns and methodological approaches, the study seeks to provide insights into the evolving research landscape. A systematic analysis of silage studies in DergiPark examined key research topics, methodologies, and trends. Research was categorized by forage quality, fermentation efficiency, and additive use. Predominant methods, including chemical analysis, digestibility studies, and in vitro techniques, were assessed. The study also evaluated the growing role of microbial additives, particularly lactic acid bacteria, in fermentation improvement. The findings revealed that silage quality, fermentation processes, and additive applications are the dominant research themes. Corn and alfalfa were identified as the primary silage crops due to their significance in feed quality and productivity. Chemical analyses and digestibility studies were the most frequently utilized methods for evaluating nutritional value and preservation efficiency. Additionally, a notable rise in the application of in vitro methodologies was observed. The use of microbial additives, especially lactic acid bacteria, was found to significantly enhance the fermentation process. This study highlights the current research trends in silage studies and suggests future directions for improving silage production efficiency. Further exploration of in vitro methodologies and microbial additives is recommended to enhance sustainability and nutritional quality. Expanding research on diverse silage crops and novel additive applications could provide valuable insights for both scientific and industrial advancements.

Keywords: Animal nutrition, DergiPark, bibliometric analysis, silage.

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Introduction

The field of ruminant nutrition is of significant consequence in the context of livestock productivity, economic viability, and animal well-being. The incorporation of roughages (silage, grass, alfalfa, corn silage, etc.) into ruminant nutrition facilitates the optimization of nutrient intake in alignment with the physiological attributes of their digestive system. Roughages constitute the fundamental component of ruminant diets, exerting a profound influence on a multitude of physiological processes, including digestion, milk and meat yield (Mertens 1997, Van Soest 1994).

Recently, there has been a notable increase in research activity pertaining to the types of roughages employed within ruminant diets and associated feeding strategies. These studies examine the impact of different feeding methods on ruminant performance, thereby contributing to the development of innovative approaches in the sector (Oba and Allen 1999, Krämer et al 2013). In particular, the effects of roughages on the nutritive value, digestibility, and productivity of ruminants are among the topics frequently addressed in the literature (Dewhurst et al 2003, Khan et al 2015). The simultaneous decrease in pasture capacity and the concomitant rise in the demand for high-quality feed have led to an accelerated increase in the prominence of silage, which is the oldest biotechnological product, and in the preparation of silo feeds with different

ingredients. Silage constitutes a type of high-quality animal feed that is obtained through the preservation of green fodder plants through fermentation under suitable conditions. Silage plays a pivotal role in animal nutrition, particularly during the winter months when fresh green forage is not readily accessible. The production of silage entails the fermentation of plants in anaerobic conditions within silos or plastic bags following the harvesting process. Lactic acid formation during the process reduces the pH level of silage, inhibits the growth of pathogenic microorganisms, and preserves the feed's nutritional value over time (Muck et al 2018). A variety of additives are employed with the objective of enhancing the quality of silage and optimizing the fermentation process. The additives include lactic acid bacteria, enzymes, organic acids, and chemical preservatives. Lactic acid bacteria facilitate the fermentation process, resulting in increased acidity and the inhibition of undesirable microbial growth. Moreover, enzymes facilitate the breakdown of plant cell walls, thereby enhancing digestibility of nutrients. The use of organic acids and chemical preservatives has been demonstrated to enhance aerobic stability and prevent silage spoilage (Kung and Shaver 2001, McDonald et al 2011). Recent studies have examined the effects of different silage additives on silage chemical composition, digestibility, and animal performance. For instance, the addition of lactic acid bacteria to silage has been shown to result in improvements in both silage quality and animal growth performance (Weinberg and Muck 1996). Similarly, the inclusion of additives such as molasses and urea in silage has been observed to enhance nutritional efficiency in ruminants by increasing the protein content (Kung et al 2003).

The significance of silage is expanding beyond its traditional role in animal nutrition, becoming a crucial element in the advancement of sustainable agricultural practices. The production of silage serves to minimize losses incurred in the feeding process and to reduce the environmental impact. Accordingly, the selection of additives utilized in the silage-making process, along with a comprehensive examination of their effects, is of paramount importance regarding enhancing feed quality and guaranteeing economic efficiency.

A literature analysis is a systematic compilation of information on a specific topic, which reveals current trends, identifies gaps in knowledge, and suggests future research needs within a given field (Grant and Booth, 2009). Such studies are of great importance for researchers in terms of synthesizing both theoretical and applied knowledge. For example, systematic analysis in healthcare is essential for evaluating the efficacy of new treatments and guiding clinical practice (Moher et al 2009). Similar studies on ruminant nutrition have evaluated the effects of feeding strategies on animal health and performance by conducting a comprehensive analysis of the existing knowledge in this field (Sauvant et al 2008). For example, meta-analysis studies compare the effects of different feed types in ruminant diets on digestibility, milk yield, and growth performance, thereby facilitating the determination of which strategies are more effective (Huhtanen et al 2009). Such analyses also assist researchers and practitioners in optimizing animal feeding programs.

In addition to the field of animal nutrition, literature analysis in a variety of other disciplines, including education, health, and social sciences, offer valuable insights. These insights include a comparative analysis of research methodologies and the identification of innovative approaches (Petticrew and Roberts 2006). In the field of education, systematic analysis contributes to the development of educational policies by evaluating the effects of instructional strategies and educational technologies on student achievement (Hattie 2008). Similarly, in the field of health sciences, systematic analysis that compares the effectiveness of clinical practices and treatment methods serve as the foundation for evidence-based medicine (Cumpston et al 2022). In social sciences, literature analysis is instrumental in comprehending social and cultural trends and addressing social issues (Arksey and O'Malley 2005). These analyses assist policymakers and researchers in making well-informed decisions regarding social change and policy development processes. Such analysis facilitates interdisciplinary knowledge sharing, thereby enabling the development of innovative solutions in a range of fields. Moreover, ruminant nutrition analysis facilitates the advancement of more environmentally conscious and efficacious feeding strategies by expanding scientific understanding in this domain.

Material and Methods

This study employed a systematic data selection and analysis approach to examine the thematic and methodological trends in silage research published in DergiPark. To ensure a structured and reproducible selection process, a structured data selection approach was implemented to systematically identify and categorize relevant publications. However, it should be noted that this study does not represent a systematic analysis; rather, it applies a structured bibliometric and content analysis to assess research trends in the field of silage studies.

Data Collection and Search Strategy

A comprehensive literature search was conducted in the DergiPark database, which includes a broad collection

of academic journals published in Türkiye. To refine the search, specific keywords were utilized, including "ruminant feeding," "silage," "hay," "alfalfa," and "corn silage." These keywords were searched in both Turkish and English within the title, keyword, and abstract sections of the publications. No restrictions were applied regarding the publication date to ensure a comprehensive dataset.

The selection of studies was based on predefined inclusion and exclusion criteria to ensure the relevance and quality of the resulting dataset. The inclusion criteria are as follows: studies focusing on silage use in ruminant feeding, research articles, congress presentations, reports, and postgraduate theses and publications available in full-text in either Turkish or English. Exclusion criteria included articles not related to silage forages used in ruminant nutrition and publications for which the full text was not accessible.

Data Extraction and Analysis

For each included study, data were systematically extracted, including information on the author, year of publication, language, research focus, methodology, and key findings. The extracted data were then subjected to a bibliometric and content analysis to identify the main research themes, methodological trends, and emerging areas of focus in silage research.

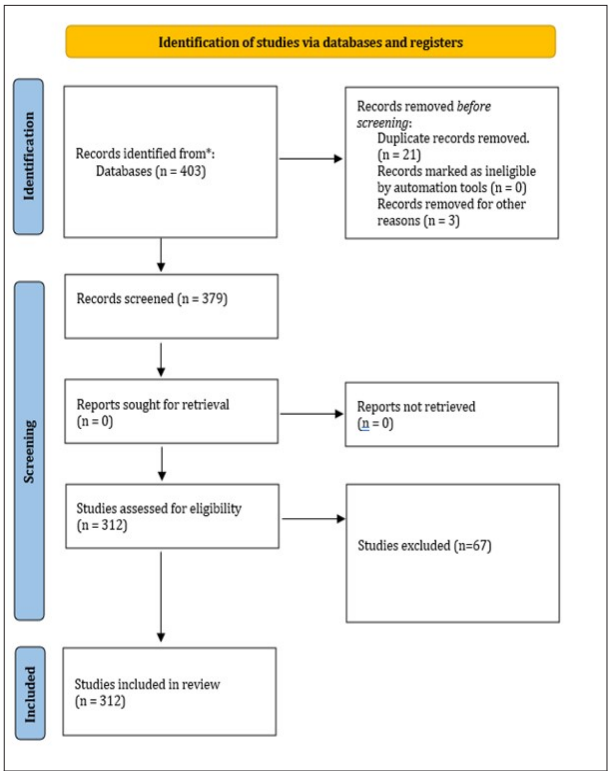

Figure 1. PRISMA 2020 Flow diagram. Adapted from: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, et al., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71 This image is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0): http://creativecommons.org/licenses/by/4.0/

The PRISMA flowchart presents a visual depiction of the study selection process, thereby ensuring transparency in the methodological framework applied (Figure 1).

To analyze the data, the R program was used with the packages "dplyr," "ggplot2," "tm," "wordcloud," "stringr," which allowed for the filtering of the data according to the number of publications by years, the distribution of studies by topic area, the language of publications, and methodological approaches. Additionally, the ratios and visualizations of the titles examined were completed.

Results

A total of 403 studies were identified through the utilization of relevant keywords. However, 24 studies were excluded prior to the commencement of the analysis, 21 of which were duplicates and 3 for various reasons, including incorrect records, missing information, and inadequate publication content. Of the 379 studies that were included in the analysis, 32 were excluded from the analysis due to a lack of access to the full text, 21 were deemed irrelevant to the study topic, and 14 were congress/conference abstracts, bringing the total to 67 studies. In accordance with the specified inclusion criteria, a total of 312 studies published between 1997 and 2024 and containing relevant keywords were analyzed. The ten most frequently utilized keywords in the articles obtained from the keyword analysis were identified, and their temporal distribution is illustrated in Figures 2 and 3.

The analysis of keywords in the graph provides a clear and detailed overview of the central themes and focal areas of interest within the domain of silage research. As anticipated, the keyword "silage" emerges as the most dominant, reflecting the foundational role of silage as the primary subject of this research. This prominence underscores the extensive scope and importance of

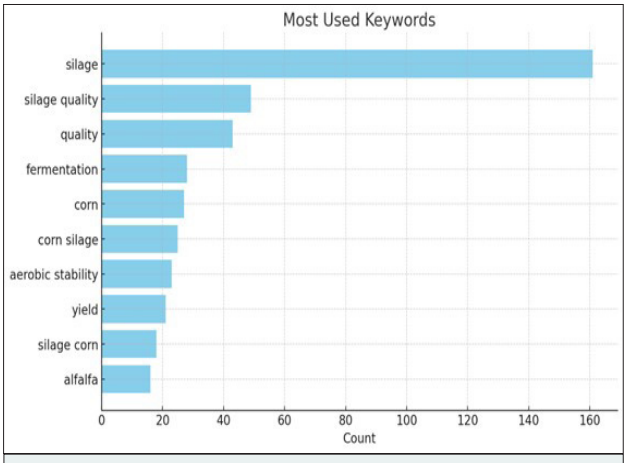

Figure 2. Most used keywords for the silage studies

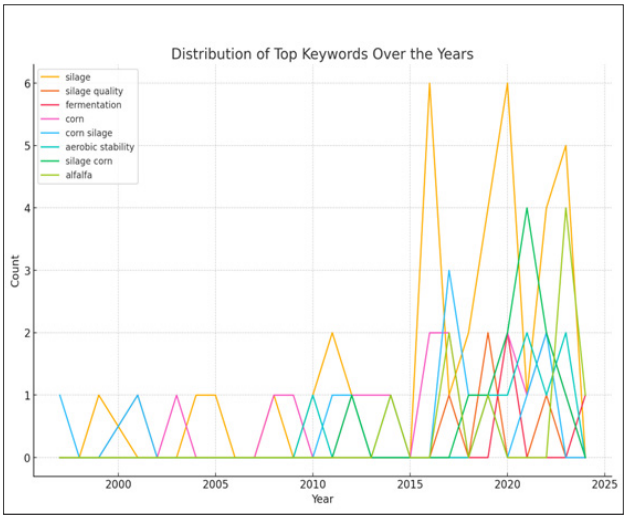

Figure 3. Distribution of top keywords in the studies over the years (1997-2024).

silage within agricultural and animal husbandry studies, serving as a cornerstone for discussions surrounding feed management and preservation. The frequent appearance of terms such as "silage quality" and "quality" highlights the emphasis placed on understanding and improving the nutritional attributes of silage. These keywords reveal a prevailing interest in evaluating how silage quality affects critical parameters such as the nutritional value delivered to livestock, the storage duration of the feed, and its overall impact on animal performance. This indicates that enhancing silage quality is not merely a peripheral concern but a central objective that directly ties into productivity and sustainability in livestock production systems. Another pivotal keyword, "fermentation," points to the biochemical processes that are integral to the production of high-quality silage. Fermentation is critical in determining the stability, palatability, and preservation of silage, making it a primary focus in both theoretical studies and practical applications. Researchers are particularly interested in understanding how factors such as microbial activity, temperature, and oxygen exposure influence fermentation outcomes, further emphasizing its significance. The notable recurrence of the terms "corn" and "corn silage" underscores the widespread reliance on corn as a key crop for silage production. Corn silage is globally recognized for its high energy content and digestibility, making it a staple feed in livestock diets, particularly for dairy and beef cattle. This prevalence suggests an ongoing interest in optimizing corn varieties, cultivation practices, and harvesting techniques to maximize yield and quality, aligning with broader efforts to improve resource efficiency in agriculture. Additionally, the keyword "aerobic stability" frequently appears, highlighting the ongoing challenges related to silage storage conditions. Aerobic stability refers to the silage's ability to resist spoilage when exposed to air, which is crucial for maintaining its nutritional integrity over time. Research in this area often seeks to develop innovative additives, sealing techniques, and management strategies to enhance aerobic stability, thereby reducing feed losses and improving cost efficiency for farmers. The term "yield" reflects a complementary area of focus, emphasizing the need to maximize the production efficiency of silage. Yield optimization encompasses both the quantity of biomass harvested and its subsequent preservation and nutritional retention during storage. This dual focus ensures that farmers can achieve both high productivity and economic viability in their silage operations. Finally, the repeated mention of "alfalfa" indicates its significant role in silage production, particularly as a high-protein forage crop. Alfalfa silage is valued for its contribution to balanced diets in livestock, particularly for dairy cows, where protein requirements are high. The prominence of this keyword suggests that alfalfa-related research may center on improving its fermentation characteristics, integrating it with other crops in mixed silages, and evaluating its environmental impact.

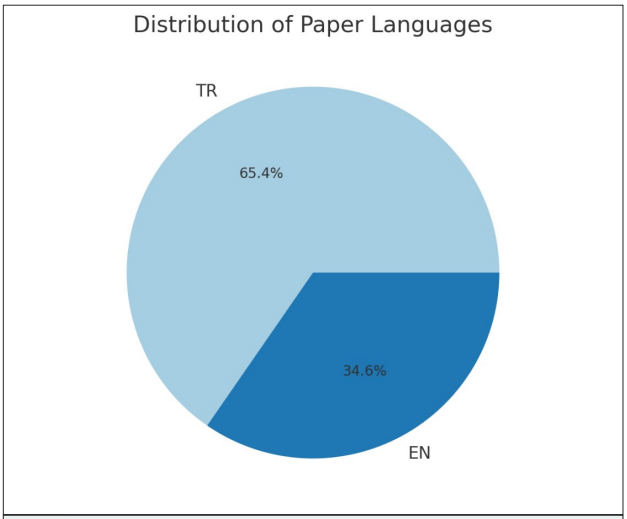

Figure 4. Distribution of primer language of the studies.

The results of the first languages of the publications analyzed in the study are given in Figures 4 and 5.

Figure 4 shows the language distribution of the articles analyzed. According to the data, 65.4 percent of the articles were written in Turkish and 34.6 percent in English. The high proportion of Turkish articles indicates that most research in Turkiye is conducted and published at the national level. This situation underlines the importance of local knowledge production and the focus on national problems. On the other hand, 34.6% of publications in English indicate that some of the studies have access to the international scientific community and contribute to global collaboration. It should be noted that publications in English allow the results to reach a wider audience.

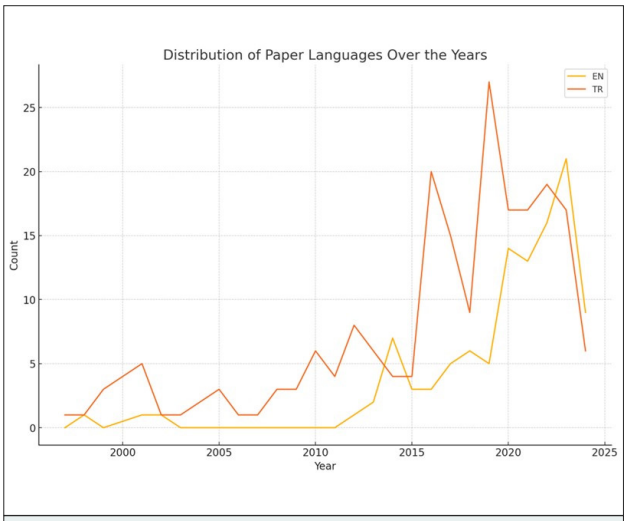

Figure 5. Distribution of primer language of the studies over the years (1997-2024).

Figure 5 shows the language distribution of articles published according to years. When the graph is analyzed, it is seen that the number of publications in both languages has increased significantly especially after 2010. Turkish publications have been numerically more dominant for many years, but English publications have gained momentum after 2015 and in some years have approached or surpassed Turkish publications. This situation shows that researchers in Turkiye have become more orientated towards the international arena over time. The post-2015 period can be considered as a period of increased interest in silage research at both national and international level. The increase in Turkish publications indicates that local problems continue to be addressed and researchers in Turkiye are contributing to the body of knowledge in this field. At the same time, the increase in English publications can be considered as a sign that Turkiye is more integrated into the global scientific community.

The number of authors of the articles included in the analysis is presented in Figures 6 and 7.

The authorship patterns observed in silage research highlight the field's collaborative nature, with a majority of studies involving two to four authors, indicating a strong tendency toward teamwork and shared expertise. This collaboration likely stems from the interdisciplinary demands of silage research, which integrates aspects of animal nutrition, microbiology, agricultural practices, and environmental science. Single-author studies, while less frequent and often of an analysis nature, contribute significantly to the synthesis and interpretation of existing knowledge, serving as foundational resources for further experimental research. Over time, the number of authors per study has not exhibited a clear upward or downward

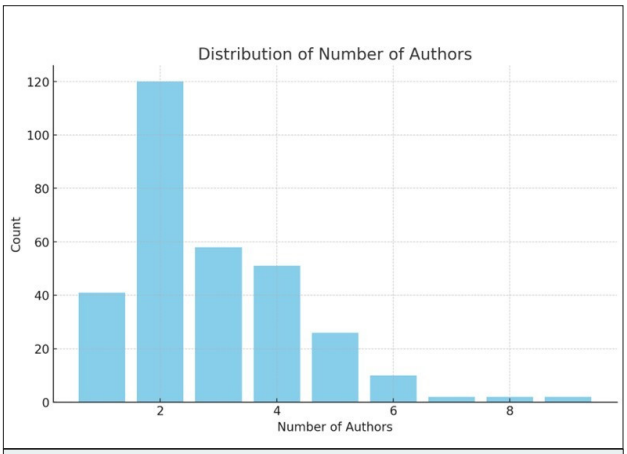

Figure 6. Number of authors from the studies.

trend, suggesting that the collaborative culture in the field has remained relatively stable. However, fluctuations in certain years reflect shifts in research priorities, funding structures, or institutional collaboration opportunities. Of particular interest is the recent increase in multi-author studies (involving five or more authors), which points to a growing trend of large-scale, multidisciplinary projects. This shift may be driven by the need to address more complex research questions, which require diverse expertise and significant resources. The increase in multi-author studies also aligns with global trends in scientific research, where collaboration is often associated with higher-quality outputs, broader data sharing, and more impactful publications. It may also reflect the influence of funding agencies that increasingly favor collaborative and interdisciplinary projects, especially in applied sciences like agriculture. This trend underscores the importance of fostering environments that encourage teamwork, resource sharing, and international partnerships to advance silage

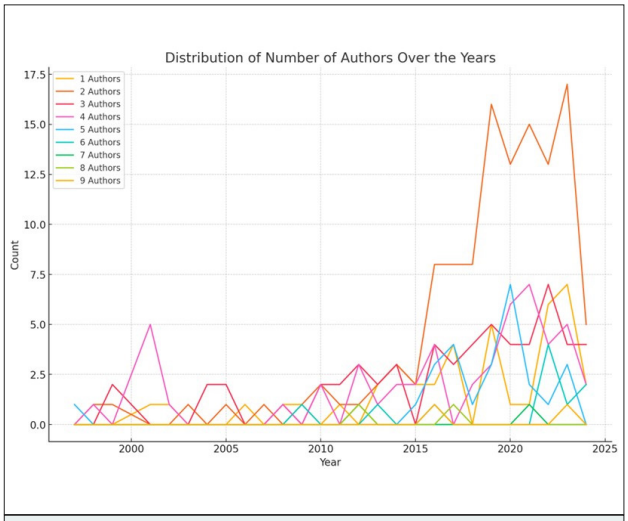

Figure 7. Distribution of number of authors over the years (1997-2024).

research. Overall, the evolving authorship patterns in this field mirror the broader scientific community's emphasis on collaboration as a cornerstone of innovation and progress.

The results of the analysis of the methodology employed in the studies under examination are presented in Figures 8 and 9.

Upon examining the titles of the studies, it is evident that in vivo and in vitro methodologies are the most frequently employed approaches in silage research, while in situ studies are comparatively less prevalent. This distribution highlights the methodological preferences and research priorities within the field. The growing number of in vivo studies in recent years suggests an increasing emphasis on experiments conducted directly on living organisms, reflecting the practical need to evaluate the effects of silage and its components within complex biological systems. This is particularly relevant in fields such as animal nutrition and health, where real-world applications and organism-level interactions are of paramount importance. The extensive use of in vitro studies underscores the critical role of controlled laboratory experiments in advancing silage research. These studies provide a high degree of control over experimental variables, allowing researchers to isolate specific factors and draw precise conclusions about silage composition, microbial activity, and fermentation processes. The versatility and reproducibility of in vitro methodologies make them a cornerstone of silage research, enabling the exploration of underlying mechanisms that might be challenging to observe in more complex systems. In contrast, the relatively low prevalence of in situ studies may reflect the methodological and logistical challenges associated with this approach. In situ studies, which are typically conducted within a specific natural or semi-natural environment, often require precise control over variables in a setting that is inherently variable and context dependent. This complexity can make in situ studies more resource-intensive and less practical for certain research questions. However, these studies are indispensable when the research goal is to assess the direct interactions between silage and its surrounding environment, such as within the rumen or a targeted agricultural context. The observed trends in study type also provide insight into the evolving priorities and constraints within silage research. The increasing reliance on in vivo and in vitro methods suggests a focus on generating actionable insights that can directly inform practical applications or contribute to foundational scientific knowledge. Meanwhile, the relatively unchanged prevalence of in situ studies indicates that, while valuable, they are often reserved for niche applications or specific research scenarios that demand this approach. These methodological trends reflect the dynamic nature of silage research, balancing

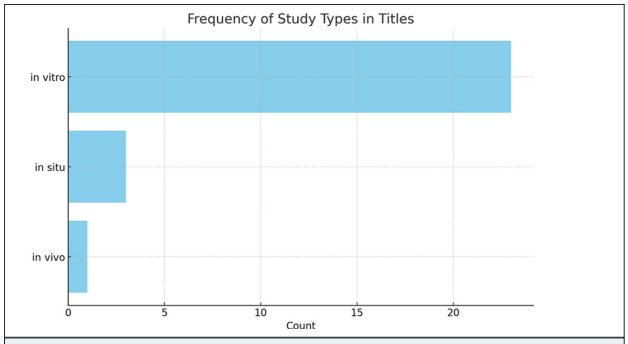

Figure 8. Frequency of the study types (percent)

the need for practical applicability, scientific rigor, and resource efficiency. They also highlight the importance of integrating multiple methodologies to achieve a comprehensive understanding of silage-related processes, from fundamental microbial interactions to organism-level impacts and environmental considerations.

The results of the analysis of the type of publication in the studies under examination are presented in Figures 10 and 11.

Most of the studies examined were Research Articles, constituting an overwhelming 92.9% of the total, followed by Analysis articles, which ranked second in prevalence. The least common publication type was Letters to the Editor, representing only 0.6% of the total. This distribution underscores the dominant role of original research in the field of silage studies, highlighting the emphasis on generating new empirical data and advancing practical applications. Analysis articles, while fewer in number, play a vital role in synthesizing existing knowledge and identifying gaps for future research directions. The near absence of Letters to the Editor suggests that this format is less favored in silage-related academic discourse, possibly due to its limited scope for detailed scientific discussion. A particularly noteworthy trend is the marked increase in research articles between 2015 and 2020. This surge coincides with growing global concerns over food security and the search for alternative feed resources, driven by

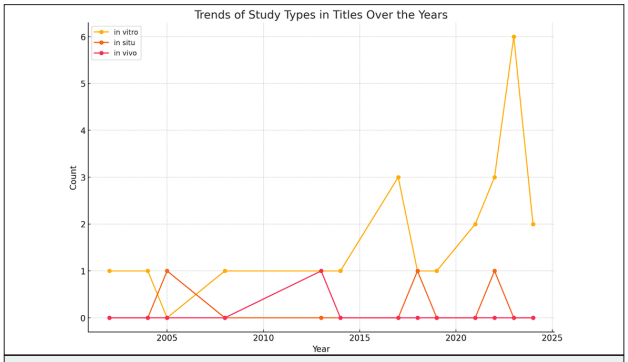

Figure 9. Study types over the years (1997-2024).

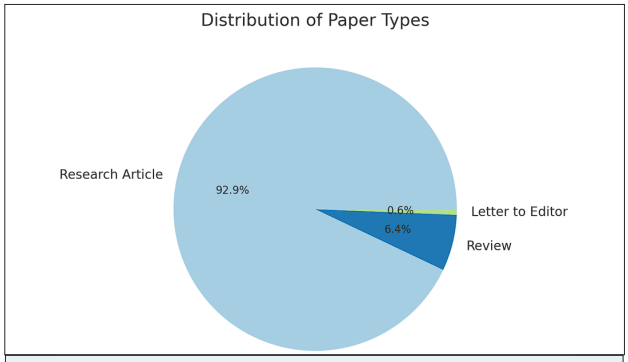

Figure 10. Distribution of paper types.

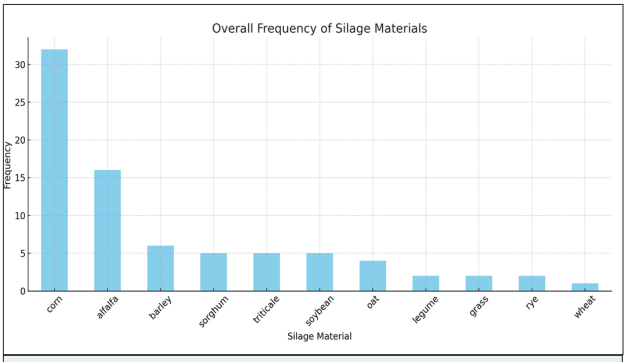

Figure 12. Most used silage material of the studies.

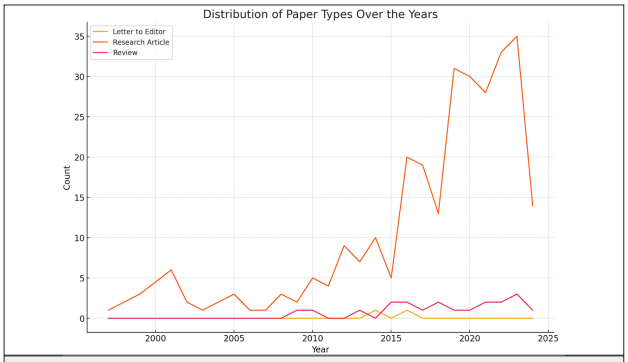

Figure 11. Distribution of paper types over the years (1997-2024).

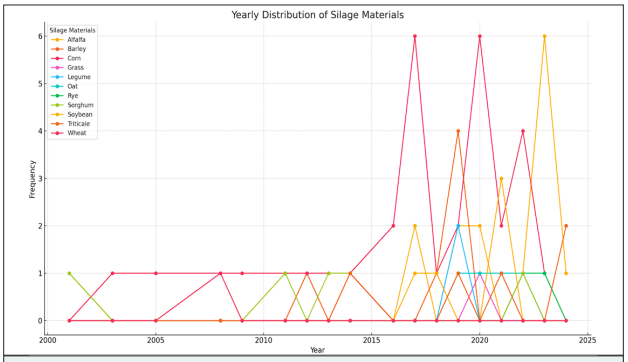

Figure 13. Changes of using silage materials over the time (1997-2024).

factors such as population growth, climate change, and resource scarcity. The heightened interest in silage research during this period can be interpreted as a direct response to these challenges, as researchers sought innovative solutions to optimize feed efficiency and sustainability in animal production systems. This increase also reflects the expanding role of silage in addressing broader issues related to agricultural resilience and environmental sustainability. The dominance of research articles suggests a strong focus on experimentation and evidence-based advancements, which are crucial for developing practical and scalable solutions. The observed publication trends also highlight the dynamic and responsive nature of silage research, adapting to emerging global challenges and contributing to the broader discourse on sustainable agricultural practices. This trend emphasizes the importance of continued investment in original research to ensure the development of innovative strategies that address both current and future demands in feed resource management.

The most frequently occurring silage materials in the titles were "corn," "alfalfa," and "barley." The results are presented in Figures 12 and 13.

As illustrated in Figures 12 and 13, corn has consistently been the most frequently referenced silage material in the research literature, maintaining its prominence over time. This reflects its widespread acceptance and reliability as a preferred feed source in animal nutrition. Corn silage is highly valued due to its superior nutritional profile, including high energy content, digestibility, and suitability for a variety of livestock species, particularly in dairy and beef production. Its prominence also highlights its role in enhancing productivity and efficiency in animal feeding systems, making it a cornerstone of silage research and practice. The utilization of silage materials, as revealed in this analysis, provides critical insight into feeding strategies and agricultural practices across different regions. While corn remains dominant, the investigation of alternative silage materials on a broader scale indicates a growing interest in diversifying feed sources. This shift may be influenced by regional differences in crop availability, cost considerations, and evolving agricultural policies. Additionally, the exploration of alternative silage materials reflects efforts to address sustainability challenges, such as the need to optimize resource use, reduce environmental impact, and adapt to changing climatic conditions. The consistent emphasis on corn, coupled with the exploration of other silage materials, underscores the dual objectives of maintaining productivity while fostering adaptability and resilience in animal nutrition strategies. This trend highlights the importance of continued research into both traditional and emerging silage materials, ensuring that feeding systems remain sustainable, efficient, and responsive to global challenges in agriculture and food security.

The distribution of additives utilized in the analyzed studies is illustrated in Figures 14 and 15.

The analysis reveals that the most frequently utilized additives in silage studies include inoculants, acids (particularly lactic acid and propionic acid), enzymes, and microorganisms such as bacteria and yeasts. These additives play a pivotal role in silage production, primarily aimed at enhancing quality, stabilizing fermentation processes, and improving the nutritional value of the final product. Their widespread use underscores the critical importance of additive-based strategies in optimizing silage fermentation and storage outcomes. Inoculants and acids, particularly lactic acid, are among the most prominently employed additives, reflecting their effectiveness in addressing key challenges in silage production. Lactic acid, for example, is widely recognized for its ability to accelerate the fermentation process, lower pH, and stabilize silage, thereby minimizing spoilage risks. Similarly, propionic acid serves as a potent antifungal agent, reducing the growth of undesirable microorganisms and extending the shelf life of silage. The recurrent use of these additives highlights their integral role in achieving high-quality silage. Enzymes and microorganisms, such as bacteria and yeasts, also hold significant importance in silage production, contributing to enhanced digestibility and reduced nutrient losses. Enzymes facilitate the breakdown of complex carbohydrates, thereby increasing the availability of fermentable sugars for lactic acid bacteria. Microorganisms, on the other hand, promote the dominance of desirable fermentation pathways, ensuring optimal preservation and nutrient retention. Over time, there has been a notable shift in additive utilization patterns. The increasing deployment of inoculants and lactic acid reflects advancements in silage technologies and a growing emphasis on improving silage stability and efficiency. However, fluctuations in the use of enzymes observed in certain years suggest a more context-dependent approach, potentially influenced by variations in crop types, silage conditions, or evolving research priorities. Overall, the findings emphasize the central role of additives in modern silage production. By improving fermentation dynamics, nutrient preservation, and overall silage quality, these substances contribute to sustainable and efficient animal feeding strategies. The evolving patterns of additive usage further highlight the adaptability of silage production practices in response to changing agricultural, economic, and environmental demands. Continued research and innovation in this area are essential for further enhancing the efficacy and sustainability of silage production systems.

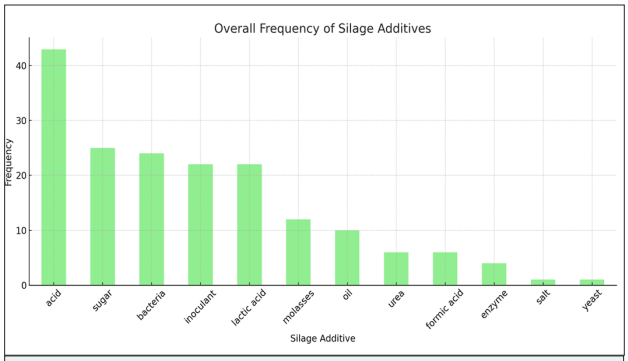

Figure 14. Most used silage additives in the studies.

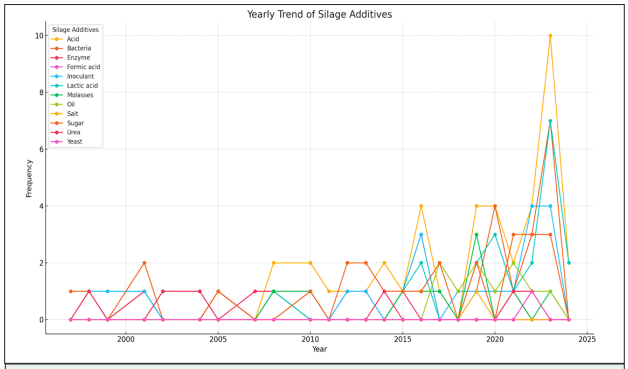

Figure 15. Changes of most used silage additives over the years (1997-2024).

The association between silage material and additive usage is illustrated in Figure 16.

The analysis revealed a specific and purposeful relationship between silage materials and the additives used during production, highlighting the tailored strategies employed to address the unique challenges associated with different materials. Notably, crops such as corn and barley were frequently paired with inoculants and acids, indicating a strategic approach to optimizing the fermentation process and ensuring the quality of the final product. This pairing reflects the scientific rationale behind the selection of additives, driven by the specific requirements of each silage material during processing and storage. For instance, inoculants are commonly utilized in corn

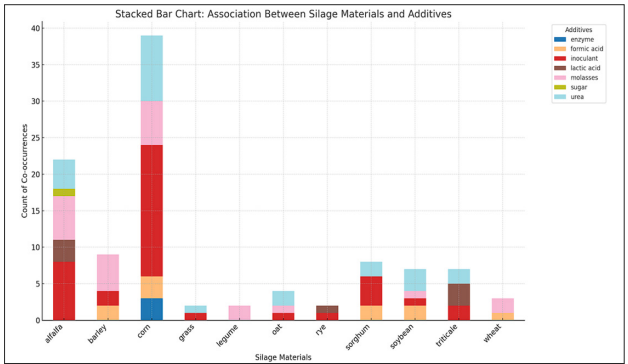

Figure 16. Additives used in different silage materials.

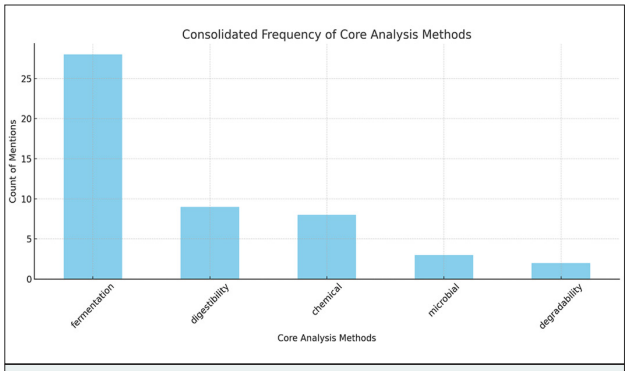

Figure 17. Analysis methods used in the studies.

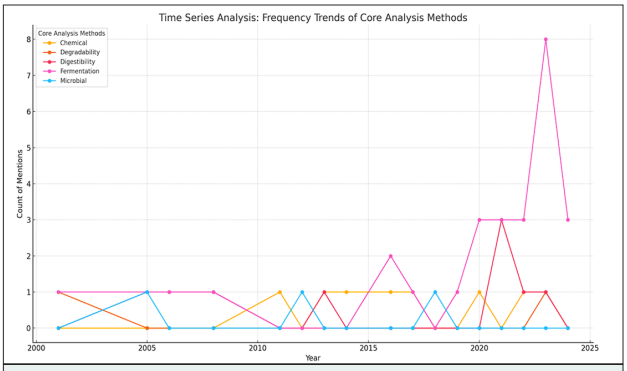

Figure 18. Distribution of analysis methods used in the studies by year (1997-2024).

silage to enhance fermentation efficiency, stabilize the microbial environment, and minimize nutrient loss. Corn silage, due to its high moisture content and carbohydrate-rich composition, provides an ideal substrate for rapid fermentation; however, it is also susceptible to spoilage if not properly managed. The application of inoculants ensures the dominance of lactic acid bacteria, which accelerates fermentation, reduces pH, and inhibits the growth of undesirable microorganisms. Similarly, acids such as lactic and propionic acids are employed to enhance silage stability, prevent spoilage, and maintain quality during storage. In the case of barley, which is often characterized by a different nutritional and structural profile compared to corn, the use of additives such as inoculants and acids may address specific challenges such as optimizing fiber digestibility and controlling fermentation dynamics. These pairings illustrate how the intrinsic properties of the silage material influence the choice of additives, reflecting a targeted approach to achieving desired outcomes in silage production. This relationship between silage materials and additives underscores the critical role of tailored strategies in enhancing the efficacy and efficiency of silage production. By aligning additive selection with the unique characteristics of the material, producers can achieve better fermentation outcomes, reduced nutrient losses, and improved feed quality. These findings highlight the importance of continued research to refine these strategies, ensuring that silage production remains adaptable to varying agricultural, environmental, and nutritional demands.

The results of the evaluation of the examination methods referenced in the titles and keywords of the analyzed studies are presented in Figures 17 and 18. Figure 19 illustrates the analysis methods according to the silage material.

A notable relationship was identified between the selection of silage materials and the analytical techniques employed, reflecting the tailored approaches used to evaluate the characteristics and quality of different materials. Specifically, chemical analyses were frequently applied to materials such as corn and alfalfa, emphasizing their importance in assessing the nutritional composition and quality parameters of these widely used silage crops. This relationship underscores the interplay between the intrinsic properties of silage materials and the research objectives that guide methodological choices. Corn and alfalfa, as silage materials, possess distinct nutritional profiles that make them central to animal nutrition studies. Corn silage, characterized by its high energy content and carbohydrate-rich composition, is often analyzed chemically to quantify parameters such as starch, fiber, and sugar content. These analyses are critical for understanding its fermentation dynamics and ensuring optimal feed quality. Similarly, alfalfa, a legume known for its high protein content and mineral composition, is frequently subjected to chemical analyses to evaluate crude protein levels, fiber fractions, and nutrient availability. These assessments are essential for determining its suitability in ration formulations, particularly for high-performance livestock. The recurrent use of chemical analyses with these materials highlights their pivotal role in aligning silage production with nutritional goals. The precise quantification of components such as carbohydrates, proteins, and fibers not only ensure that silage meets dietary requirements but also facilitates

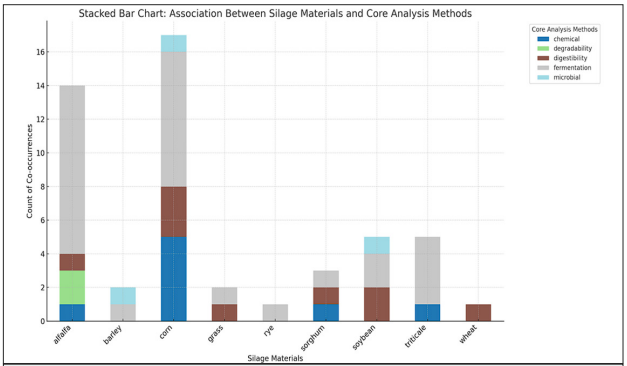

Figure 19. Analysis methods according to the silage materials.

adjustments in processing and additive use to optimize fermentation and storage outcomes. The variation in analytical techniques applied to different silage materials further illustrates how research objectives influence methodological approaches. While chemical analyses are indispensable for understanding the nutritional aspects of corn and alfalfa, other materials with distinct properties might necessitate microbiological, physical, or enzymatic analyses to address specific challenges or objectives. This targeted approach enables a comprehensive understanding of silage properties, fostering advancements in production practices and feeding strategies. Overall, the observed relationship between silage materials and analytical techniques reflects the scientific precision required to optimize silage quality and utility. It also highlights the importance of continuing to refine and adapt analytical methodologies to address the evolving demands of silage research and production.

The total page numbers of the analyzed studies were also subjected to analysis, and the results are presented in Figures 20 and 21.

The page numbers of studies according to article type are provided in Figure 22.

The analysis revealed that analysis articles have the highest average number of pages among the identified publication types. This is likely because analysis articles are inherently designed to provide an in-depth synthesis, analysis, and interpretation of existing literature, requiring detailed explanations and extensive coverage of the subject matter. Their broader scope and the need to integrate findings from multiple studies contribute to their longer format compared to other article types. In contrast, research articles, while substantial in their content, typically have a lower average page count than analysis articles. This difference can be attributed to the focused nature of research articles, which are primarily structured to report specific experimental findings or address targeted research questions. As such, they are often concise in their presentation, prioritizing clarity and efficiency in communicating methodologies, results, and conclusions. The publication type with the lowest average page count was letters to the editor, which are generally brief communications addressing specific points, providing commentary, or responding to previously published articles. These articles are not intended for comprehensive discussions or in-depth analyses, which explain their minimal page counts. This variation in average page count across article types underscores the differing objectives and structural requirements inherent to each format. Analysis articles serve as foundational resources for understanding broad topics, research articles focus on empirical contributions, and letters to the editor offer concise, topical insights. These distinctions reflect the diverse ways in which scholarly communication adapts to the needs of the scientific community, ensuring that each publication type serves its unique purpose effectively.

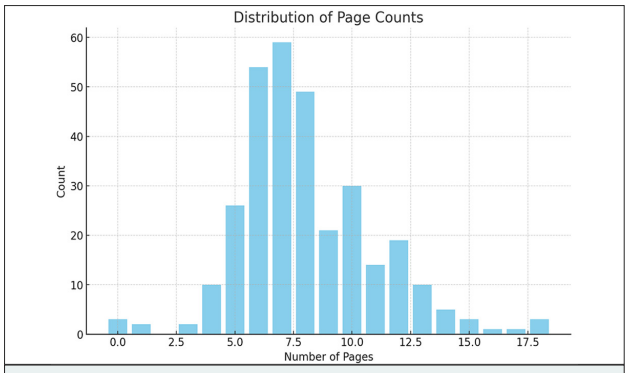

Figure 20. Distribution of the page counts.

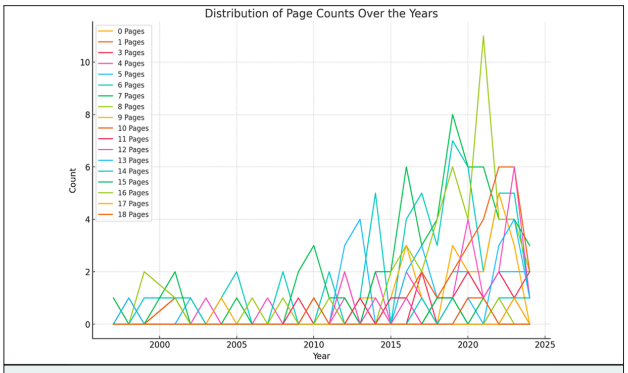

Figure 21. Distribution of the page counts over the years (1997-2024).

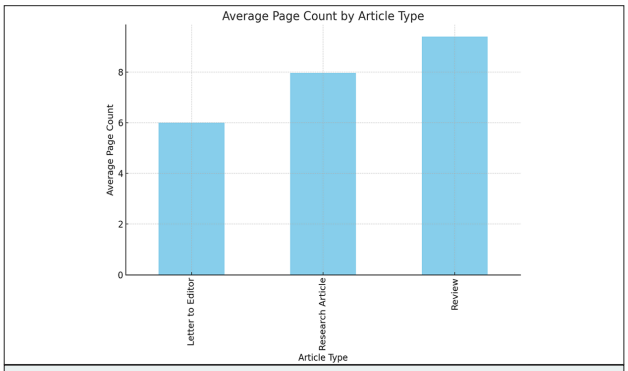

Figure 22. Average page number by different article types.

Discussion

Silage plays an indispensable role in livestock nutrition, particularly during periods when fresh forage is scarce, such as winter months (Muck et al., 2018). The anaerobic fermentation of green forage crops ensures the preservation of nutritional quality while preventing spoilage, a process primarily driven by lactic acid formation (Kung and Shaver, 2001; McDonald et al., 2011). The incorporation of additives like lactic acid bacteria has been shown to

enhance the quality of silage and improve livestock growth performance (Weinberg and Muck, 1996). However, the strategic selection of crops, additives, and analytical methodologies provides deeper insights into the evolving priorities and innovations within silage research.

The analysis of silage materials revealed the consistent dominance of corn and alfalfa, underscoring their nutritional and fermentation advantages (Oba and Allen, 1999). These crops are frequently paired with specific additives, such as lactic acid bacteria and acids, to optimize fermentation dynamics. Corn silage, due to its high energy content and fermentation compatibility, is often associated with lactic acid bacteria to accelerate fermentation and enhance stability. Similarly, alfalfa silage benefits from chemical additives that address its unique protein and fiber profiles. These pairings illustrate a tailored approach to silage production, aligning crop properties with additive functionalities to maximize efficiency and quality.

The visual data further highlighted the significant role of additives such as inoculants, enzymes, and acids in silage production. Inoculants and lactic acid were shown to have increased utilization over time, reflecting advancements in silage technology and an emphasis on optimizing fermentation. However, the fluctuating use of enzymes in certain years suggests a more context-dependent approach, likely influenced by crop type, silage objectives, or regional agricultural practices. These trends underscore the importance of continually adapting additive strategies to align with evolving research and production needs.

Another notable relationship identified in the study was between silage materials and the analytical techniques employed. Chemical analyses were predominantly applied to corn and alfalfa silages, reflecting their importance in evaluating nutritional composition and fermentation parameters. The increased adoption of in vitro methodologies in recent years indicates a shift towards more controlled and reproducible experiments (Krämer et al., 2013). These techniques allow researchers to isolate variables and draw precise conclusions, contributing to the refinement of silage production practices.

However, in situ analyses, which offer insights into silage behavior in specific environments, remain underutilized. This may be attributed to logistical challenges and resource-intensive requirements. Nonetheless, integrating in-situ studies with in vitro findings could provide a more comprehensive understanding of silage dynamics, bridging laboratory results with real-world applications.

The analysis of Turkish silage research revealed a dual contribution: addressing local challenges through Turkish-language publications and contributing to global knowledge through English-language research. This balance between local and international publications reflects the dual objectives of silage research: solving regional problems while engaging in global scientific discourse. Figures demonstrating publication trends over time showed a steady increase in research articles, particularly between 2015 and 2020, which coincides with a growing global focus on food security and sustainable feed production.

The visualizations in this study provided crucial insights but could benefit from further detailed interpretation. For instance, the word cloud used to represent frequently occurring keywords highlights thematic priorities such as "corn", "fermentation", and "additives". However, the contribution of this visualization to the overall analysis could be elaborated by discussing how these keywords align with observed research trends and gaps. Additionally, graphs depicting the utilization of additives over time reveal an increasing emphasis on optimizing silage quality through advanced fermentation strategies. These visualizations emphasize the importance of ongoing innovation in additive technologies.

While the study provides a comprehensive overview of silage research in Türkiye, it also highlights areas for further exploration. The increasing trend in microbial additive research, as demonstrated in this study, suggests a need for further investigations comparing the effectiveness of specific additives across various silage crops. The integration of international datasets and broader comparative analyses could enhance the generalizability of findings, providing a more global perspective on silage research trends. Moreover, increasing the utilization of in situ methodologies and exploring the interactions between microbial communities and chemical additives could yield valuable insights into optimizing silage production (Huhtanen et al 2009).

Conclusion

This study presents a comprehensive analysis of silage research published in the DergiPark infrastructure, revealing the current trends and research priorities of the field. The findings show that silage quality, fermentation processes and the use of additives are among the most salient topics in literature. In particular, the critical importance of crops such as corn and alfalfa in silage production has been identified, emphasizing the key role of microbial additives such as lactic acid bacteria in improving fermentation processes. Furthermore, recent years have seen a marked increase in the use of in vitro methodologies, reflecting the need for greater control and reproducibility in silage production processes. A word cloud generated from the analyzed studies is given in Figure 23.

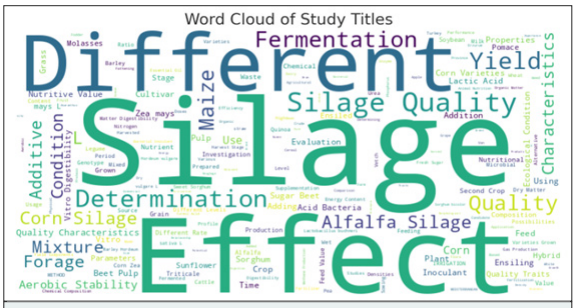

Figure 23. Word cloud obtained from the analyzed studies.

The word cloud (Figure 23) provides an important overview of the most frequently studied themes in silage research. Keywords such as "silage", "quality", "impact", "corn", and "fermentation" reflect prominent topics in the literature, indicating that the research focus is on the efficiency and sustainability of silage. This visualization contributes to identifying not only current trends but also potential directions for future research. For example, by focusing on key topics such as fermentation processes and additives, practices in the sector can be improved and innovative methods developed. This study makes an important contribution to understanding the current status and trends of silage research. The findings provide clues that can guide future research to improve sustainability and productivity. It also provides a scientific basis for the development of strategic approaches for the selection and utilization of silage additives. In this context, further research is needed to improve practices in the sector and to establish innovative methods.

In conclusion, visualizations make an important contribution to the overall scope of the study by providing a better understanding of the findings and identifying gaps in the literature. In particular, tools such as word clouds allow the themes in the literature to be expressed visually and increase the overall impact of the study.

Declarations

Competing Interests

Authors declares that there are no conflicts of interest related to the publication of this article.

Availability of Data and Materials

The data that support the findings of this study are available on request from the corresponding author.

Author Contributions

Motivation / Concept: SE, EE; Design: EE; Control/Supervision: SE; Data Collection and / or Processing: SE, EE; Analysis and / or Interpretation: EE; Literature Review: SE, EE; Writing the Article: EE; Critical Review: SE

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