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Exploring research dynamics in pasture-based automatic milking systems: a bibliometric approach

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Review Article

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Abstract

The worldwide adoption of automatic milking systems (AMSs) has expanded, attracting growing interest from researchers. Although several reviews have already been carried out regarding the features of AMS in confined systems, a comprehensive bibliometric analysis of the literature on automated milking in pasture-based systems is still lacking. Therefore, this review set out to provide a bibliometric approach focused on pasture-based AMS to explore and map the extent of research in the scientific literature. Initially, a comprehensive search was carried out in the Web of Science and Scopus databases. Then, a four-step PRISMA evaluation was applied on 235 identified articles, resulting in a final sample of 45 articles. Most studies were conducted in Europe (44%), in research herds (79%), involving Holstein-Friesian cows (76%), using automated milking from Lely (57%) and DeLaval brands (30%). White clover and perennial and annual ryegrass are the most commonly used pastures among the countries (87.5% vs. 75%). The main topics (33%) investigated over studies were milk production, composition and efficiency of AMS on pasture, followed by animal behaviour (27%), animal nutrition (16%), heat stress (9%), methane emissions (7%), health disorders (2%), economic viability (2%), somatic cell count and mastitis (2%) and energy consumption (2%). Concentrate allocation and heat stress were identified as emerging research areas that deserve greater attention in future studies. This study contributes to our understanding of scientific developments, trends and research gaps regarding pasture-based AMSs.

The adoption of automated milking systems (AMSs) has expanded globally since their introduction in the 1990s (Bach and Cabrera, 2017), driven by labour shortages and the desire for greater production efficiency, profitability and improved quality of life for farmers. Beyond operational benefits, AMS have also been associated with enhanced individualized animal management, fostering better health and welfare outcomes (Tse *et al.*, 2018a; Matera *et al.*, 2024). The benefits and worldwide adoption of AMS have attracted increasing research interest, with the number of studies on this technology increasing over the last two decades (Cogato *et al.*, 2021). Several reviews have summarized technological trends and research gaps, addressing the evolution of the AMS over time and the current status of scientific research and patents (Lyons *et al.*, 2014; John *et al.*, 2016; Cogato *et al.*, 2021; Marques *et al.*, 2023).

Initially developed for zero-grazing systems (Cogato *et al.*, 2021; Marques *et al.*, 2023), AMS were later integrated into pasture-based farms (Matera *et al.*, 2024). On a global scale, it is estimated that only 10–15% of milk production is in pasture-based systems (Moscovici Joubran *et al.*, 2021), and the integration of AMS represents less than 1% of farms worldwide (Eastwood and Renwick, 2020). The slower adoption of AMS in pasture-based systems remains less well understood and has been associated with challenges such as greater distances between grazing areas and the milking unit, which can affect cow traffic and system efficiency. In addition, the limited availability of comparative studies evaluating the productive and economic performance of pasture-based AMS relative to conventional milking systems (e.g., herringbone, parallel or rotary systems; Gargiulo *et al.*, 2020) may also contribute to this scenario.

Despite the limited integration of AMS and pasture-based systems, studies suggest that this practice offers significant benefits, including reduced feed costs (O'brien and Hennessy, 2017), improved milk quality (O'Callaghan *et al.*, 2017) and enhanced animal health, thereby contributing to the overall sustainability of dairy production (Shortall *et al.*, 2016). To our

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Table 1. Search strategy to identify articles for the systematic review characterizing pasture-based automatic milking systems in dairy cow operations, published in English during March 2025

Strategy	Search terms
1	('cattle' OR 'dairy cattle' OR 'dairy cows' OR 'cow' OR 'cows' OR 'lactating cows')
2	('automatic milking system' OR 'robotic milking' OR 'AMS' OR 'voluntary milking system' OR 'VMS')
3	('pasture-based' OR 'grazing' OR 'pasture-fed')

knowledge, no previous bibliometric review has focused specifically on pasture-based AMS, underscoring the need for an in-depth analysis of this topic. Also, to provide an overview of vantages and barriers influencing the adoption of AMS in pasture-based systems and to summarize the existing knowledge, this bibliometric review aims to: (1) describe the evolution of research on pasture-based AMS over time; (2) characterize the main research themes; (3) identify the forage species addressed; (4) highlight emerging trends and opportunities for pasture-based AMS; and (5) identify key challenges and directions for future research.

Materials and methods

Protocol

This review was conducted in accordance with the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses protocol (PRISMA; Page *et al.*, 2021), using a bibliometric review approach. As this study did not involve the use of animals or human subjects, approval from an Animals or Ethics Committee or Human Research Ethics Committee was not required.

Search strategy

A systematic search was conducted exclusively on March 14, 2025, in the Web of Science (WoS) and Scopus (Scp) databases. An updated search was performed on February 19, 2026, and no additional studies meeting the inclusion criteria were identified. For this purpose, English search terms related to pasture-based AMS were employed, combined with Boolean operators (i.e., AND, OR and NOT) to connect words or phrases, as well as wildcard truncation (indicated by quotation marks '') to encompass different forms of words. Table 1 presents the search terms used. No restrictions on the year of publication were applied. The studies were validated based on the correspondence between their keywords and the search terms used.

Study inclusion criteria and screening

The search conducted in the WoS database returned 114 results, while 120 results were returned by the Scp search. One article was added based on the reference list of previous articles. In total, 235 results were imported into the Mendeley® software. After importing, duplicates were removed, followed by a four-stage screening and evaluation process to select relevant articles. All screening stages were conducted manually by the first author. Titles, abstracts and full texts were carefully read and evaluated to ensure that the selected studies met the inclusion criteria. No automated selection procedures were applied beyond duplicate removal. In the first stage, articles written in languages other than English were excluded. In addition, review articles, theses, books, book chapters, conference proceedings and reports were removed, as it was not possible to ensure that these sources had been peer-reviewed. In the second stage, the titles and abstracts of the selected articles were analysed to exclude literature outside the subject. For example, articles that deal with AMS in confinement, automatic milking rotary, pasture milk production systems without automated milking, studies with non-lactating cows, modelling and/or studies unavailable in the databases consulted were removed. In the third stage, all titles and abstracts were re-evaluated to identify and exclude articles that did not address the main topic of interest. Also, articles containing experimental research wereexcluded if the experiment did not specifically address pasture-based AMS. Finally, in the fourth stage, the remaining articles were included in our review and analysed in detail.

Data extraction

The selected articles were then analysed in R (version 4.4.3; R Core Team, 2025) using the Bibliometrix package (version 4.3.3). The bibliometric analysis was based on terms extracted from the included articles, and research terms emerged from their frequency, co-occurrence and temporal occurrence across the literature corpus, without prior manual categorization by the authors. Bibliometrix is an open-source package developed specifically for carrying out bibliometric and co-citation analyses on scientific publications (Dervis, 2019). The tool makes it possible to investigate the intellectual structure of scientific domains through network analysis, employing multiple correspondence analyses based on keywords, titles and abstracts of studies (Aria and Cuccurullo, 2017). The co-occurrence network was built to analyse the connections between the terms present in the abstracts of the articles, reflecting the relationship between different areas of knowledge (Cobo *et al.*, 2011). In this occurrence network, the size of each node (circle) represents the frequency of occurrence of the term in the selected articles, while the links between the nodes indicate the strength of the associations between the concepts and their respective areas of knowledge (Aria and Cuccurullo, 2017). To analyse trends in terms used in the pasture-based AMS, a Bibliometrix 'Trend Topics' graph (Aria and Cuccurullo, 2017) was made, which highlights the words in the abstracts of the most popular authors at specific times. To identify trend terms, a minimum frequency threshold of five occurrences and the display of up to three intervals per year were adopted. To explore potential patterns between journals, institutions and keywords, the Bibliometrix 'three-field plot' map was constructed. In this map, thicker links indicate stronger collaboration between the connected elements, while thinner links indicate less frequent interaction (Aria and Cuccurullo, 2017). Additionally, a Microsoft Excel® spreadsheet was created with the information extracted from the selected studies, including study identification, author, year, title, objective, research area, country, herd characteristic (e.g., number of animals, breed, days in lactation, milk production and milking frequency), AMS brand, number of AMS and pasture species.

Results and discussion

Overview

The results of the search, as well as the flow of inclusions and exclusions, are presented in Figure 1. The publication year of the 45 articles included in this review ranged from January 2004 to

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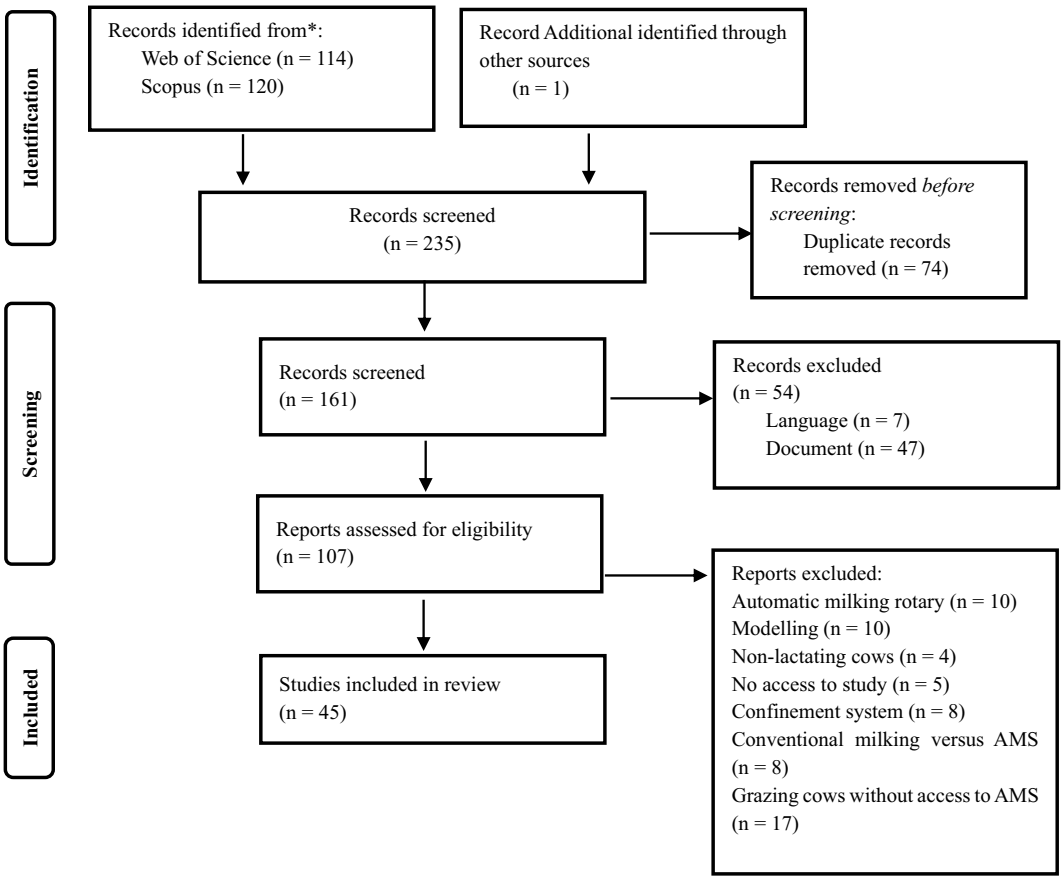


Figure 1. PRISMA flow diagram illustrating the selection process of studies included in the bibliometric analysis of pasture-based automatic milking systems in milk production systems.

March 2025. Considering the research advances in this field of the last 20 years, it is important to highlight that the combination of AMS and pasture-based systems was first reported in the early 2000s in New Zealand as part of a research project (Jago *et al.*, 2004). In the same year, this integration was adopted in Australia, initially on a commercial farm, and in 2006, a pasture-based AMS was implemented as part of the 'National Future Dairy Program' (Greenall *et al.*, 2004). Then, several studies have been conducted to investigate pasture-based AMS. The studies published in the last two decades have provided both theoretical and practical knowledge, and have also helped identify knowledge gaps, for both the dairy industry and farmers who use or are interested in adopting the system.

Main affiliations, journals and keywords

A three-field plot map representing connections among three fields of analysis is shown in Figure 2. The fields of analysis were defined according to the research objectives (Aria and Cuccurullo, 2017) included in this review. For this analysis, institutional affiliations, journals (or sources) and keywords were selected. Thicker links indicate stronger collaboration between the connected elements, while thinner links represent less frequent interactions. In this way, it is possible to observe patterns in the journals where certain universities commonly publish, allowing for a deeper understanding of each research field and the keywords used (Linnenluecke *et al.*, 2020).

The connection between the *University of Sydney* and the journal *Animal* is associated with the five keywords 'automatic milking system', 'automatic milking', 'grazing', 'pasture' and 'cow traffic', although these interactions are less frequent. The *University of Sydney, Michigan State University* and the *Animal and Grassland Research and Innovation Centre* have a strong connection with the *Journal of Dairy Science*. The high frequency of keywords such as 'automatic milking system', 'automatic milking' and 'grazing' suggests that the journal has established itself as an important outlet for scientific dissemination focused on the interface between pasture-based AMS technologies and the interaction between technological innovation and more sustainable management practices. Additionally, journals such as *Livestock Science, Animals* and *Asian-Australasian Journal of Animal Sciences* also appear with interactions involving institutions and keywords, although with lower intensity.

Trends in research on pasture-based AMS

The use of trend graphs provides an overview of the temporal evolution of the most relevant terms over time. The terms analysed are shown in Figure 3. It is observed that the expression 'milk yield' peaked at 58 occurrences, followed by 'milk frequency', with 48 occurrences, and 'automatic milking', with 44 occurrences, during the period from 2015 to 2019. The use of these terms in different periods demonstrates the continued interest in productive perfor-

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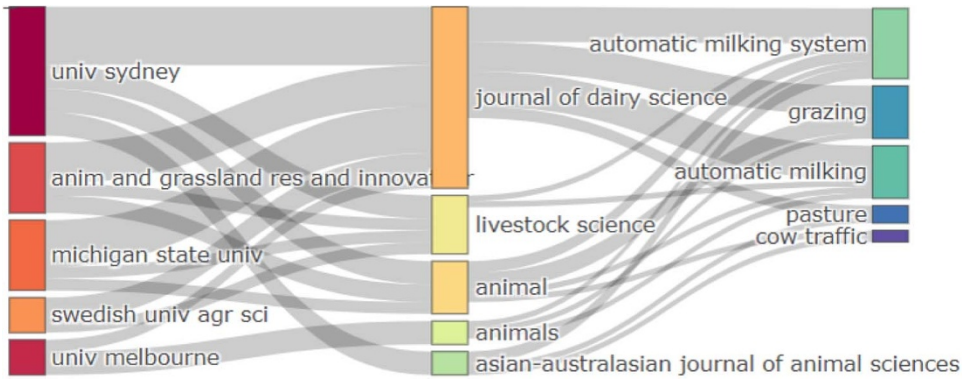


Figure 2. Diagram of the main relationships between affiliations, sources/journals and keywords of the 45 articles included in this review. The figure is organized as a three-field diagram, where each column represents a bibliography dimension and nodes to the most frequent items within each bibliography field (i.e., affiliations, sources/journals and keywords). Connections between nodes indicate co-occurrence within the same study, linking affiliations, publication outlets and thematic keywords. Thicker links indicate a higher frequency of co-occurrence between connected elements, whereas thinner links represent less frequent associations.

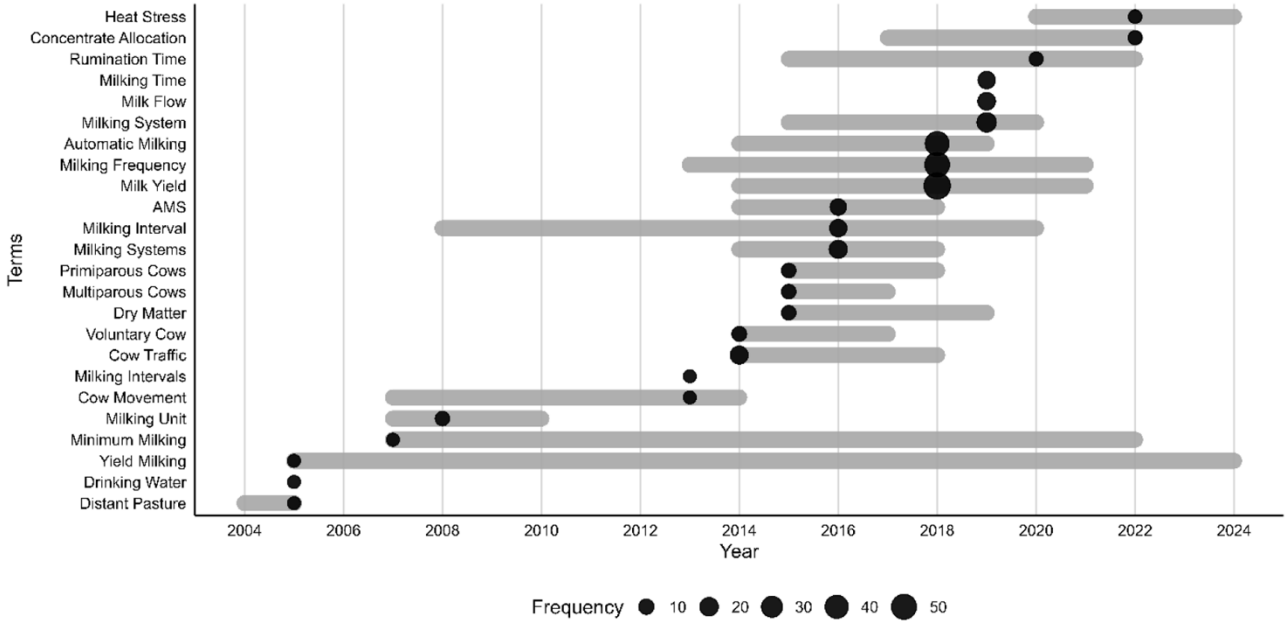


Figure 3. Trending words in the articles ($n = 45$) included in the bibliometric review regarding pasture-based automatic milking systems from 2004 to March 2025. The grey line represents the interval of occurrence of the term over time. The black circle indicates the year with the highest concentration of the term, and the size of the circle represents its total frequency.

mance and system efficiency. Since 2013, there has been a rise in studies focused on cow movement within pasture-based automated milking systems. Starting in 2018, emerging terms such as 'concentrate allocation', 'heat stress' and 'pasture-based automatic' emerged, representing new lines of research.

Geographic location

The studies were mainly conducted in Europe (44%, 19/43), followed by Australia/Oceania (42%, 18/43), North America (12%, 5/43) and South America (2%, 1/43), as illustrated in Figure 4. Australia contributed the largest number of studies (37%, 16/43), which may be explained by the high percentage of livestock farming based on pasture (Lessire *et al.*, 2020). In Australia, approximately 60–65% of a cow's dry matter comes from grazing over the course of a year (Dairy Australia, 2025). Similarly, New Zealand has 11.1 million hectares of pasture, of which 5.4 million hectares are used for milk production (Schipper *et al.*, 2010); then, pasture can account for 82% of the composition of dairy cows' diets (Roche *et al.*, 2017; Wales and Kolver, 2017). Ireland is well represented among European countries, as more than 80% of its agricultural area is used for producing pasture, hay and forage silage (European Commission: Agriculture in Ireland, 2025), and approximately 80% of cows' dry matter intake comes from pasture (O'brien and Hennessy, 2017). Many other countries in Europe, North America and South America also include pasture in their dairy cows' diets, but with lower inclusion rates than in New Zealand, Ireland and Australia, due to the shorter grazing season or adverse weather conditions (Farina *et al.*, 2021; Morales *et al.*, 2024). In South America, Uruguay stands out, with dairy herd diets consisting, on average, of 56% pasture and 44% conserved forages and concentrates (INALE, 2019).

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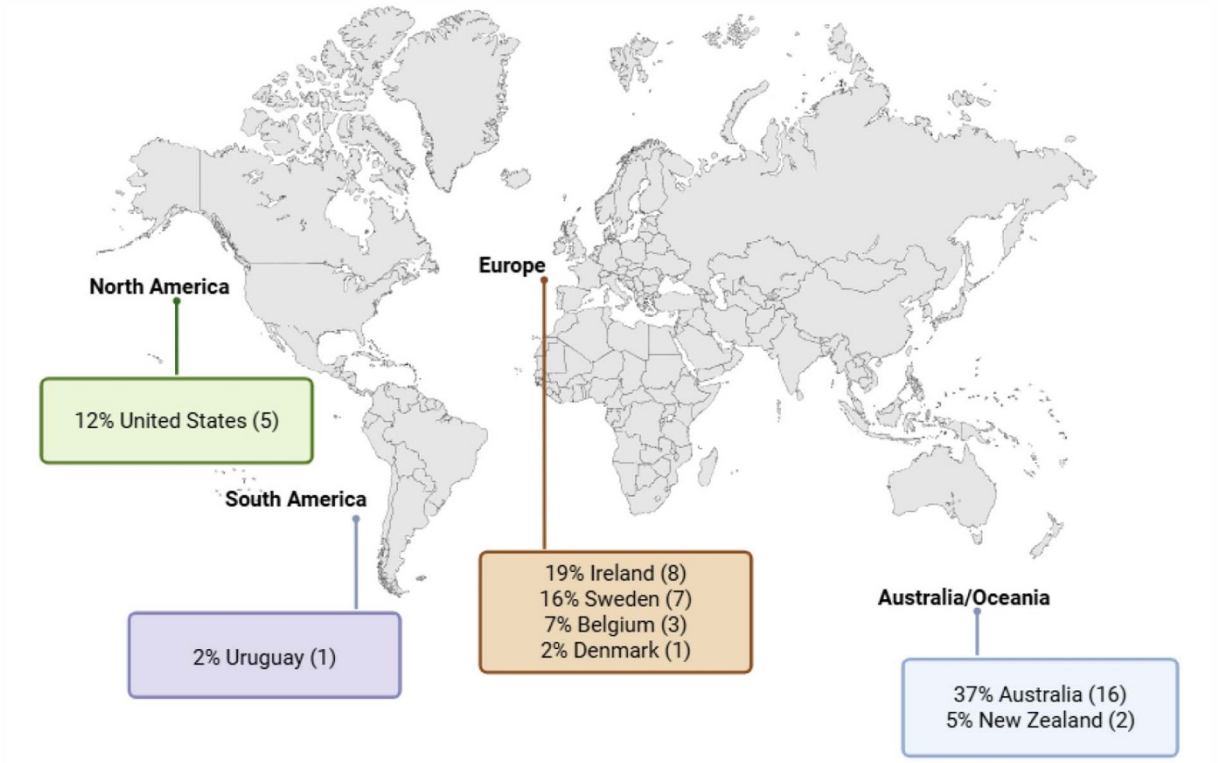


Figure 4. Geographic distribution of studies ($n = 43$) included in the bibliometric review regarding pasture-based automatic milking systems.

Breed composition and brands of pasture-based AMSs

Of the 29 articles that reported the breeds included in the studies (Table 2), the majority evaluated Holstein-Friesian (76%, 22/29), followed by Swedish Red and White (21%, 6/29) and crossbreeds (Jersey × Holstein-Friesian and Norwegian Red × Holstein-Friesian – 14%, 4/29). Cattle breed was not reported in 16 articles (35%, 16/45). The distribution of AMS brands in relation to countries is shown in Figure 5. Thirty-seven articles mentioned the brand of the pasture-based AMS. Lely equipment was referenced in 57% (21/37) of the studies, followed by DeLaval (30%, 11/37), Fullwood Merlin (8%, 3/37) and GEA (3%, 1/37). The number of AMS varied from one to four across the studies, and in only one study (3%, 1/37), there was more than one brand (Lely and DeLaval). It is important to highlight that the Lely brand was already identified as predominant around the world dairy farms in another review (Marques *et al.*, 2023), even in zero-grazing systems. This may be related to Lely's early development of AMS technology, with the first four units installed in 1992 (Bottema, 1992).

Table 2. Description of dairy cattle breeds reported in the studies included in the bibliometric review regarding pasture-based automatic milking systems

Breed (s) reported in the articles	Number of articles (*n*)	Percentage of articles (%)
Holstein-Friesian	22	76
Swedish Red	6	21
Swedish White	6	21
Jersey × Holstein-Friesian	4	14
Norwegian Red × Holstein-Friesian	4	14
Jersey	3	10
Illawarra	3	10
Ayrshire	1	3

Note: The percentages for the breeds, based on the 29 articles that reported them, do not add up to 100%, as more than one breed may be described in a single article.
Values are expressed as the number of articles (*n*) and the percentage of articles (%) in which each breed was reported. Percentages were calculated based on the total number of articles that provided breed information ($n = 29$).

Words from abstracts reported for pasture-based AMSs

The co-occurrence network analysis and the connections between the most relevant words used in the abstracts are presented in Figure 6. The aim of this analysis is to examine the co-occurrence of specific terms in abstracts of the articles, providing a deeper understanding of the prominent themes, patterns and research areas (Aria and Cuccurullo, 2017). This analysis contributes to a clearer delineation of the main areas of interest and research directions in this field (Gutiérrez-Salcedo *et al.*, 2018). The red cluster focuses on variables associated with milk production. The purple and pink clusters reinforce the relationship between operational dynamics and production performance, suggesting critical factors that influence milk yield in pasture-based AMSs. The brown cluster addresses the performance of the pasture-based AMS and denotes management strategies that directly impact the system's productivity. Finally, the clusters represented by the colours blue and black are directly associated with the operational efficiency of the milking process.

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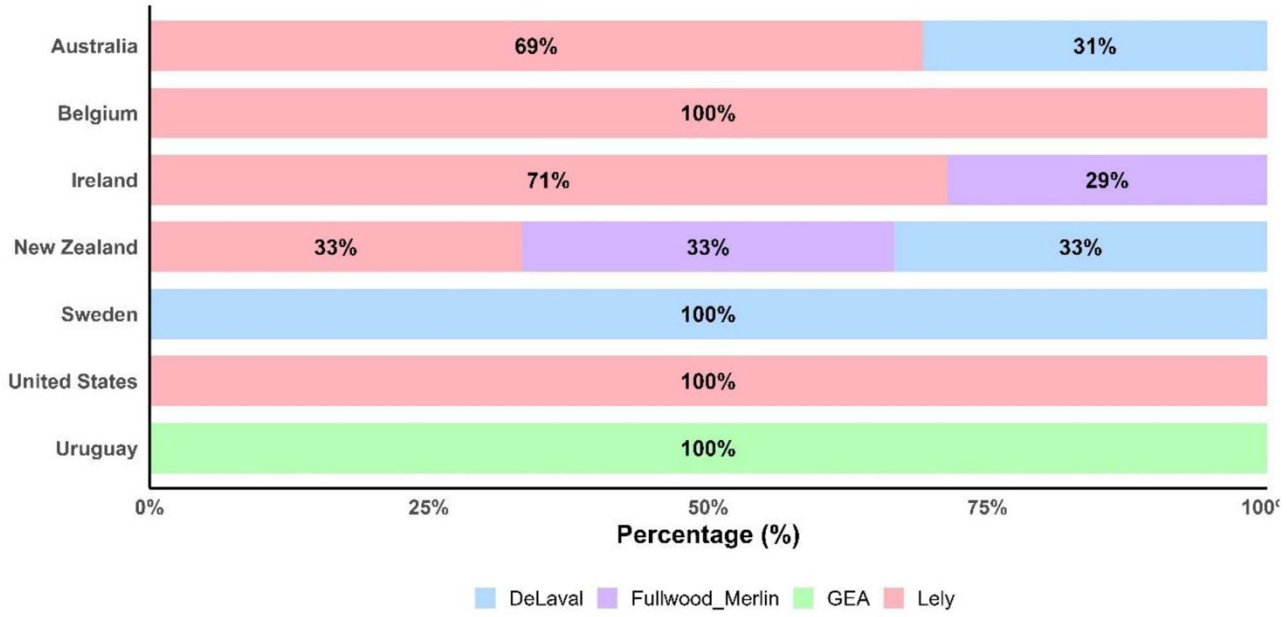


Figure 5. Percentage of the main brands of milking robots by countries in the studies ($n = 37$) included in the bibliometric review regarding pasture-based automatic milking systems.

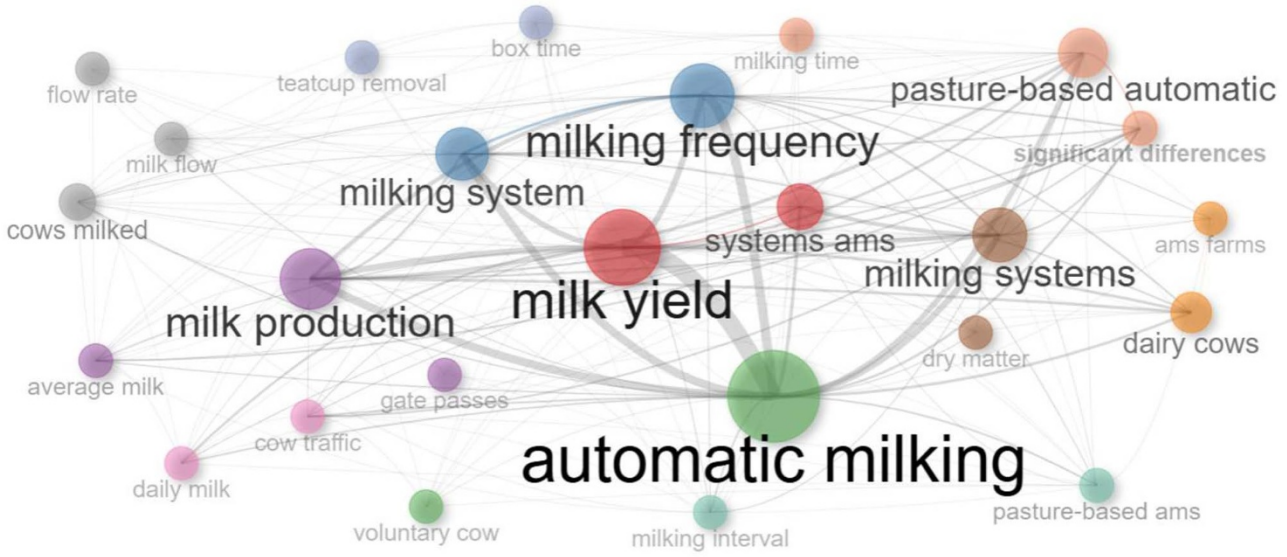


Figure 6. Co-occurrence network of the words in the abstracts from the 45 articles included in this bibliometric review. The size of the label and circle is determined by the number of times the word was used, and the links show the relationship between the knowledge areas, where the closing words have a strong relationship.

Forage species

We found that white clover (*Trifolium repens* L.) and perennial and annual ryegrass (*Lolium multiflorum* L.) were present in most of the countries included in this review, 87.5% (7/8) and 75% (6/8) of them, respectively (Table 3). In the grazing systems prevalent in northwestern Europe (north temperate climate regions), New Zealand, Australia and the southern part of Latin America (south temperate climate regions), grazed pasture is the main source of food for cattle. In these countries, cows graze for more than 270 days a year (O'Brien *et al.*, 2017). Pastures in these regions are composed of different species of grasses and legumes, with perennial ryegrass (*Lolium perenne* L.) being the predominant species of grasses due to its high productivity and nutritional quality (Morales *et al.*, 2024). In addition, legumes have demonstrated not only productive benefits but also environmental ones, standing out for their ability to reduce nitrous oxide emissions, fix atmospheric nitrogen and reduce the carbon footprint (Yan *et al.*, 2013). Nevertheless, the efficiency of pastoral systems depends not only on the choice of forage species but also on the ability to ensure a continuous and balanced supply of forage throughout the year. Another important aspect of these systems is the continuous production of pasture throughout the year, especially in temperate

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Table 3. Description of forage species by countries in the studies included in the bibliometric review regarding pasture-based automatic milking systems

Country	Forage species
Australia	Kikuyu Grass (*Pennisetum clandestinum* Hochst. Ex Chiov.)
	Perennial Ryegrass (*Lolium perene* L.)
	Annual Ryegrass (*Lolium multiflorum* L.)
	White clover (*Trifolium repens* L.)
	Oats (*Secale cereale* L.)
Belgium	Perennial Ryegrass (*Lolium perenne* L.)
	White clover (*Trifolium repens* L.)
Denmark	White clover (*Trifolium repens* L.)
United States	Perennial Ryegrass (*Lolium perenne* L.)
	White clover (*Trifolium repens* L.)
	Red clover (*Trifolium pratense* L.)
	Orchard grass (*Dactylis glomerata* L.)
	Tall fescue (*Festuca arundinacea* Schreb.)
	Alfalfa (*Medicago sativa* L.)
Ireland	Perennial Ryegrass (*Lolium perenne* L.)
Sweden	Meadow fescue (*Festuca pratensis L.*)
	Perennial Ryegrass (*Lolium perenne* L.)
	Timothy grass (*Phleum pratense L.*)
	Bluegrass de Kentucky (*Poa pratensis L.*)
	White clover (*Trifolium repens L.*)
	Red fescue (*Festuca rubra L.*)
Uruguay	Alfalfa (*Medicago sativa* L.).
	White clover (*Trifolium repens* L.)
	Orchard grass (*Dactylis glomerata* L.) Tall fescue (*Festuca arundinacea* Schreb.)
	Common bromegrass (*Bromus catharticus* Vahl.)
New Zealand	Not specified

regions, where forage growth can be limited at certain times due to the end of the forage species' cycle and adverse environmental conditions. To meet the animals' nutritional requirements, the diet is generally supplemented with concentrates and preserved fodder to guarantee an adequate supply of energy for dairy cows.

Relationship between production indicators and forage-to-concentrate ratio

Table 4 summarizes the average values of days in milk, milk production and milking frequency reported in the articles included in this review, grouped by country. Among the articles included in this review, those conducted in Ireland reported lower average milk production (18.58 kg/cow/day; Table 4), whereas studies from the United States reported higher values (30.26 kg/cow/day; Table 4). In Belgium, although some articles reported higher milking frequencies (up to 2.76 milkings/cow/day; Table 4), milk yield values were variable. These differences should be interpreted

Table 4. Characterization of days in lactation, milk production and milking frequency of cows grouped by countries in the studies included in the bibliometric review regarding pasture-based automatic milking systems

Country	Days in milk	Milk production (kg/day)	Milking frequency (milking /cow/day)
Australia	162.72 ± 146.27	24.37 ± 4.76	2.16 ± 0.60
United States	148.85 ± 52.18	30.26 ± 8.35	2.23 ± 0.28
Uruguay	NA[a]	29.10 ± 7.21	2.17 ± 0.33
Ireland	112.94 ± 85.55	18.58 ± 3.75	1.55 ± 0.27
New Zealand	NA[a]	23.03 ± 0.79	1.66 ± 0.04
Belgium	137 ± 23.14	24.76 ± 2.83	2.76 ± 0.56
Sweden	161.62 ± 139.65	29.49 ± 2.41	2.45 ± 0.17
Mean	146.22 ± 94.27	25.95 ± 6.53	2.20 ± 0.55

Note: Values represent averages derived from the articles included in this review and are grouped by country for descriptive purposes only. These data reflect specific study conditions and should not be interpreted as representative of national production systems, as they are influenced by factors such as breed, management and production environment.
[a]NA, not analysed.

with caution, as they are influenced by factors such as breed, management and production system. For example, Ireland and New Zealand have a high proportion of pasture in the dairy cows' diets (~80%), combined with a low concentrate supply (1.92 kg/cow/day). Australia is characterized by a mixed system, combining grazing (~50%) with the provision of preserved forage and concentrate (4.00 kg/cow/day). Belgium, the United States and Sweden, in contrast, have a lower proportion of grazing (~30%) throughout the year and are characterized by more intensive systems, with a higher concentrate supply (6.56 kg/cow/day) in dairy cow diets (Lessire *et al.*, 2020). However, variations in pasture availability and concentrate supplementation among production systems may directly influence not only milk yield but also cow traffic and milking frequency in AMSs.

Milk production, besides being a key indicator of productive efficiency on dairy farms, is directly associated, in the AMS, with the amount of concentrate offered both in the robot and in the partially mixed diet (PMR) in the feeding area. However, the ideal amount of concentrate to be offered in the robot is still unclear. In general, cows do not consume all the concentrate allocated in the robot when the concentrate supply is high (>4 kg/d; Bach and Cabrera, 2017). Furthermore, a high supply of concentrate in the robot can influence the cows' stay time. The amount of concentrate supplied and ingested in the robot depends on its composition, palatability and physical form (DeVries and Penner, 2022). Cows typically consume bran-based concentrate at a rate below 200–250 g/min (Spörndly and Åsberg, 2006; Harper *et al.*, 2016) and pelleted concentrate at rates ranging from 250 to 400 g/min (Kertz *et al.*, 1981). Considering an average stay in the robot of about 7 minutes (Castro *et al.*, 2012) and an average consumption rate of 250 g/min of concentrate, cows can consume up to 1.7 kg of concentrate per milking session (DeVries and Penner, 2022).

The relationship between concentrate consumption in the robot and the feeding behaviour of cows also extends to the post-milking period, since both the amount of concentrate ingested during milking and PMR supplementation after that time can influence grazing

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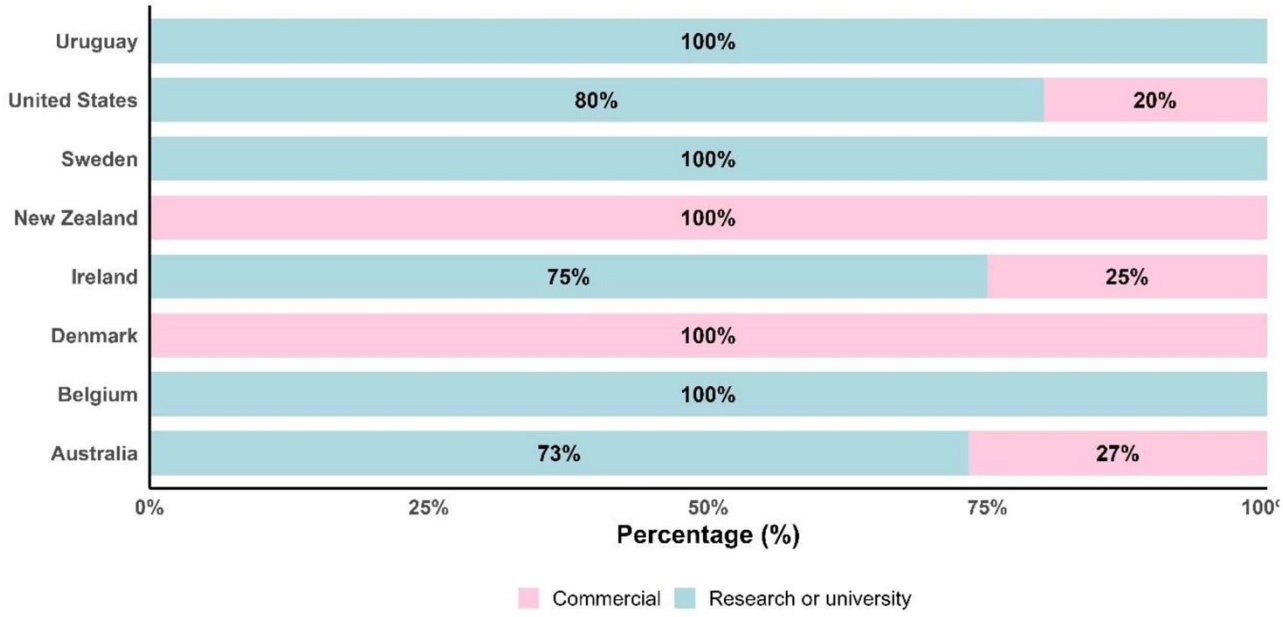


Figure 7. Percentage of the main herds by countries in the studies ($n = 38$) included in the bibliometric review regarding pasture-based automatic milking systems.

behaviour and the voluntary return of cows to the milking unit. PMR supplementation in pasture-based AMS can alter cows' grazing behaviour (Bargo *et al.*, 2002), such as reducing grazing time and/or the proportion of time spent grazing (Pérez-Ramírez *et al.*, 2008; Kennedy *et al.*, 2011). Nieman *et al.* (2015) observed a reduction of 78–36 minutes in access time to pasture per kg of PMR fed to cows on based-pasture AMS. However, this reduction in grazing time had no effect on milk production (Nieman *et al.*, 2015), suggesting that cows may have adjusted the duration and/or intensity of grazing in response to PMR supplementation. The impact of PMR supplementation and the amount of forage consumed by the animals still needs to be thoroughly investigated in pasture-based AMS.

Description of research areas and herds evaluated

The main topics (33%, 15/45) investigated in the studies included in this review were milk yield, milk composition and AMS efficiency on pasture, followed by cow's behaviour (27%, 12/45), nutrition (16%, 7/45), heat stress (9%, 4/45), methane emission (7%, 3/45), health disorders (2%, 1/45), economic viability (2%, 1/45), somatic cell count and mastitis (2%, 1/45) and energy consumption (2%, 1/45). There was an increase in the number of studies involving pasture-based AMS in the last decades; however, most of the results obtained remain at an experimental level (Fig. 7). Of the studies analysed, 79% (30/38) utilized research or university herds, while 21% (8/38) were conducted on commercial herds. In the remaining 16% (7/45), the herd origin was not specified. Although most of the studies were conducted in research settings, caution is warranted when extrapolating certain results, as experimental herds typically do not operate under commercial conditions and, in most cases, test the effect of different treatments on variables such as performance in controlled environments. Nevertheless, these studies play a fundamental role in research, providing valuable insights that support systems contribute to decision-making, advancing dairy production and improving milk ability under real management conditions.

Milk yield, composition and pasture-based AMS efficiency

Among the research areas identified in this review, milk production, milk composition and the efficiency of pasture-based AMS represent 33% of the analysed articles. These themes continue to be among the main topics of investigation, with significant growth in the last 10 years. This subsection describes the main approaches observed in research in this category. In general, studies have highlighted an increase in cow production after the implementation of AMS, with increases that can reach up to 12% (Jacobs and Siegford, 2012). However, this increase is related to milking frequency – one of the main performance indicators in AMS – which in turn is influenced by the interval between milkings and the distribution of cows to the AMS (Lyons *et al.*, 2014).

In addition to milk production and AMS efficiency, milk composition has also been extensively investigated in the last 10 years in this pasture-based system. Pasture-based AMS is largely dependent on pasture conditions. Milk composition in pasture-based systems can be influenced by seasonal variations in forage quality and availability (Timlin *et al.*, 2021; Hayes *et al.*, 2023). This challenge can be overcome by offering food supplements (e.g., silage and grain; Ribeiro-Filho *et al.*, 2021) and through a combination of pasture management strategies, such as rotational grazing (Wang and Kreuter, 2024; Ge *et al.*, 2025). Despite that, a pasture-based diet has been associated with benefits to milk quality, such as increased milk fat and protein content (O'Callaghan *et al.*, 2016; Gulati *et al.*, 2018), which may result in higher yields of dairy products (Moscovici Joubran *et al.*, 2021) and add value to the raw material.

Cows' behaviour in pasture-based AMSs

Cow behaviour was one of the main topics analysed in the included articles, representing 27% of the publications. In general, we observed studies focused on behavioural factors that affect the voluntary movement of cows and consequently limit the efficiency of pasture-based milk AMS. The voluntary movement of cows in

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pasture-based AMS can be impacted by greater distances travelled by the animals and by the cows' lower motivation to visit the robot. These behavioural limitations reduce milking efficiency, especially in medium and long herds (>200 lactating cows) typical of Australia and New Zealand (Clark *et al.*, 2013; Wildridge *et al.*, 2017; Gargiulo *et al.*, 2018; John *et al.*, 2019). Long distances not only affect visits to the milking box but also influence how cows access other essential resources. When a cow needs to walk a long distance, its decision to do so depends on its level of motivation and need. For example, when a water trough is located more than 250 m away, cows tend to reduce their water intake if the perceived benefit of drinking water is lower than the benefit of staying in their current location (Phillips, 2002). This logic applies to a cow's decision to visit the milking box, because the animals in this system must be motivated to voluntarily walk between the pasture and the AMS several times a day. Sporndly and Wredle (2004) found that when the distance between the pasture and the AMS was close (50 m), the cows produced on average 1.6 L more milk per day and had a higher milking frequency (2.5 milkings/cow/day), compared to cows that were kept at a greater distance (250 m; 2.3 milkings/cow/day). Thus, the need to reconcile considerable distances between paddocks and milking facilities becomes a key factor in achieving production targets on farms. One example is the provision of concentrate feed inside the milking box, or by implementing a forced or guided cow traffic system, where cows must pass through the AMS before reaching the feed bunk (Bach and Cabrera, 2017). In 2016, John *et al.* (2016) reviewed the literature on the distribution of milking box utilization and suggested that future research should investigate topics such as the impact of distance to pasture on milking frequency and the interaction between time of day, the AMS location relative to shade and pasture distance on AMS utilization. However, nearly a decade later, this gap remains unaddressed in the literature.

Heat stress in dairy cow in pasture-based AMSs

Another relevant research topic identified in the studies included in this review refers to the impact of heat stress on dairy cows, which accounts for 9% of the studies. A reduction in cow motivation for milking during periods of higher temperatures was observed, impacting milking frequency and milk production. Over the past decade, climatic conditions have been identified as one of the main challenges faced by this pasture-based system. Environmental conditions (especially periods of high temperatures and humidity) change the voluntary movement and cow motivation to access the milking box in pasture-based AMS (Talukder *et al.*, 2023). During and after heat events (including at night), a reduction in milking frequency and milk yield has been observed in cows managed under pasture-based AMS (Wildridge *et al.*, 2018). Osei-Amponsah *et al.* (2020) reported a decline of up to 14% in milk yield during periods of heat stress in this type of system. However, modifications to the infrastructure (e.g., heat abatement resources) and management in pasture-based AMS farms must be further explored, since the provision of shade and cooling in the pre-milking area may increase the cows' waiting time for milking compared to systems without heat abatement resources (Wildridge *et al.*, 2017). Given the challenges posed by climatic variables, especially heat stress, it is evident that tools enabling a rapid and precise response to changes in cow behaviour, production and health are needed. In this context, the use of monitoring technologies in AMS emerges as a promising strategy to mitigate the challenges faced in grazing systems. Nevertheless, the integration and strategic use of these technologies in the context of pasture-based AMS represents an area that demands further research and investigation.

Energy consumption in pasture-based AMSs

Energy consumption was addressed in only 2% of the articles, highlighting a potential gap in the literature. Despite its numerous benefits, the adoption of pasture-based AMS still faces significant challenges, particularly related to profitability. One of the main limitations is the reduced profitability compared to conventional milking technologies (Shortall *et al.*, 2016). In addition to the high capital cost required for the implementation of the milking robot, the increased energy consumption can also be considered a contributing factor. For example, in the United States, 62% of large farms (above 500 milking cows) with AMS reported an increase in energy consumption (de Lage *et al.*, 2024). This consumption represents between 35 and 40% of the operating cost of AMS (Marques *et al.*, 2023), with 77% of the total energy use allocated to milking (milk pumping, vacuum pumping, water heating and system-related devices), air compression (robotic arms, cleaning of milk lines, entry and exit gates at the robot unit, sorting and post-selection grazing gates) and milk cooling (Shortall *et al.*, 2018). Moreover, electricity consumption is directly related to milking frequency, i.e., the higher the frequency, the greater the energy use. However, this increase may be offset, as higher milk production leads to a dilution of the energy cost per litre of milk, making the system more energy efficient (Shortall *et al.*, 2018). One point to consider in mitigating the increase in energy costs is the use of photovoltaic panels to generate electricity (Weselek *et al.*, 2019), which can be combined with the agricultural system to generate shade for grazing dairy cows (Sharpe *et al.*, 2021). In addition, this system significantly reduces the demand for labour (18% – Jacobs and Siegford, 2012; 21% – de Lage *et al.*, 2024; and 29% – Bijl *et al.*, 2007), which is a relevant compensating factor, as well as enabling greater flexibility in producers' time, less stressful and physically demanding work for the body, easier management of employees, improved herd health and management, and greater involvement and interest from the younger generation (Tse *et al.*, 2018b). It should also be noted that pasture-based dairy production has the potential to add value, serving an expanding niche market that values attributes such as sustainability, animal welfare and the origin of the raw material.

Final considerations

This bibliometric review was conducted to understand the evolution, trends and research topics related to the use of pasture-based AMSs, allowing us to identify challenges and underexplored research opportunities. The bibliometric analysis highlights a field in transition, focusing on production, milk composition, AMS operational efficiency and pasture use, towards a broader approach that integrates sustainability, economic viability, climate conditions, health issues, etc. Despite advances over the last two decades, the literature still lacks applied research on the distance from the pasture area to the milking site, the use of animal monitoring tools, energy consumption and the relationship between pasture and concentrate use. Furthermore, few studies seek to understand how climate change influences the management of AMS in pasture-based systems and its impacts on production indices, milking behaviour and animal behaviour. In this sense, the bibliometric analysis not only describes the field of research on pasture-based

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AMS but also provides insights into new research avenues in this area.

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Data availability. The datasets used in this study can be obtained from the corresponding author upon request.

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References

Aria M and Cuccurullo C (2017) Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics* **11**, 959–975.

Bach A and Cabrera V (2017) Robotic milking: Feeding strategies and economic returns. *Journal of Dairy Science* **100**, 7720–7728.

Bargo F, Muller LD, Delahoy JE and Cassidy TW (2002) Performance of high producing dairy cows with three different feeding systems combining pasture and total mixed rations. *Journal of Dairy Science* **85**, 2948–2963.

Bijl R, Kooistra SR and Hogeveen H (2007) The profitability of automatic milking on Dutch dairy farms. *Journal of Dairy Science* **90**, 239–248.

Bottema J (1992) Automatic milking: Reality. In Ipema AH, Lippus AC, Metz JHM and Rossing W (eds), *Proceedings of the International Symposium on Prospects for Automatic Milking*. Wageningen, the Netherlands: European Association for Animal Production, pp. 63–71. Publication 65.

Castro A, Pereira JM, Amiama C and Bueno J (2012) Estimating efficiency in automatic milking systems. *Journal of Dairy Science* **95**, 929–936.

Clark CEF, Horadagoda A, Kerrisk KL, Scott V, Islam MR, Kaur R and Garcia SC (2013) Grazing soybean to increase voluntary cow traffic in a pasture-based automatic milking system. *Asian-Australasian Journal of Animal Sciences* **27**, 422–430.

Cobo MJ, López-herrera AG, Herrera-viedma E and Herrera F (2011) An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. *Journal of Informetrics* **5**, 146–166.

Cogato A, Brščić M, Guo H, Marinello F and Pezzuolo A (2021) Challenges and tendencies of automatic milking systems (AMS): A 20-years systematic review of literature and patents. *Animals* **11**, 1–21.

Dairy Australia (2025) Situation and Outlook Reports March 2025. Available at https://www.dairyaustralia.com.au/feeding-and-farm-systems/pastures (accessed 4 April 2025).

Dervis H (2019) Bibliometric analysis using bibliometrix an R package. *Journal of Scientometric Research* **8**, 156–160.

de Lage CFA, Marques TC, Bruno DR, Endres MI, Ferreira F, Pires APA, Leão K and de Lima FS (2024) Farmers' Perceptions on implementing automatic milking systems in large USA dairies: Decision-making process, management practices, labor, and herd performance. *Animals* **14**, 218.

DeVries TJ and Penner GB (2022) *Nutritional Opportunities and Challenges with Robot Milked Cows*. Ithaca: Cornell University. Available at https://ecommons.cornell.edu/server/api/core/bitstreams/c016ef96-1d4c-4aa6-a705-71065fe0d73f/content (accessed 21 May 2025).

Eastwood CR and Renwick A (2020) Innovation uncertainty impacts the adoption of smarter farming approaches. *Frontiers in Sustainable Food Systems* **4**, 1–14.

European Commission: Agriculture in Ireland (2025) European Commission: (2025) Agriculture in Ireland. Representation of the European Commission in Ireland. Available at https://ireland.representation.ec.europa.eu/index_en (accessed 27 March 2025).

Farina SR, Baudracco J and Bargo F (2021) Dairy production in diverse regions: Latin America. *Encyclopedia of Dairy Sciences: Third Edition* **2**, 244–252.

Gargiulo JI, Eastwood CR, Garcia SC and Lyons NA (2018) Dairy farmers with larger herd sizes adopt more precision dairy technologies. *Journal of Dairy Science* **101**, 5466–5473.

Gargiulo JI, Lyons NA, Kempton K, Armstrong DA and Garcia SC (2020) Physical and economic comparison of pasture-based automatic and conventional milking systems. *Journal of Dairy Science* **103**, 8231–8240.

Ge P, Xue J, Ru Y, Li Y, Li D, Han P, Li A and Huang J (2025) Intensive rotational grazing has positive effects on productivity of rangeland. *Agriculture, Ecosystems and Environment* **384**, 109558.

Greenall RK, Warren E and Warren M (2004) Integrating Automatic Milking Installations (AMIs) into grazing systems: Lessons from Australia. In Meijering A, Hogevven H and de Koning CJAM (eds), *Automatic Milking: A Better Understanding*. Wageningen, the Netherlands: Wageningen Academic Publishers, pp. 291–296.

Gulati A, Galvin N, Lewis E, Hennessy D, O'Donovan M, McManus JJ, Fenelon MA and Guinee TP (2018) Outdoor grazing of dairy cows on pasture versus indoor feeding on total mixed ration: Effects on gross composition and mineral content of milk during lactation. *Journal of Dairy Science* **101**, 2710–2723.

Gutiérrez-Salcedo M, Martínez MÁ, Moral-Munoz JA, Herrera-Viedma E and Cobo MJ (2018) Some bibliometric procedures for analyzing and evaluating research fields. *Applied Intelligence* **48**, 1275–1287.

Harper MT, Oh J, Giallongo F, Lopes JC, Weeks HL, Faugeron J and Hristov AN (2016) Short communication: Preference for flavored concentrate premixes by dairy cows. *Journal of Dairy Science* **99**, 6585–6589.

Hayes E, Wallace D, O'donnell C, Greene D, Hennessy D, O'shea N, Tobin JT and Fenelon MA (2023) Trend analysis and prediction of seasonal changes in milk composition from a pasture-based dairy research herd. *Journal of Dairy Science* **106**, 2326–2337.

INALE (2019) Encuesta Lechera Nacional (National Dairy Survey). *Instituto Nacional de La Leche*. Available at https://www.inale.org/estadisticas/encuesta-lechera-2019-resultados-definitivos/ (accessed 19 May 2025).

Jacobs JA and Siegford JM (2012) Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. *Journal of Dairy Science* **95**, 2227–2247.

Jago J, Jackson A, Davis K, Wieliczko R, Copeman P, Ohnstad I, Claycomb R and Woolford M (2004) Is automatic milking possible with a 100% pasture diet. In Meijering A, Hogeveen H and de Koning CAM (eds), *Automatic Milking: A Better Understanding*. Netherlands, Wageningen: Brill, Leiden, The Netherlands, p. 307.

John AJ, Clark CEF, Freeman MJ, Kerrisk KL, Garcia SC and Halachmi I (2016) Review: Milking robot utilization, a successful precision livestock farming evolution. *Animal* **10**, 1484–1492.

John AJ, Cullen BR, Oluboyede K, Freeman MJ, Kerrisk KL, Garcia SC and Clark CEF (2019) The effect of pasture quantity temporal variation on milking robot utilization. *Journal of Dairy Science* **102**, 2551–2559.

Kennedy E, Curran J, Mayes B, McEvoy M, Murphy JP and O'Donovan M (2011) Restricting dairy cow access time to pasture in early lactation: The effects on milk production, grazing behaviour and dry matter intake. *Animal* **5**, 1805–1813.

https://doi.org/10.1017/S0022029926102465 Published online by Cambridge University Press

Kertz AF, Darcy BK and Prewitt LR (1981) Eating rate of lactating cows fed four physical forms of the same grain ration. *Journal of Dairy Science* **64**, 2388–2391.

Lessire F, Moula N, Hornick JL and Dufrasne I (2020) Systematic review and meta-analysis: Identification of factors influencing milking frequency of cows in automatic milking systems combined with grazing. *Animals* **10**, 1–23.

Linnenluecke MK, Marrone M and Singh AK (2020) Conducting systematic literature reviews and bibliometric analyses. *Australian Journal of Management* **45**, 175–194.

Lyons NA, Kerrisk KL and Garcia SC (2014) Milking frequency management in pasture-based automatic milking systems: A review. *Livestock Science* **159**, 102–116.

Marques TC, Lage CFA, Bruno DR, Fausak ED, Endres MI, Ferreira FC and Lima FS (2023) Geographical trends for automatic milking systems research in non-pasture-based dairy farms: A scoping review. *Journal of Dairy Science* **106**, 7725–7736.

Matera R, Silva Boloña P and O'Brien B (2024) Randomized-controlled study assessing the effect of milking permission settings and concentrate supplementation on milking frequency and milk yield in a pasture-based automatic milking system. *Journal of Dairy Science* **107**, 6971–6982.

Morales AG, Cockrum RR, Teixeira IAMA, Ferreira G and Hanigan MD (2024) Graduate Student Literature Review: System, plant, and animal factors controlling dietary pasture inclusion and their impact on ration formulation for dairy cows. *Journal of Dairy Science* **107**, 870–882.

Moscovici Joubran A, Pierce KM, Garvey N, Shalloo L and O'Callaghan TF (2021) Invited review: A 2020 perspective on pasture-based dairy systems and products. *Journal of Dairy Science* **104**, 7364–7382.

Nieman CC, Steensma KM, Rowntree JE, Beede DK and Utsumi SA (2015) Differential response to stocking rates and feeding by two genotypes of Holstein-Friesian cows in a pasture-based automatic milking system. *Animal* **9**, 2039–2049.

O'brien B and Hennessy D (2017) Scientific appraisal of the Irish grass-based milk production system as a sustainable source of premium quality milk and dairy products. *Irish Journal of Agricultural and Food Research* **56**, 120–129.

O'Brien D, Moran B and Shalloo L (2017) A national methodology to quantify the diet of grazing dairy cows. *Journal of Dairy Science* **101**, 8595–8604.

O'Callaghan TF, Faulkner H, McAuliffe S, O'Sullivan MG, Hennessy D, Dillon P, Kilcawley KN, Stanton C and Ross RP (2016) Quality characteristics, chemical composition, and sensory properties of butter from cows on pasture versus indoor feeding systems. *Journal of Dairy Science* **99**, 9441–9460.

O'Callaghan TF, Mannion DT, Hennessy D, McAuliffe S, O'Sullivan MG, Leeuwendaal N, Beresford TP, Dillon P, Kilcawley KN, Sheehan JJ *et al.* (2017) Effect of pasture versus indoor feeding systems on quality characteristics, nutritional composition, and sensory and volatile properties of full-fat Cheddar cheese. *Journal of Dairy Science* **100**, 6053–6073.

Osei-Amponsah R, Dunshea FR, Leury BJ, Cheng L, Cullen B, Joy A, Abhijith A, Zhang MH and Chauhan SS (2020) Heat stress impacts on lactating cows grazing australian summer pastures on an automatic robotic dairy. *Animals* **10**(5), 869. https://doi.org/10.3390/ani10050869.

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE and Chou R (2021) The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *The BMJ* **372**.

Pérez-Ramírez E, Delagarde R and Delaby L (2008) Herbage intake and behavioural adaptation of grazing dairy cows by restricting time at pasture under two feeding regimes. *Animal* **2**, 1384–1392.

Phillips JCC (2002) Nutritional behaviour. In Philips CJC (ed), *Cattle Behaviour and Welfare*. Oxford: Blackwell Science Ltd, pp. 12–151.

Ribeiro-Filho HMN, Dall-orsoletta AC, Mendes D and Delagarde R (2021) Dry matter intake and milk production of grazing dairy cows supplemented with corn silage or a total mixed ration offered ad libitum in a subtropical area. *Animal Science Journal* **92**, 1–10.

Roche JR, Berry DP, Bryant AM, Burke CR, Butler ST, Dillon PG, Donaghy DJ, Horan B, Macdonald KA and Macmillan KL (2017) A 100-Year Review: A century of change in temperate grazing dairy systems. *Journal of Dairy Science* **100**, 10189–10233.

Schipper L, Parfitt R, Ross C, Baisden W, Claydon J and Fraser S (2010) Gains and losses in C and N stocks of New Zeland pasture soils depend on land use. *Agriculture, Ecosystems and Environment* **139**, 611–617.

Sharpe KT, Heins BJ, Buchanan ES and Reese MH (2021) Evaluation of solar photovoltaic systems to shade cows in a pasture-based dairy herd. *Journal of Dairy Science* **104**, 2794–2806.

Shortall J, O'Brien B, Sleator RD and Upton J (2018) Daily and seasonal trends of electricity and water use on pasture-based automatic milking dairy farms. *Journal of Dairy Science* **101**, 1565–1578.

Shortall J, Shalloo L, Foley C, Sleator RD and O'Brien B (2016) Investment appraisal of automatic milking and conventional milking technologies in a pasture-based dairy system. *Journal of Dairy Science* **99**, 7700–7713.

Spörndly E and Åsberg T (2006) Eating rate and preference of different concentrate components for cattle. *Journal of Dairy Science* **89**, 2188–2199.

Sporndly E and Wredle E (2004) Automatic milking and grazing—Effects of distance to pasture and level of supplements on milk yield and cow behavior. *Journal of Dairy Science* **87**, 1702–1712.

Talukder S, Qiu D, Thomson PC, Cheng L and Cullen BR (2023) Impact of heat stress on dairy cow rumination, milking frequency, milk yield and quality in a pasture-based automatic milking system. *Animal Production Science* **64**, AN22334.

Timlin M, Tobin JT, Brodkorb A, Murphy EG, Dillon P, Hennessy D, O'donovan M, Pierce KM and O'callaghan TF (2021) The impact of seasonality in pasture-based production systems on milk composition and functionality. *Foods* **10**, 1–32.

Tse C, Barkema HW, Devries TJ, Rushen J and Pajor EA (2018a) Impact of automatic milking systems on dairy cattle producers' reports of milking labour management, milk production and milk quality. *Animal* **12**, 2649–2656.

Tse C, Barkema HW, DeVries TJ, Rushen J, Vasseur E and Pajor EA (2018b) Producer experience with transitioning to automatic milking: Cow training, challenges, and effect on quality of life. *Journal of Dairy Science* **101**, 9599–9607.

Wales WJ and Kolver ES (2017) Challenges of feeding dairy cows in Australia and New Zealand. *Animal Production Science* **57**, 1366–1383.

Wang T and Kreuter U (2024) Revisiting the Rotational Grazing Dilemma: The role of terminology in system comparison outcomes. *Rangeland Ecology and Management* **98**, 246–255.

Weselek A, Ehmann A, Zikeli S, Lewandowski I, Schindele S and Hogy P (2019) Agrophotovoltaic systems: Applications, challenges, and opportunities. A review. *Agronomy For Sustainable Development* **39**, 35.

Wildridge AM, Garcia SC, Thomson PC, Jongman EC, Clark CEF and Kerrisk KL (2017) The impact of a shaded pre-milking yard on a pasture-based automatic milking system. *Animal Production Science* **57**, 1219–1225.

Wildridge AM, Thomson PC, Garcia SC, John AJ, Jongman EC, Clark CEF and Kerrisk KL (2018) Short communication: The effect of temperature-humidity index on milk yield and milking frequency of dairy cows in pasture-based automatic milking systems. *Journal of Dairy Science* **101**, 4479–4482.

Yan MJ, Humphreys J and Holden NM (2013) The carbon footprint of pasture-based milk production: Can white clover make a difference? *Journal of Dairy Science* **96**, 857–865.

https://doi.org/10.1017/S0022029926102465 Published online by Cambridge University Press