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INTRODUCTION

Preamble

Until now, there have been several suggestions regarding the definition of animal welfare. Presently, the dominant interpretation associates an animal's welfare with its optimal biological performance[1]. According to the World Organization for Animal Health, an animal is considered to be in a positive state when it enjoys good health, receives sufficient nourishment, resides in a safe and comfortable environment, can engage in natural behaviours, and is not exposed to unfavorable conditions, distress, fear, or pain.

According to Dawkins (2017), the most straightforward and applicable definition of "good welfare" is achieved when an animal is healthy and its fundamental needs are met.[1] This perspective highlights the significance of prioritizing animal health, which involves factors such as nutrition, hydration, and injury prevention, all contributing to their overall well-being. Furthermore, acknowledging the animal's preferences emphasizes that welfare extends beyond mere physical health. This dual approach is advantageous for its simplicity, as it considers the expression of natural behaviour and individual characteristics not only within the species but also at the individual level[1].

. In 1993, John Webster articulated the five freedoms of animals, highlighting the multi-dimensional significance of animal welfare[2].According to these freedoms, animals should be free from hunger, malnutrition, and thirst, ensuring access to fresh water and a diet conducive to maintaining optimal health. They should also be free from exposure and discomfort, provided with suitable shelter and a comfortable resting space. Furthermore, it is essential to guarantee

1. Dawkins, Marian Stamp. “Animal Welfare and Efficient Farming: Is Conflict Inevitable?” *Animal Production Science* 57, no. 2 (2017): 201. https://doi.org/10.1071/an15383.
2. Webster, John. *Animal welfare*. Blackwell Scientific, 1995.

freedom from injury, pain, and disease through preventive measures and prompt diagnosis and treatment. Moreover, animals must be granted freedom from distress and, fear achieved through the implementation of conditions and practices that alleviate mental suffering[3].

Moreover, it is crucial to ensure that animals have the opportunity to exhibit their natural behaviours, which can be facilitated by providing sufficient space, suitable amenities, and interaction with other animals of the same species. The welfare of animals depends on how their living conditions are perceived, which includes both physical and social aspects. To assess the welfare of farms, it is advisable to use a comprehensive range of indicators that take into account the production methods, farming practices, and the health and behaviour of the animals. Justifying the selection of these indicators is essential for effectively evaluating the welfare status of individual farms.

Initially, closely monitoring animal behaviour is a fundamental aspect of evaluating their welfare. This includes observing natural behaviours, detecting abnormal behaviours indicative of stress or discomfort, and gauging overall activity levels. Animals' choices in various environments and their stress levels during these behavioural decisions can shed light on whether they have genuine access to their essential needs. With evolving welfare standards, there's a pressing need for non-invasive technology and corresponding methodologies to assess behaviour and well-being. Numerous studies highlight animal behavioural responses as valuable indicators for welfare assessment. Integrating behavioural measurements into welfare assessments involves comparing animals' behaviour in different housing systems with established descriptions of normal behavioural patterns. This approach aids in identifying whether animals are well-adapted to the production system or are showing signs of distress. For more precise welfare

3. Mellor, DJ, and NJ Beausoleil. “Extending the ‘Five Domains’ Model for Animal Welfare Assessment to Incorporate Positive Welfare States.” *Animal Welfare* 24, no. 3 (August 2015): 241–53. https://doi.org/10.7120/09627286.24.3.241.

assessments, it's vital to consider the distinct behavioural traits of genetic lines, recognizing that different lines may react differently to environmental challenges[4].

Furthermore, routine health assessments, which include evaluating body condition, disease prevalence, and reproductive success, play a vital role in assessing animals' overall health and fitness. Disease is particularly important in welfare assessments because it's often associated with adverse experiences like pain, discomfort, or anxiety. An indicator for welfare assessments at the exploitation level could be the prevalence and severity of specific health issues within the herd, determined through methods such as clinical examinations. Furthermore, significant events like historical animal deaths, obtained from herd data and owner interviews, are also taken into consideration during the evaluation process.[4]

Lastly, analyzing physiological indicators, such as heart rate, body temperature, and blood parameters like cortisol levels or acute phase proteins, can provide valuable insights into the well-being or stress levels of animals. However, it's essential to interpret these measures considering the species and specific circumstances. Physiological measurements can offer clues about poor welfare. For instance, an elevated heart rate, increased adrenal activity following an ACTH challenge, or a weakened immunological response post-challenge may indicate compromised welfare compared to individuals without such changes. Careful consideration is needed when interpreting these findings, similar to other measures discussed. Impairment in immune system function and specific physiological alterations might indicate a pre-pathological condition. Since higher brain centers play a significant role in coping

4. Sejian, Veerasamy, Jeffrey Lakritz, Thaddeus Ezeji, and Rattan Lal. "Retracted: Assessment Methods and Indicators of Animal Welfare." *Asian Journal of Animal and Veterinary Advances* 6, no. 4 (March 15, 2011): 301–15. https://doi.org/10.3923/ajava.2011.301.315.

mechanisms, a thorough welfare assessment should also include evaluations of brain function[5].

Assessing the housing conditions of animals, encompassing factors like living space quality, cleanliness, and availability of appropriate food and water, is crucial. A favorable and stimulating environment is key to promoting positive welfare. It's important to recognize that evaluating animal welfare can be complex, and employing various approaches may be necessary for a thorough understanding. Additionally, cultural and ethical factors can significantly influence the interpretation of welfare indicators. Ongoing research efforts aim to improve and develop methods for assessing and ensuring the well-being of animals across different environments[4].

Animal welfare can be evaluated using various metrics. Combining behaviour measurements with physiological, immunological, productive, and reproductive parameters is deemed the most comprehensive approach for obtaining thorough and detailed information [6,7].

Health-related quality of life can be assessed from three perspectives: physical, social, and psychological. "Physical" pertains to the animal's perception and capability to fulfill daily activities and responsibilities, "social" involves the ability to interact and communicate with other animals, and "psychological" concerns the mental well-being of the animal[8].

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7. McLennan, Krista M., Carlos J.B. Rebelo, Murray J. Corke, Mark A. Holmes, Matthew C. Leach, and Fernando Constantino-Casas. “Development of a Facial Expression Scale Using Footrot and Mastitis as Models of Pain in Sheep.” *Applied Animal Behaviour Science* 176 (March 2016): 19–26. https://doi.org/10.1016/j.applanim.2016.01.007
8. Camilleri-Brennan J, Steele RJ. Measurement of quality of life in surgery. J R Coll Surg Edinb. 1999 Aug;44(4):252-9. PMID: 10453149.
9. Φθενάκης Γ. *Αναπαραγωγή μικρών μηρυκαστικών*. Εκδόσεις Τσιόλα ,(Δεκέμβριος 2011).

Mastitis

Mastitis, an inflammation of the mammary gland, is triggered by various factors. It is characterized by an increase in white blood cells in milk and pathological changes in mammary tissue. Mastitis poses a significant infection risk in dairy ruminants, leading to considerable economic repercussions. Typically, the disease occurs when bacteria enter the mammary gland through the teat. In favorable internal conditions within the mammary gland, these microorganisms multiply, causing irritation to the mammary ducts and triggering an inflammatory response. Mastitis stands as the most significant disease affecting the mammary gland[9].

Several studies have explored the impact of clinical mastitis. Detrimental consequences include significant reductions in milk yield, decreased milk quality, escalated expenses for treatment, veterinary care and additional labour. Furthermore, affected animals have a higher risk for mortality or culling. Clinical mastitis serves as a primary driver for antimicrobial usage on dairy farms, despite the fact that antimicrobial treatment may not be necessary in all instances of clinical mastitis[10].

Various risk factors have been identified as significant contributors to the occurrence of bovine mastitis, encompassing pathogen-related, host-related or environmental factors.

These elements are crucial considerations in mastitis control programs. Contagious pathogens like Staphylococcus aureus and Streptococcus agalactiae, along with less common species such as Mycoplasma bovis and Corynebacterium bovis, play significant roles. Various bacterial species, including Streptococcus spp. (e.g., Strep. uberis), coliforms (e.g., E. coli,

10. Jamali, Hossein, Herman W. Barkema, Mario Jacques, Eve-Marie Lavallée-Bourget, François Malouin, Vineet Saini, Henrik Stryhn, and Simon Dufour. "Invited Review: Incidence, Risk Factors, and Effects of Clinical Mastitis Recurrence in Dairy Cows." *Journal of Dairy Science* 101, no. 6 (June 2018): 4729–46. https://doi.org/10.3168/jds.2017-13730

Klebsiella spp., Enterobacter spp.), and Pseudomonas spp., have been identified as causes of environmental mastitis[11].

Genetic factors and dairy cow breeding also influence susceptibility or resistance to mastitis. Additionally, the udder's structure, such as large funnel-shaped teats or pendular-shaped udders and blind quarters after calving, can increase the risk of sub-clinical mastitis[12].

The welfare and health of animals are significantly influenced by the environmental conditions and management practices within herds. Maintaining cleanliness and ensuring comfort for the herd can effectively lower both the frequency and severity of mastitis cases [13].

In order to effectively manage clinical mastitis in cattle, it is crucial to have reliable methods for detecting and assessing the severity of infection. The implementation of a clinical evaluation system, which considers both local and systemic signs of the disease, has been identified as the most sensitive and accurate classification system for clinical mastitis, with minimal false-positive results[14].

The yearly occurrence rate of clinical mastitis in dairy farms should ideally remain below 2% to 3%. However, under unfavourable husbandry conditions, this rate can escalate significantly, sometimes even reaching up to 30%[15-16]. In the majority of cattle farms, the occurrence

11. M, Shaheen, and Tantary HA. "A Treatise on Bovine Mastitis: Disease and Disease Economics, Etiological Basis, Risk Factors, Impact on Human Health, Therapeutic Management, Prevention and Control Strategy." *Advances in Dairy Research* 04, no. 01 (2015). https://doi.org/10.4172/2329-888x.1000150.
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13. Weigel K.A, Shook G.E. "Genetic selection for mastitis resistance." *Vet Clin Food Anim Pract.* 34:457–72 (2018). doi: 10.1016/j.cvfa.2018.07.001.
14. Wenz, John R., George M. Barrington, Franklyn B. Garry, R. Page Dinsmore, and Robert J. Callan. "Use of Systemic Disease Signs to Assess Disease Severity in Dairy Cows with Acute Coliform Mastitis." *Journal of the American Veterinary Medical Association* 218, no. 4 (February 15, 2001): 567–72. https://doi.org/10.2460/javma.2001.218.567.
15. Menzies, Paula I., and Siti Z. Ramanoon. "Mastitis of Sheep and Goats." *Veterinary Clinics of North America: Food Animal Practice* 17, no. 2 (July 2001): 333–58. https://doi.org/10.1016/s0749-0720(15)30032-3.
16. Fitzpatrick, J., M. Scott, and A. Nolan. "Assessment of Pain and Welfare in Sheep." *Small Ruminant Research* 62, no. 1–2 (March 2006): 55–61. https://doi.org/10.1016/j.smallrumres.2005.07.028.

rate of clinical mastitis typically falls between 13 to 40 cases per 100 cows annually, varying across countries and types of housing[10-17].

Previous studies have examined mild and moderate cases of clinical mastitis, observing changes in pain thresholds, rectal temperature, respiratory rate, heart rate, altered stance and in affected cows compared to healthy cows. Cows with moderate clinical mastitis exhibited higher heart rates, rectal temperatures, and respiratory rates compared to those with mild clinical mastitis and healthy cows. Additionally, cortisol levels and somatic cell counts were significantly elevated in mastitic cows compared to healthy ones. Affected cows also displayed increased hock-to-hock distances and heightened sensitivity to mechanical pressure stimuli on the affected leg, indicating altered stance and pain processing due to inflammation[18].

However, clinical mastitis is typically identified during milking through direct observation of the milk and mammary gland. With the ongoing trend of increasing farm sizes and decreasing available labour, dairy producers are increasingly reliant on automated systems rather than visual detection. This shift reduces the time spent on individual cow observation, increasing the risk of overlooking or misdiagnosing mild or moderate cases of clinical mastitis [19]. [6]

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17. Bergonier, Dominique, Ren﷽e de Cr﷽moux, Rachel Rupp, Gilles Lagriffoul, and Xavier Berthelot. "Mastitis of Dairy Small Ruminants." *Veterinary Research* 34, no. 5 (September 2003): 689–716. https://doi.org/10.1051/vetres:2003030.
18. Fitzpatrick J,NolanA,Young F, et al. "Objective measurement of pain and inflammation in dairy cows with clinical mastitis.''Proceedings of the 9th Symposium of the International Society for Veterinary Epidemiology and Economics. Colorado, USA, 2000
19. Petersson-Wolfe, Christina S., Kenneth E. Leslie, and Turner H. Swartz. "An Update on the Effect of Clinical Mastitis on the Welfare of Dairy Cows and Potential Therapies." *Veterinary Clinics of North America: Food Animal Practice* 34, no. 3 (November 2018): 525–35. https://doi.org/10.1016/j.cvfa.2018.07.006.

Mastitis through individual and social behaviour

Illness can significantly contribute to pain and distress in animals, influencing their behaviour, undermining their welfare, and detrimentally impacting production. Clinical mastitis, for example, is a painful disease affecting animals, characterized by inflammation in the affected mammary gland due to pathogen invasion[20]. Moreove, lesions within the teat canal, often stemming from the disease, can cause discomfort to afflicted animals. In severe cases, rapid onset of mastitis infections can occur, potentially leading to the death of affected animals[21].

The concept of sickness behaviour refers to a natural behavioural response aimed at combating illness, which has been preserved through evolution. When the body is invaded by pathogens, it initiates an energy-demanding immune reaction, such as fever, to enhance the effectiveness of the immune system. Consequently, there are behavioural changes, including reduced activity, loss of appetite, feelings of sadness, and decreased grooming, all aimed at supporting the immune response. From an evolutionary perspective, ruminants, being prey animals, have a tendency to conceal signs of pain and weakness, even in the presence of harmful stimuli. This resilience complicates the identification of sickness behaviour and, consequently, the detection of disease[19].[7]

20. Gelasakis, A.I., V.S. Mavrogianni, I.G. Petridis, N.G.C. Vasileiou, and G.C. Fthenakis. "Mastitis in Sheep – the Last 10 Years and the Future of Research." *Veterinary Microbiology* 181, no. 1–2 (December 2015): 136–46. https://doi.org/10.1016/j.vetmic.2015.07.009.
21. Mavrogianni, V.S., G.C. Fthenakis, A.R. Burriel, P. Gouletsou, N. Papaioannou, and I.A. Taitzoglou. "Experimentally Induced Teat Stenosis in Dairy Ewes: Clinical, Pathological and Ultrasonographic Features." *Journal of Comparative Pathology* 130, no. 1 (January 2004): 70–74. https://doi.org/10.1016/s0021-9975(03)00070-7.

Assessing the pain and welfare implications for dairy ruminants with mild to moderate clinical mastitis is more complex than for severe cases. Recent research indicates that ruminants affected by mastitis demonstrate signs of discomfort. These signs include restlessness, heightened kicking during milking, decreased appetite, and changes in behaviour both before and after diagnosis when compared to healthy animals. For example, affected cows tend to eat less due to slower intake rates, visit the feeder less often, and show decreased competitiveness for feed. Additionally, they spend less time resting compared to healthy cows following diagnosis [19].

Mechanical hyperalgesia, which refers to pain or allodynia triggered by touch or brushing, is a potential symptom of mastitis. This supports the notion that the condition is indeed painful and could influence the behavioural state of the animal[22].Mastitis, whether clinical or subclinical, can alter the behaviour of affected ewes, potentially disrupting the behaviour of the entire herd. Pain and discomfort, predominant symptoms of clinical mastitis, are regarded as significant limiting factors for animal welfare and quality of life[7].

Mastitis and individual 'physical' status

General alterations in animal behaviour resulting from inflammation have been documented. Reduced feed intake and activity levels are observed behavioural changes in response to various diseases across animal species, including ovine mastitis. In cases of hyperacute mastitis, characteristic clinical signs include fever followed by hypothermia, depression, anorexia, dehydration, along with observable clinical changes in the affected mammary gland [15-23].[8]

22. [8] Dolan, Sharron, and Andrea M Nolan. "Behavioural Evidence Supporting a Differential Role for Group I and II Metabotropic Glutamate Receptors in Spinal Nociceptive Transmission." *Neuropharmacology* 39, no. 7 (June 2000): 1132–38. https://doi.org/10.1016/s0028-3908(99)00200-2.

Research on ewes with chronic mastitis has identified mechanical hyperalgesia as a potential behavioural manifestation[16-22].

Assessing various behavioural measures may be necessary to identify pain associated with mastitis. Illness or pain in an animal often manifests through changes in posture or gait. Pain or depression, with or without inflammation, can lead to lameness, reluctance to walk, and a tilting head gait. Notably, lameness on the side of the affected mammary gland can aid in identifying ewes with mastitis within a flock [7-20]. Additionally, general lethargy and apathy are commonly seen as indicative of pain and severe illness in animals. Therefore, behavioural studies typically involve monitoring reduced activity, such as altered gait or responsiveness, and a reluctance to move away from the handler[24,25]. When these clinical signs are observed, further investigation into differential diagnosis among various diseases is warranted.

In cows, manifestations of sickness behaviour during mastitis have been consistently observed. Specifically, alterations in lying time, activity, and feeding patterns have been extensively studied[25- 26]. Siivonen et al. (2011) presented findings indicating that cows afflicted with mastitis tend to spend more time standing up and lying on the side opposite the affected mammary gland compared to previous days[25]. This behavioural change, not typically associated with classical sickness behaviour, is attributed to discomfort in the infected mammary gland while lying down.

23. Fragkou, I.A., C.M. Boscos, and G.C. Fthenakis. “Diagnosis of Clinical or Subclinical Mastitis in Ewes.” *Small Ruminant Research* 118, no. 1–3 (May 2014): 86–92. https://doi.org/10.1016/j.smallrumres.2013.12.015.

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Additionally, Rousing et al. (2004) demonstrated that cows with teat lesions may exhibit aggressive reactions during milking, a response that could also be anticipated in cases of mastitis[27]. While there is a lack of systematic data on relevant behaviour in sheep, anecdotal evidence from veterinarians and farmers suggests that ewes with mastitis exhibit similar behavioural patterns[24].

Mastitis and social behaviour in farms

In a dairy farm, established social order, rank, dominance, and hierarchy serve as potential indicators to confirm welfare status. For instance, ewes with higher milk production typically have priority access to the milking parlor compared to those with lower milk production, establishing a hierarchical order and preference for specific sides or places[28]. Consequently, any unusual alteration in the order of animal approach to the parlor may often be linked to health issues, including mastitis, prompting further examination[29].[9]

In cows, Paranhos da Costa and Broom (2001) have illustrated that a significant number of animals exhibit consistent habituation in their preference for a particular side in the milking parlor[30]. The ability to choose a preferred position and side in the parlor is an important indicator of comfort during milking. Hence, being prevented from accessing the habitual side due to

26. [9] Medrano-Galarza, C., J. Gibbons, S. Wagner, A.M. de Passillé, and J. Rushen. "Behavioural Changes in Dairy Cows with Mastitis." *Journal of Dairy Science* 95, no. 12 (December 2012): 6994–7002. https://doi.org/10.3168/jds.2011-5247.
27. Rousing, Tine, Marianne Bonde, Jens Henrik Badsberg, and Jan Tind Sørensen. "Stepping and Kicking Behaviour during Milking in Relation to Response in Human–Animal Interaction Test and Clinical Health in Loose Housed Dairy Cows." *Livestock Production Science* 88, no. 1–2 (June 2004): 1–8. https://doi.org/10.1016/j.livprodsci.2003.12.001
28. Margetínová, J.; Brouček, J.; Apolen, D.; Mihina, S. "Relationship between age, milk production and order of goats during au-tomatic milking." Czech *J. Anim. Sci*. 2003, 48, 257-264
29. Wasilewski, Anja. "Demonstration and Verification of a Milking Order in Dairy Sheep and Its Extent and Consistency." *Applied Animal Behaviour Science* 64, no. 2 (June 1999): 111–24. https://doi.org/10.1016/s0168-1591(99)00032-5.

health or social constraints could lead to stress responses similar to those observed when animals are milked in an unfamiliar environment [29-31]. Consequently, deviation from the habitual milking position due to inflammation may be a crucial factor for dairy animals, and the deprivation of their preferred side and stance could result in stress and a subsequent decrease in milk yield.

Hence, mastitis, being a source of discomfort and pain, has the potential to influence the overall motivation and movement of affected animals, along with their milk production. This could lead to a disruption of the usual milking order, causing distress not only to the impacted ewes but also to the entire flock.

The detrimental impact of mastitis on both the quality and quantity of milk is reportedly more pronounced in ewes compared to cows[32]. Extensive documentation exists regarding the sequential decrease in milk production and quality in dairy ewes afflicted with mastitis, with the severity of the condition depending on whether one or both mammary glands are involved. In cases of bilateral mastitis, reductions of up to 60% in milk yield have been reported in ewes[33,34,35]. [10]

30. [10]Paranhos da Costa, Mateus J.R, and Donald M Broom. "Consistency of Side Choice in the Milking Parlour by Holstein–Friesian Cows and Its Relationship with Their Reactivity and Milk Yield." *Applied Animal Behaviour Science* 70, no. 3 (January 2001): 177–86. https://doi.org/10.1016/s0168-1591(00)00158-1.
31. Bruckmaier, Rupert M., Dieter Schams, and Jürg W. Blum. "Milk Removal in Familiar and Unfamiliar Surroundings: Concentrations of Oxytocin, Prolactin, Cortisol and *β*–Endorphin." *Journal of Dairy Research* 60, no. 4 (November 1993): 449–56. https://doi.org/10.1017/s0022029900027813
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33. Marogna, Gavino, Sandro Rolesu, Stefano Lollai, Sebastiana Tola, and Guido Leori. "Clinical Findings in Sheep Farms Affected by Recurrent Bacterial Mastitis." *Small Ruminant Research* 88, no. 2–3 (February 2010): 119–25. https://doi.org/10.1016/j.smallrumres.2009.12.019.
34. McCarthy, F. D., J. B. Lindsey, M. T. Gore, and D. R. Notter. "Incidence and Control of Subclinical Mastitis in Intensively Managed Ewes." *Journal of Animal Science* 66, no. 11 (1988): 2715. https://doi.org/10.2527/jas1988.66112715x.
35. Gonzalo, C., A. Ariznabarreta, J.A. Carriedo, and F. San Primitivo. "Mammary Pathogens and Their Relationship to Somatic Cell Count and Milk Yield Losses in Dairy Ewes." *Journal of Dairy Science* 85, no. 6 (June 2002): 1460–67. https://doi.org/10.3168/jds.s0022-0302(02)74214-8.

Several studies have also highlighted consequential growth restrictions and significantly diminished growth rates in lambs nursed by affected ewes. This has been attributed to both the reduced quantity and deficient nutritional quality of milk from affected ewes[33,36,37].

According to Pickup and Dwyer (2001), ewes experiencing subclinical mastitis exhibit increased vocalization and decreased head-up posture behaviours, which are typically used to call their lambs for suckling[38]. Interestingly, despite the expected discomfort, the behaviour of hindering sucking, which would indicate ewe discomfort, was actually reduced in challenged ewes. These alterations in behaviour suggest compromised ewe welfare as a result of subclinical mastitis[39]. Research has demonstrated that suckling behaviour is a crucial aspect of the bond between ewes and lambs, playing a significant role in the survival and growth of newborns[40]. Gougoulis et al. (2008) have presented compelling evidence indicating that subclinical mastitis can disrupt suckling behaviour, affecting both ewes and lambs[39]. Ewes with subclinical mastitis in one mammary gland exhibited a reduced frequency of calling lambs to suckle and spent less time suckling. Additionally, lambs showed a heightened preference to suckle more frequently from the unaffected mammary gland. Consequently, changes in the typical udder side preference were observed in ewes with subclinical mastitis. In severe cases, an increase in lamb mortality has been directly linked to mastitis in the dams due to the direct impact of milk deprivation[41].

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36. Torres-Hernandez, Glafiro, and William Hohenboken. “Genetic and Environmental Effects on Milk Production, Milk Composition and Mastitis Incidence in Crossbred Ewes.” *Journal of Animal Science* 49, no. 2 (August 1, 1979): 410–17. https://doi.org/10.2527/jas1979.492410x.
37. Fthenakis, G.C., and J.E.T. Jones. “The Effect of Experimentally Induced Subclinical Mastitis on Milk Yield of Ewes and on the Growth of Lambs.” *British Veterinary Journal* 146, no. 1 (January 1990): 43–49. https://doi.org/10.1016/0007-1935(90)90075-e.
38. Pickup, H. E., and C. M. Dwyer. "Does variation in the onset of maternal behaviour affect the strength of association between ewes and their lambs." *Proceedings of 35th International Congress of the International Society for Applied Ethology,* 2001, USA..
39. Gougoulis, D.A., I. Kyriazakis, N. Papaioannou, E. Papadopoulos, I.A. Taitzoglou, and G.C. Fthenakis. “Subclinical Mastitis Changes the Patterns of Maternal–Offspring Behaviour in Dairy Sheep.” *The Veterinary Journal* 176, no. 3 (June 2008): 378–84. https://doi.org/10.1016/j.tvjl.2007.02.024

According to Ewbank and Hess (1967-1974), single lambs do not exhibit a preference for sucking from a specific mammary gland of their dam[42,43]. This finding was supported by Gougoulis et al. (2008) among lambs of ewes with mastitis prior to infection. However, after the challenge, these lambs altered their behaviour and began to suckle from the uninoculated gland of their dam more frequently[39.]. The frequency and duration of sucking were closely related to the milk yield of the infected glands. This change in behaviour was observed three days after infection, coinciding with the onset of milk yield reduction in subclinical mastitis, which typically occurs within the first day after infection. This suggests that lambs may quickly sense that the infected gland cannot meet their milk requirements[38]. The taste of milk from mammary glands could potentially influence lamb preference[44]. Differences in the frequency of sucking attempts and initiation of sucking bouts indicate that lambs distinguish between the two glands of their dam, approaching the healthy gland more often. The reduction in milk yield observed in subclinical mastitis is attributed to the destruction of glandular elements by invading microorganisms[37]. Gougoulis et al. (2008) further confirmed through bacteriological, cytological, and histopathological examinations that subclinical mastitis leads to changes in maternal-offspring behaviour patterns[39].[11]

Control of mastitis distress and discomfort

40. Dwyer, C.M. “Behavioural Development in the Neonatal Lamb: Effect of Maternal and Birth-Related Factors.” *Theriogenology* 59, no. 3–4 (February 2003): 1027–50. https://doi.org/10.1016/s0093-691x(02)01137-8.
41. Watson, D.J., and J.F. Buswell. “Modern Aspects of Sheep Mastitis.” *British Veterinary Journal* 140, no. 6 (November 1984): 529–34. https://doi.org/10.1016/0007-1935(84)90003-4
42. [11] Ewbank, Roger. “Nursing and Suckling Behaviour amongst Clun Forest Ewes and Lambs.” *Animal Behaviour* 15, no. 2–3 (April 1967): 251–58. https://doi.org/10.1016/0003-3472(67)90007-3.
43. Hess, Christine E., H. B. Graves, and L. L. Wilson. “Individual Preweaning Suckling Behaviour of Single, Twin and Triplet Lambs.” *Journal of Animal Science* 38, no. 6 (June 1, 1974): 1313–18. https://doi.org/10.2527/jas1974.3861313x.
44. Oliveira, et al. "Composition and sensory evaluation of whole yogurt produced from milk with different somatic cell counts." *Australian Journal of Dairy Technology* 57.3 (2002): 192.

Due to the difficulties in accurately identifying and characterizing the beginning stages of illness in cases of naturally occurring clinical mastitis, researchers have developed models to induce intramammary inflammation in dairy cattle. Effective treatment of clinical mastitis relies on having dependable methods for detecting and classifying the severity of infection. Implementing a clinical evaluation system that considers both local and systemic signs of disease has proven to be the most sensitive and accurate approach for classifying clinical mastitis, with minimal false-positive results[19].

Ensuring effective management of pain and distress is essential during the treatment of clinical mastitis, as insufficient use of analgesics could jeopardize the welfare of affected animals[45]. However, administering analgesic medications to ruminants poses numerous challenges, such as the cost of the drugs, extended withdrawal periods for these pharmaceutical agents, and reluctance to use drugs off-label[46]. The challenge of identifying and quantifying pain and discomfort in farm animals has been consistently highlighted as a limiting factor in welfare assessment in various previous studies[47-48].

As previously noted, ruminants afflicted with mastitis may at times receive inadequate or no treatment for pain and distress, and ineffective use of analgesics in mastitis cases could potentially compromise the welfare of these animals. On this way, we need to explain the term pain. In general, pain is a subjective experience rooted in human perception and can differ from person to person. The International Association for the Study of Pain has broadly defined pain

45. Huxley, J. N., and H. R. Whay. "Current Attitudes of Cattle Practitioners to Pain and the Use of Analgesics in Cattle." *Veterinary Record* 159, no. 20 (November 2006): 662–68. https://doi.org/10.1136/vr.159.20.662.
46. Lizarraga, I, and JP Chambers. "Use of Analgesic Drugs for Pain Management in Sheep." *New Zealand Veterinary Journal* 60, no. 2 (March 2012): 87–94. https://doi.org/10.1080/00480169.2011.642772
47. Koltzenburg, Martin, Hermann O. Handwerker, and H.Erik Torebjörk. "The Ability of Humans to Localise Noxious Stimuli." *Neuroscience Letters* 150, no. 2 (February 1993): 219–22. https://doi.org/10.1016/0304-3940(93)90540-2.
48. Flecknell, P. "Analgesia from a Veterinary Perspective." *British Journal of Anaesthesia* 101, no. 1 (July 2008): 121–24. https://doi.org/10.1093/bja/aen087.

as ‘an unpleasant sensory and emotional encounter associated with actual or potential tissue damage or described in terms of such damage’. This definition is broad and can be interpreted in various ways. Individuals may perceive pain differently, posing a significant challenge in its characterization. While humans can express their pain verbally, assessing pain in animals relies on observing their behavioural and physiological reactions. These reactions can vary depending on species, individual animals, disease stages, and the nature of the condition, be it acute or chronic. Consequently, defining pain remains a contentious matter. It's important to distinguish between pain behaviour and sickness behaviour as separate concepts. However, in instances of inflammatory diseases like mastitis, these behavioural changes may intersect[19].[13]

Perception of pain in dairy animals with mastitis

Bovine mastitis, an inflammatory disease primarily caused by bacterial infection, is commonly regarded as painful. Severe clinical instances of mastitis are easily recognizable due to the evident signs of discomfort displayed by the animal. These signs may include a depressed appearance, weight loss, reduced milk yield, decreased social interactions, and abnormal postures. Nonetheless, mild to moderate instances of mastitis often lack overt signs of pain, and these milder cases occur much more frequently. Consequently, there's a significant possibility that numerous animals may be experiencing pain that goes unnoticed. In many cases, the failure to detect behavioural alterations signaling animal discomfort leads to the oversight of pain. However, there is a consensus that severe mastitis is undeniably painful in dairy cattle[19].

Non-steroidal anti-inflammatory drugs are commonly included in therapeutic regimens for farm animals, including those affected by mastitis[49]. Their usage is typically reserved for

49. Christie, H. The veterinary uses of a non-steroidal anti-inflammatory agent: flunixin meglumine. *Br. Vet. J.* 1988, Suppl. 1, 8.

animals displaying severe clinical symptoms or systemic manifestations, such as anorexia or lethargy. The infrequent use of non-steroidal anti-inflammatory drugs for treating sheep may ultimately lead to increased costs for farmers, longer withdrawal periods for drugs, and a lack of licensed analgesic products for sheep[16]. However, it's worth noting that the beneficial effects of administering flunixin for mastitis, leading to a reduction in relevant clinical symptoms and an improvement in the overall condition of affected ewes, have been documented[50].[14]

Research has detailed the pharmacokinetics of various non-steroidal anti-inflammatory drugs (NSAIDs), including flunixin and carprofen, in sheep. Lizarraga and Chambers (2012) underscored the importance of timing in administering analgesia, noting that most drugs exhibit greater effectiveness when given before the onset of inflammation[46]. They advocate for the proactive use of NSAIDs in situations where progressive hyperalgesia due to inflammation is anticipated in sheep medicine. Administering analgesics before the establishment of a painful condition is more efficacious, and medications should be given promptly upon the development of inflammation[46].

Mastitis and welfare assessment

Mastitis can result in significant financial losses in sheep flocks, particularly in dairy operations. However, with the implementation of suitable therapeutic protocols, it is feasible to manage and mitigate these issues effectively.

The advancement in animal welfare assessment and indicators provides a more holistic approach to health concerns compared to the traditional resource-based analysis. By

50. [14] Fthenakis, G.C. "Field Evaluation of Flunixin Meglumine in the Supportive Treatment of Ovine Mastitis." *Journal of Veterinary Pharmacology and Therapeutics* 23, no. 6 (December 2000): 405–7. https://doi.org/10.1046/j.1365-2885.2000.00284.x.

examining mastitis incidents and causes within the national flock, epidemiological and demographic welfare indices can be assessed. This methodology can deepen our comprehension of the disease's impact on sheep welfare, transcending conventional considerations focused solely on economic and clinical factors. Investigating the individual mechanisms of sheep in regulating their interaction with the environment could offer insights, thereby decoding this interaction[51,52].

The AWIN project was initiated in 2015 to address animal welfare concerns[53]. The project's outcomes have led to the development of monitoring systems based on individual measures, such as behaviour recording, laboratory variables, or a combination of husbandry assets and individual measures. These systems aim to provide a comprehensive evaluation of animal welfare in sheep flocks. In the established welfare assessment protocols for sheep, a two-level approach can be implemented. The first level involves a quick screening of the flock, incorporating robust and feasible animal-based indicators collected with minimal or no animal handling. Depending on the results of the first level assessment, a second level assessment is recommended, which entails a more thorough and in-depth evaluation. This requires restraining animals and collecting individual data[52].[15]

This approach was developed to improve the practicality of the assessment process. The selection of indicators has been guided by the four principles and twelve criteria outlined by the Welfare Quality® project, which comprehensively cover all aspects of animal welfare. For mastitis, the following animal-based measures have been proposed for evaluation at the first level:

51. [15] Wemelsfelder, Françoise. "The Scientific Validity of Subjective Concepts in Models of Animal Welfare." *Applied Animal Behaviour Science* 53, no. 1–2 (May 1997): 75–88. https://doi.org/10.1016/s0168-1591(96)01152-5
52. Caroprese, M., F. Napolitano, S. Mattiello, G.C. Fthenakis, O. Ribó, and A. Sevi. "On-Farm Welfare Monitoring of Small Ruminants." *Small Ruminant Research* 135 (February 2016): 20–25. https://doi.org/10.1016/j.smallrumres.2015.12.010

- Qualitative behaviour assessment, such as social withdrawal and abnormal posture.

- Quantitative behaviour assessment, including the number of animals exhibiting qualitative behaviour descriptors and the intensity of these descriptors.

- Assessment of fearfulness through human approach, involving parameters like minimum distance from humans and time taken to resume normal behaviour.

- Evaluation of lameness or abnormal gait.

Additionally, newborn mortality and growth rate can also be assessed. For the second level evaluation, a more comprehensive assessment is recommended to seek further evidence, such as inflammation and hyperalgesia in the mammary gland[54].

Research in animal behaviour and mastitis

Mastitis can lead to behavioural alterations, likely due to the sensation of pain. These changes should be assessed through behavioural recordings using predefined and rigorous experimental designs. Behavioural observations are crucial elements of clinical research for understanding animal behaviour and condition[55]. However, it is widely recognized that observational methods in behavioural studies have limitations. These include the subjective viewpoint of the observers, the diverse influences on animal baseline behavioural norms, and the subjective analysis and interpretation of results by researchers[56]. [16]

53. [16] Animal Welfare: Concepts, study methods and indicators ... Accessed February 19, 2024. https://www.researchgate.net/publication/298464767_Animal_welfare_Concepts_study_methods_and_indicators_translation_of_Spanish_original.
54. Wemelsfelder, F, and M Farish. "Qualitative Categories for the Interpretation of Sheep Welfare: A Review." *Animal Welfare* 13, no. 3 (August 2004): 261–68. https://doi.org/10.1017/s0962728600028372.
55. Wurtz, Kaitlin, Irene Camerlink, Richard B. D'Eath, Alberto Peña Fernández, Tomas Norton, Juan Steibel, and Janice Siegford. "Recording Behaviour of Indoor-Housed Farm Animals Automatically Using MACHINE VISION TECHNOLOGY: A Systematic Review." *PLOS ONE* 14, no. 12 (December 23, 2019). https://doi.org/10.1371/journal.pone.0226669
56. Krauth, David, Tracey J. Woodruff, and Lisa Bero. "Instruments for Assessing Risk of Bias and Other Methodological Criteria of Published Animal Studies: A Systematic Review." *Environmental Health Perspectives* 121, no. 9 (September 2013): 985–92. https://doi.org/10.1289/ehp.1206389

Strong and reliable conclusions in animal behavioural studies and their interpretation are achievable only through experimental work conducted under consistent and controlled conditions, akin to those of human clinical trials. Clinical trials are widely regarded as the "gold standard" in scientific documentation and intention-to-treat analysis[57]. In behavioural research, randomized controlled trials are considered the optimal method for assessing the efficacy of interventions, as they help minimize confounding and intervening variables and prevent inconclusive findings[58]. However, in behavioural and observational research, randomization may not necessarily enhance validity if "blinding" is not implemented. Blinding regarding treatment or intervention allocation in animal clinical trials aims to prevent researchers from introducing subjective biases into their recordings and analysis of results[59].

Scientometrics refers to the study of analysis and measure of the published scientific literature. It is described as referring to 'all quantitative aspects of science and scientific research'[60]. and produces new knowledge by dealing with information regarding articles published previously published.

The various sub-topics within the broad field of scientometrics include the assessment of impact of published papers, the understanding of citations in other scientific publications and the employment of the findings of such assessments in management and policy contexts [61]. There are significant overlaps between scientometrics and other scientific fields, e.g., meta-science. Meta-science is defined as QUOTE the use of research methods to study and appraise

57. Harris, Justin A. "The Importance of Trials." *Journal of Experimental Psychology: Animal Learning and Cognition* 45, no. 4 (October 2019): 390–404. https://doi.org/10.1037/xan0000223
58. Sargeant, J. M., D. F. Kelton, and A. M. O'Connor. "Randomized Controlled Trials and Challenge Trials: Design and Criterion for Validity." *Zoonoses and Public Health* 61, no. S1 (June 2014): 18–27. https://doi.org/10.1111/zph.12126
59. Holman, Luke, Megan L. Head, Robert Lanfear, and Michael D. Jennions. "Evidence of Experimental Bias in the Life Sciences: Why We Need Blind Data Recording." *PLOS Biology* 13, no. 7 (July 8, 2015). https://doi.org/10.1371/journal.pbio.1002190.
60. Sengupta, I. N.. "*Bibliometrics, Informetrics, Scientometrics and Librametrics: An Overview*" *Libri* 42, no. 2 (1992): 75-98. https://doi.org/10.1515/libr.1992.42.2.75
61. Milojević, Staša, and Loet Leydesdorff. "Information Metrics (iMetrics): A Research Specialty with a Socio-Cognitive Identity?" Scientometrics 95, no. 1 (October 9, 2013): 141–57. https://doi.org/10.1007/s11192-012-0861-z.

research itself and the areas where improvements can be made; the field deals with reporting, methods, evaluation, reproducibility, and incentives, which are related with communication, performance, evaluation, verification, and rewarding research, respectively UNQUOTE[62].

Scientometrics studies can be used for the assessment of developments and changes in technology and in scientific research, as well as for evaluating output derived from these, through the making of a quantitative evaluation of relevant published papers. Moreover, the approach can be used to identify priorities in research, to allocate budgetary funds and to reward excellence. Scientometrics-based articles are different from review articles: reviews summarise and discuss state of knowledge regarding a topic, without presentation of new data, reports of new results or performing of new analyses [61,63].

In the international literature on veterinary or animal science, there are only few scientometrics-based papers. A topic search in the Web of Science database by using the terms: [‘(‘veterinary’ OR ‘animal’) AND scientometrics’] retrieved only 15 published articles.

Gupta et al. [2015] evaluated the research output on camels internationally: 3089 papers from 2003 to 2012. Freire and Nicol [2019] showed the modifications in the reporting on animal welfare from 1968 to 2017. Gonzalez and Salgado-Arroyo [2020] presented the veterinary research output from Colombia: 3000 papers from 2010 to 2019. Garg et al [2021] assessed the same type of papers from India: 7056 papers from 2001 to 2020. Vaziri et al. [2022] presented a scientometrics-based history of international publications related to poultry science. Lianou and Fthenakis [2022] assessed the scientific outputs from Greece regarding small ruminants[64,65,66,67,68].

62. Ioannidis, John P., Daniele Fanelli, Debbie Drake Dunne, and Steven N. Goodman. “Meta-Research: Evaluation and Improvement of Research Methods and Practices.” PLOS Biology 13, no. 10 (October 2, 2015). https://doi.org/10.1371/journal.pbio.1002264.
63. Lianou, Daphne T., and George C. Fthenakis. “Scientometrics Approach to Research in Ovine Mastitis from 1970 to 2019 (with a Complete List of Relevant Literature References).” Pathogens 9, no. 7 (July 17, 2020): 585. https://doi.org/10.3390/pathogens9070585.
64. Gupta, B. M., K. K. Ahmed, Ritu Gupta, and Rishi Tiwari. “World Camel Research: A Scientometric Assessment, 2003–2012.” Scientometrics 102, no. 1 (August 24, 2014): 957–75. https://doi.org/10.1007/s11192-014-1405-5.

OBJECTIVES OF THE STUDY

The objectives of the study were: (a) the evaluation of published papers on the association of welfare in mastitis and (b) the presentation of quantitative characteristics regarding the scientific content and bibliometric details of these papers.

65. Freire, R, and CJ Nicol. "A Bibliometric Analysis of Past and Emergent Trends in Animal Welfare Science." Animal Welfare 28, no. 4 (2019): 465–85. https://doi.org/10.7120/09627286.28.4.465.
66. González T, Marco, and Luis Carlos Salgado-Arroyo. "Análisis Bibliométrico de Los Artículos Científicos Publicados En Medicina Veterinaria y Zootecnia En Colombia 2010-2019." Revista MVZ Córdoba 25, no. 3 (September 1, 2020). https://doi.org/10.21897/rmvz.2114.
67. "Bibliometrics of Indian Veterinary Science Research Output during 2001-2020." Annals of Library and Information Studies 68, no. 4 (December 12, 2022). https://doi.org/10.56042/alis.v68i4.54472.
68. Garg, K C; Kumar, Suresh ; Bansal, Sonia. "Bibliometrics of Indian Veterinary Science Research Output during 2001-2020." Annals of Library and Information Studies 68, no. 4 (December 12, 2022). https://doi.org/10.56042/alis.v68i4.54472.
69. Lianou, Daphne T., and George C. Fthenakis. "Scientometrics Study of Research Output on Sheep and Goats from Greece." Animals 12, no. 19 (October 4, 2022): 2666. https://doi.org/10.3390/ani12192666

MATERIALS AND METHODS

Search procedure

For the search of published papers, the platform of Web of Science (www.webofknowledge.com; Clarivate Analytics, Philadelphia, USA) was used. Only publications that could be accessed in this platform were included in the study and assessed.

Search terms employed were: [*mastitis*] AND [*welfare*]. Timespan was set to '*1970–2023*'.

The following two collections of Web of Science were included in the search: (i) Science citation index expanded and (ii) Emerging sources citation index.

The documents were downloaded on 17 July 2023 ('freeze date').

The documents produced after the initial search, was analysed by means of performing document analysis, to include only 'articles' and 'reviews'. That way, 669 records remained for detailed assessment.

Search procedure

The abstracts of all these 669 records were read and evaluated in the platform. Papers that did not deal with mastitis were excluded. Moreover, papers that did specifically study welfare of animals with mastitis, were also excluded.

Subsequently, 150 papers remained and were individually assessed. In each paper, the following details were recorded.

- Year of publication.
- Country and scientific establishment of origin (the country(ies) and the scientific establishment(s) of only the first and the last authors were taken into account).

- Type of paper: (i) original (paper presenting and providing new information, e.g., results or analyses, including case reports) or (ii) review (paper surveying and summarizing previously published studies, with no presentation and report of new facts or analyses). For original papers, the following details were also recorded.
    - Animal species referred to in the study.
    - Production type referred to in the study.
    - Type of study described in the paper: (i) experimental study, (ii) field study or (iii) meta-analysis study; only one of these three types was assigned per paper.
    - Welfare work described in the paper: (i) animal-based, (ii) management or (iii) resources; all those that applied were assigned per paper.
- Journal in which it was published.
- Total number of citations received by each paper.
- Number and names of all co-authors.
- Accessibility of papers

Data management ana analysis

All data were entered into Microsoft Excel. Descriptive analysis was performed initially. The frequency of the various outcomes was evaluated in tables of cross-categorised frequency data by use of the Pearson chi-square test as appropriate. Comparisons between continuous data were performed by use of one-way analysis of variance. Correlations were performed as indicated and significance of the result was evaluated. Statistical significance was defined at $p < 0.05$.

RESULTS

Among the 150 published papers evaluated in detail, there were 102 (68.0%) original papers and 48 (32.0%) reviews.

Year of publication

The first paper of mastitis and welfare of animals was published in 1996. The number of papers published throughout the years increased progressively (Figure 1) (slope: 1.477 ± 0.171; $p < 0.0001$).

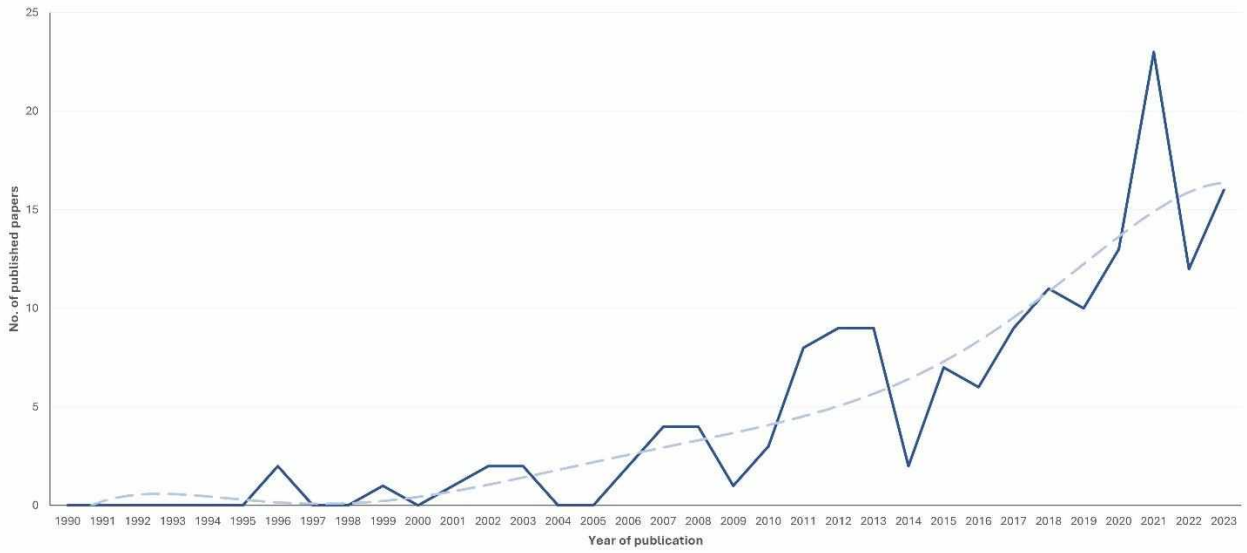

Figure 1. Number of papers published annually on mastitis and welfare of animals from 1990 to 2023 (dashed line is trendline).

Moreover, the proportion of papers on mastitis and welfare among all papers on mastitis also increased progressively from 0.1% (95% confidence intervals (CI): 0.0%-0.2%) before 2001

to 1.3% (95% CI: 0.9%-1.7%) during the period 2021 to 2023 (Figure 2) (slope: 0.001 ± 0.001; $p <$ 0.0001).

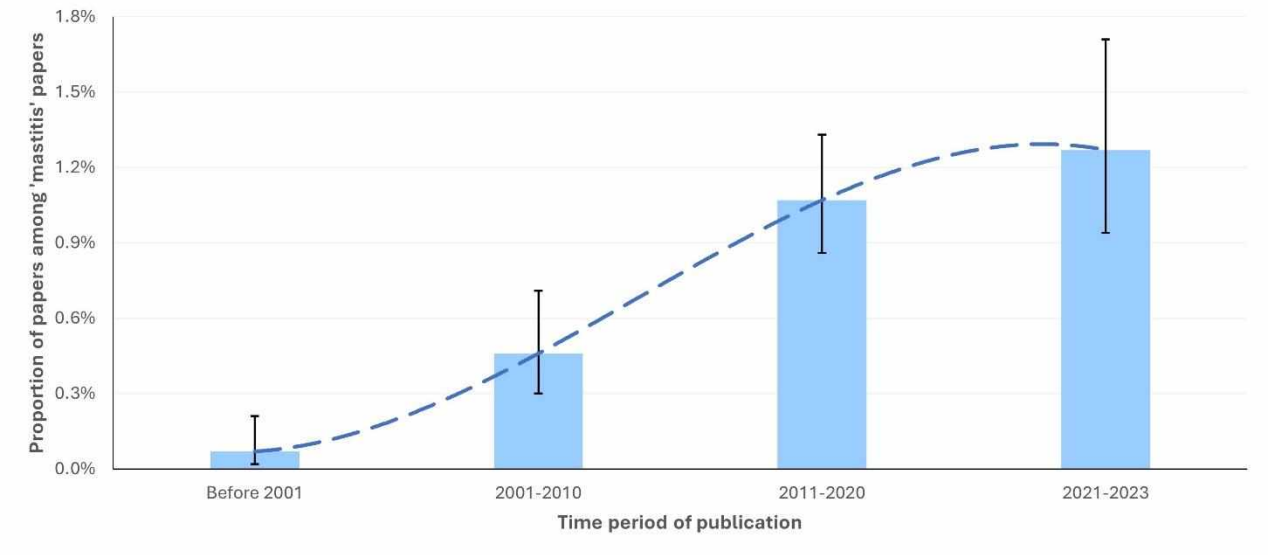

Figure 2. Proportion of papers on mastitis and welfare among all published papers on mastitis (dashed line is trendline).

Country and affiliation of origin

Papers originated from 43 different countries (Table 1). The median number of papers per country was 2 (interquartile range: 3). Seventeen (17, 11.3%) papers originated from two different countries Most papers originated from the United Kingdom and the Unites States of America (n = 20 from each, 13.3%) and Italy (n = 15, 10.0%). Seventy-six papers originated from the five countries with most paper (50.7% of all papers). When geographical regions were considered, it was found that most papers originated from European countries (n = 107, 71.3% of all papers) (Table 2).

Table 1. Countries of origin of papers on mastitis and welfare and number of papers published from each.

Country	No. of published papers
United Kingdom	20 (13.3%)
United States of America	20 (13.3%)
Italy	15 (10.0%)
Germany	12 (8.0%)
Canada	9 (6.0%)
Denmark	8 (5.3%)
Brazil	6 (4.0%)
Switzerland	6 (4.0%)
Australia	5 (3.3%)
Austria	5 (3.3%)
France	5 (3.3%)
Estonia	3 (2.0%)
Ireland	3 (2.0%)
Lithuania	3 (2.0%)
Mexico	3 (2.0%)
Norway	3 (2.0%)
Poland	3 (2.0%)
Portugal	3 (2.0%)
Spain	3 (2.0%)
The Netherlands	3 (2.0%)
Belgium	2 (1.3%)
China	2 (1.3%)
Colombia	2 (1.3%)
Finland	2 (1.3%)
New Zealand	2 (1.3%)
Sweden	2 (1.3%)
Algeria	1 (0.7%)
Bangladesh	1 (0.7%)
Bhutan	1 (0.7%)
Chile	1 (0.7%)
Egypt	1 (0.7%)
European Union	1 (0.7%)
Greece	1 (0.7%)
Hungary	1(0.7%)
India	1 (0.7%)
Iran	1 (0.7%)
Jordan	1 (0.7%)
Luxembourg	1 (0.7%)
Romania	1 (0.7%)
Serbia	1 (0.7%)
South Africa	1 (0.7%)
Sri Lanka	1 (0.7%)
Turkey	1 (0.7%)

Table 2. Origin of papers on mastitis and welfare in accord with the continent of the country of origin.

Country	No. of published papers
Europe	107 (71.3%)
Americas	41 (27.3%)
Asia	9 (6.0%)
Oceania	7 (4.7%)
Africa	3 (1.0%)

Papers originated from 114 different scientific establishments (Table 3). Most papers originated from the University of Aarhus (Denmark) (n = 6, 4.0%) and the University of Minnesota (n = 5, 3.3%). The median number of papers per scientific establishment was 1 (interquartile range: 1). Of these establishments, 97 (82.9%) were universities and 17 (17.1%) entities of other type (e.g., research institutes, commercial companies, state organisations). There was a tendency for more papers per establishment among universities than among the other entities: 1 (1) *versus* 1 (0) (p = 0.06) (Figure 3).

Table 3. Scientific establishments of origin of papers on mastitis and welfare and number of papers published from each.

Scientific establishment	Country	No. of published papers
Aarhus University	Denmark	6 (4.0%)
University of Minnesota	United States of America	5 (3.3%)
University of Bristol	United Kingdom	4 (2.7%)
University of Clermont Auvergne	France	4 (2.7%)
University of Foggia	Italy	4 (2.7%)
University of Guelph	Canada	4 (2.7%)
University of Liverpool	United Kingdom	4 (2.7%)
University of Melbourne	Australia	4 (2.7%)
University of Natural Resources & Life Sciences, Vienna	Austria	4 (2.7%)
University of Veterinary Medicine Hannover	Germany	4 (2.7%)
Estonian University of Life Sciences	Estonia	3 (2.0%)
Justus Liebig University of Giessen	Germany	3 (2.0%)
Norwegian University of Life Sciences	Norway	3 (2.0%)
Teagasc	Ireland	3 (2.0%)
University of Basilicata	Italy	3 (2.0%)
University of British Columbia	Canada	3 (2.0%)
University of Copenhagen	Denmark	3 (2.0%)
University of London	United Kingdom	3 (2.0%)
University of Milan	Italy	3 (2.0%)
University of Nottingham	United Kingdom	3 (2.0%)

Autonomous University of Barcelona	Spain	2 (1.3%)
Colombian Centre of Agricultural Investigation	Colombia	2 (1.3%)
Colorado State University	United States of America	2 (1.3%)
Federal University of Rio Grande do Sul	Brazil	2 (1.3%)
Free University of Berlin	Germany	2 (1.3%)
Lithuanian University of Health Sciences	Lithuania	2 (1.3%)
Massey University	New Zealand	2 (1.3%)
Michigan State University	United States of America	2 (1.3%)
University Antonio Narino	Colombia	2 (1.3%)
University of Bern	Switzerland	2 (1.3%)
University of Gottingen	Germany	2 (1.3%)
University of Kassel	Germany	2 (1.3%)
University de Toulouse	France	2 (1.3%)
Virginia Polytechnic Institute & State University	United States of America	2 (1.3%)
Wageningen University & Research	The Netherlands	2 (1.3%)
Aberystwyth University	United Kingdom	1 (0.7%)
Aristotle University of Thessaloniki	Greece	1 (0.7%)
Austral University of Chile	Chile	1 (0.7%)
Autonomous Metropolitan University of Mexico	Mexico	1 (0.7%)
Autonomous University of Mexico	Mexico	1 (0.7%)
Bangladesh Agricultural University	Bangladesh	1 (0.7%)
China Agricultural University	China	1 (0.7%)
CONVIS	Belgium	1 (0.7%)
Cornell University	United States of America	1 (0.7%)
European Food Safety Authority	European Union	1 (0.7%)
Federal University of Parana	Brazil	1 (0.7%)
Federal University of Pelotas	Brazil	1 (0.7%)
Federal University of Santa Catarina	Brazil	1 (0.7%)
Ghent University	Belgium	1 (0.7%)
Harper Adams University	United Kingdom	1 (0.7%)
Indian Council of Agricultural Research	India	1 (0.7%)
Italian Society of Veterinary Immunology	Italy	1 (0.7%)
Jordan University of Science & Technology	Jordan	1 (0.7%)
Kaunas University of Technology	Lithuania	1 (0.7%)
Lithuanian University of Health Science	Lithuania	1 (0.7%)
McGill University	Canada	1 (0.7%)
Mississippi State University	United States of America	1 (0.7%)
Moredun Research Institute	United Kingdom	1 (0.7%)
Nanjing University of Information Science & Technology	China	1 (0.7%)
National Institute of Agricultural and Environmental Research	France	1 (0.7%)
National Institute of Research and Technology in Agriculture and Food Science	Spain	1 (0.7%)
Natural Resources Institute of Finland	Finland	1 (0.7%)
National Veterinary Institute	Sweden	1 (0.7%)
New Mexico State University	United States of America	1 (0.7%)
Ohio State University	United States of America	1 (0.7%)
Pennsylvania State University	United States of America	1 (0.7%)

Poznan University of Life Sciences	Poland	1 (0.7%)
Queens University Belfast	United Kingdom	1 (0.7%)
Research & Development Station of Cattle Breeding of Dancu	Romania	1 (0.7%)
Research Institute for Organic Agriculture	Switzerland	1 (0.7%)
Royal University of Bhutan	Bhutan	1 (0.7%)
Royal Veterinary and Agricultural University	Denmark	1 (0.7%)
Scotland's Rural College	United Kingdom	1 (0.7%)
Selcuk University	Turkey	1 (0.7%)
State University of Sao Paolo	Brazil	1 (0.7%)
Swedish University of Agricultural Sciences	Sweden	1 (0.7%)
Swiss Federal Research Station Agroscope	Switzerland	1 (0.7%)
Swiss Federal Veterinary Office	Switzerland	1 (0.7%)
Szent Istvan University	Hungary	1 (0.7%)
United States Department of Agriculture	United States of America	1 (0.7%)
University of Belgrade	Serbia	1 (0.7%)
University of Brasilia	Brazil	1 (0.7%)
University of Calgary	Canada	1 (0.7%)
University of Cambridge	United Kingdom	1 (0.7%)
University of Chester	United Kingdom	1 (0.7%)
University of Evora	Portugal	1 (0.7%)
University of Florence	Italy	1 (0.7%)
University of Georgia	United States of America	1 (0.7%)
University of Glasgow	United Kingdom	1 (0.7%)
University of Hamburg	Germany	1 (0.7%)
University of Helsinki	Finland	1 (0.7%)
University of Kentucky	United States of America	1 (0.7%)
University of Liege	Belgium	1 (0.7%)
University of Lisbon	Portugal	1 (0.7%)
University of Messina	Italy	1 (0.7%)
University of Mouloud Mammeride Tizi Ouzou	Algeria	1 (0.7%)
University of Naples Federico II	Italy	1 (0.7%)
University of Paris Saclay	France	1 (0.7%)
University of Peradeniya	Sri Lanca	1 (0.7%)
University of Pretoria	South Africa	1 (0.7%)
University of Queensland	Australia	1 (0.7%)
University of Tras-os-Montes & Alto Douro	Portugal	1 (0.7%)
University of Turin	Italy	1 (0.7%)
University of Utrecht	The Netherlands	1 (0.7%)
University of Vermont	United States of America	1 (0.7%)
University of Veterinary Medicine Vienna	Austria	1 (0.7%)
University of Warmia & Mazury	Poland	1 (0.7%)
University of Wisconsin	United States of America	1 (0.7%)
University of Wyoming	United States of America	1 (0.7%)
University of Zurich	Switzerland	1 (0.7%)
University of Zanjan	Iran	1 (0.7%)
Vytautas Magnus University	Lithuania	1 (0.7%)
Warsaw University of Life Sciences	Poland	1 (0.7%)
Zagazig University	Egypt	1 (0.7%)

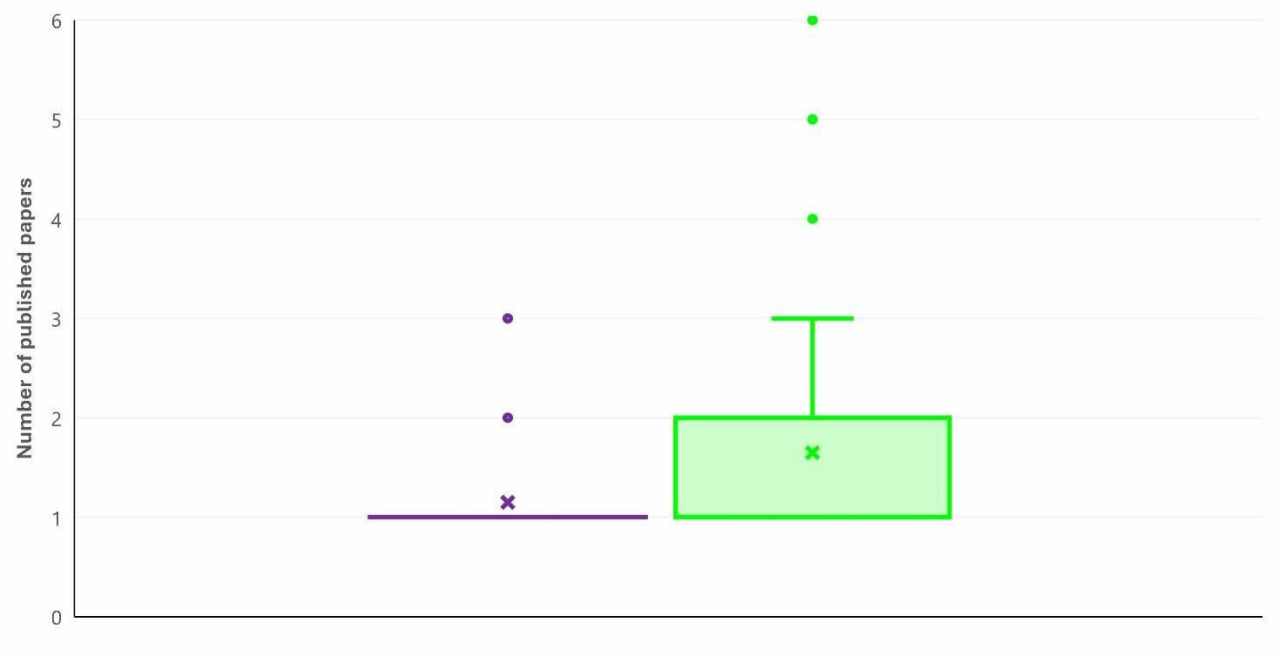

Figure 3. Box and whisker plot of number of papers on mastitis and welfare per scientific establishment among universities (green) or other entities (purple).

Most scientific establishments with published papers were located in the United States (n = 14) and the United Kingdom (n =12) (Table 4, Figure 4). There was a clear correlation between the number of scientific establishments in a country and the number of relevant papers that originated from that country (r_{sp} = 0.769, p = 0.006) (Figure 5).

Table 4. Countries of origin of papers on mastitis and welfare and number of papers published from each.

Country	No. of published papers
United States of America	14
United Kingdom	12
Italy	8
Germany	7
Brazil	6
Canada	4
France	4
Switzerland	4
Denmark	3

Australia	2
Austria	2

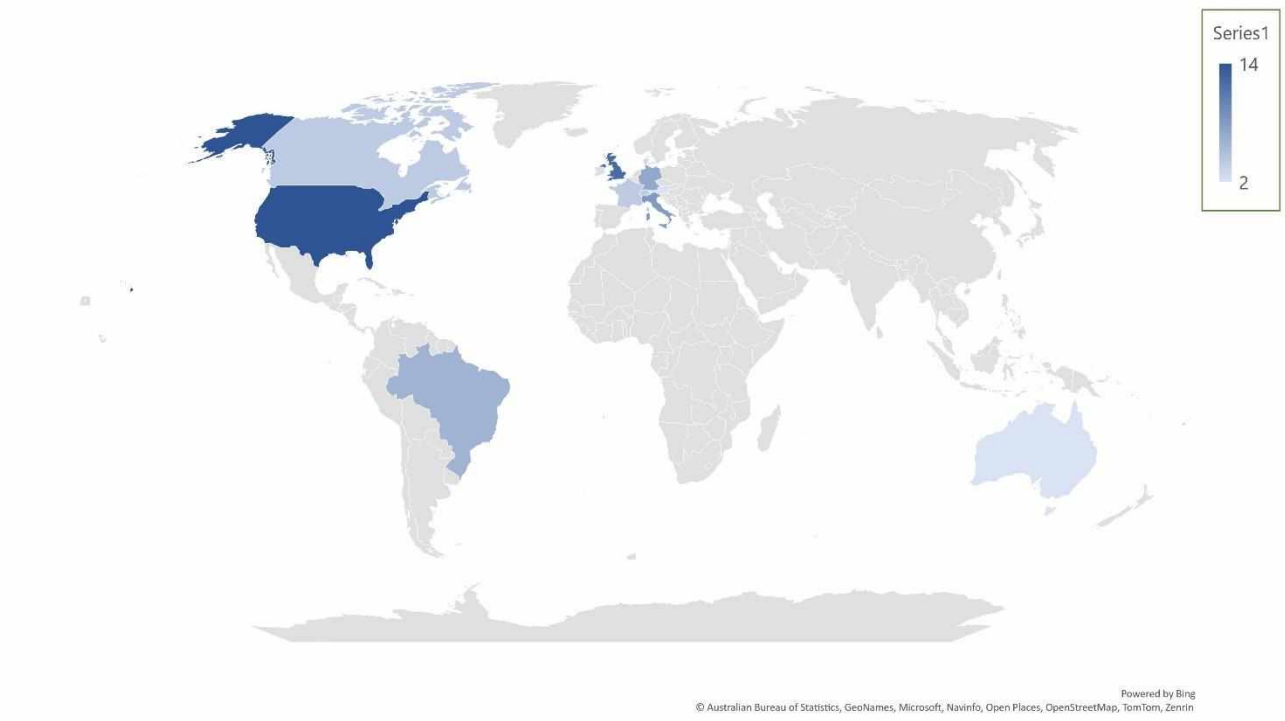

Figure 4. Map of countries with at least three scientific establishments with published papers on mastitis and welfare (number of establishments per country in accord with colour legend).

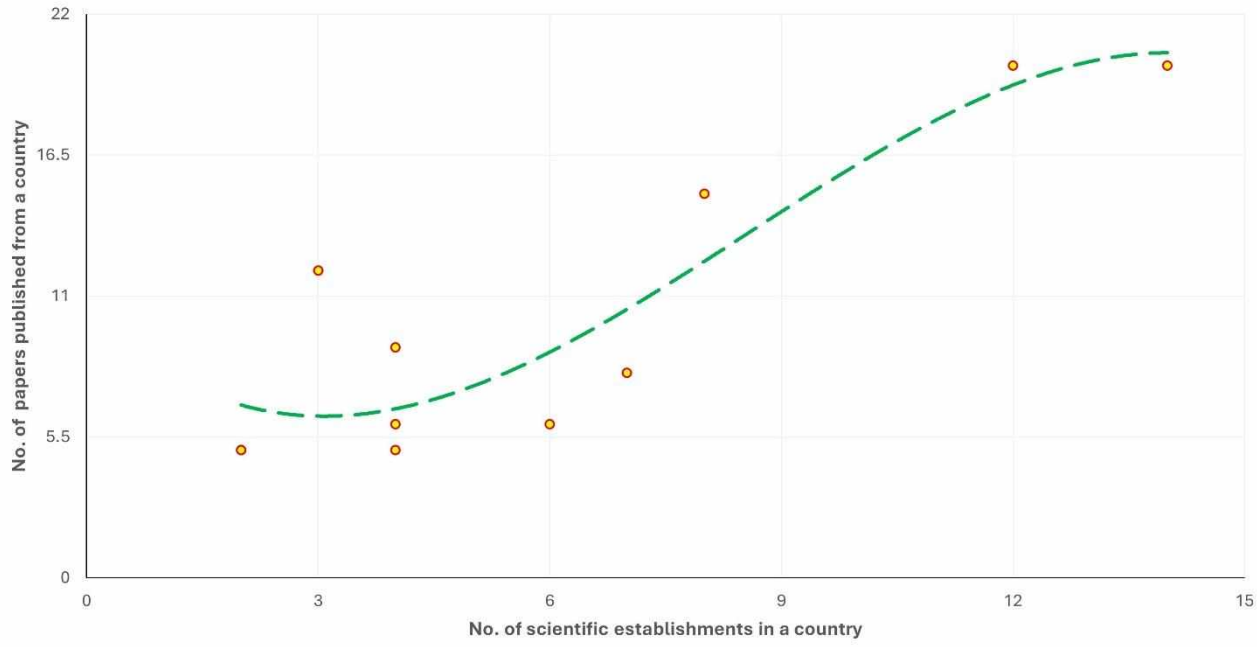

Figure 5. Cross-plot of number of scientific establishments in a country *versus* number of papers that originated from that country (dashed line is trendline).

Animal species involved in studies

The majority of original papers (*n* = 99, 97.1%) dealt with mastitis and welfare in ruminants, mostly cattle (*n* = 81, 79.4%). Other species on which relevant studies were performed, were sheep (*n* = 12, 11.8%), goats (*n* = 4, 3.9%), buffaloes (*n* = 2, 2.0%), pigs (*n* = 2, 2.0%), mink (*n* = 1, 1.0%) and yak (*n* = 1, 1.0%) (Figure 6). There was no significant difference in the proportion of papers that originated from the 11 countries with most original articles (*p* = 0.17) (Figure 7).

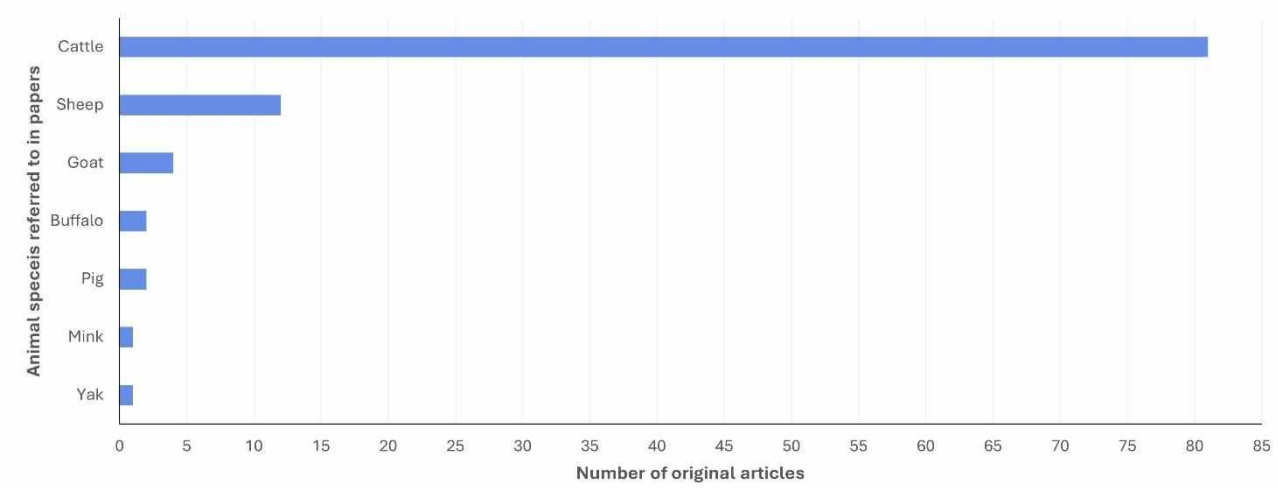

Figure 6. Number of original articles on mastitis and welfare in accord with animal species involved in the relevant studies.

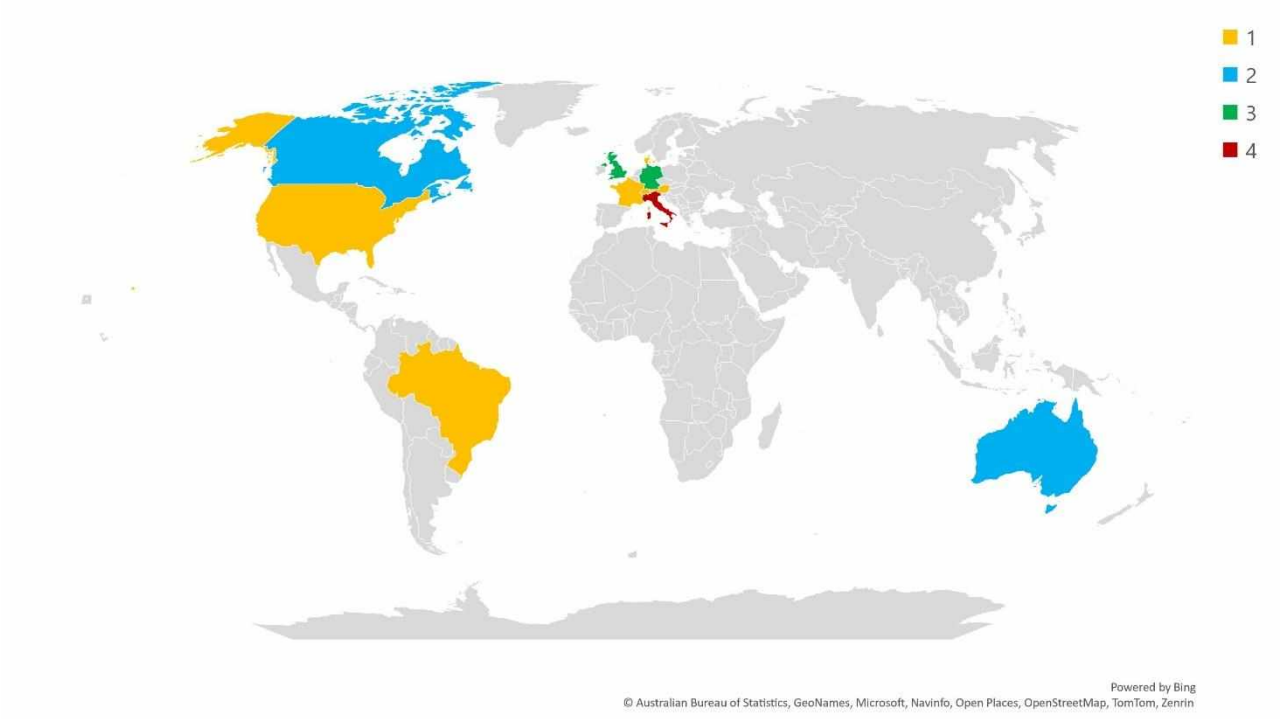

Figure 7. Map of countries in accord with the number of animal species involved in studies in original articles on mastitis and welfare of animals.

Production type referred to in studies

The majority of original papers (*n* = 98, 96.1%) dealt with mastitis and welfare in dairy production systems (*n* = 81, 79.4%). Other production systems in which relevant studies were performed, were meat production (*n* = 4, 3.9%) and fur (*n* = 1, 1.0%).

Type of study described in papers

Most papers described field studies (*n* = 84, 82.4%), whilst fewer ones described experimental studies (*n* = 16, 15.7%) or meta-analyses (*n* = 2, 2.0%). There was no significant difference in the proportion of papers that originated from the 11 countries with most original articles (*p* = 0.48).

Type of welfare work described in papers

All papers described animal-based work (*n* = 102, 100.0%), whilst fewer ones also described management (*n* = 56, 54.9%) or resources (*n* = 11, 10.8%) work. There was no difference in the type welfare work described in papers in accord with production type referred to in studies ($p = 0.49$) or type of study ($p = 0.89$) (Table 5, Figure 8). There was no significant difference in the proportion of papers that originated from the 11 countries with most original articles ($p = 0.97$).

Table 5. Type of welfare work described in papers on mastitis and welfare, in accord with production type referred to and type of study described therein.

	No. of original articles		
	Dairy production systems	Non-dairy production systems	
Animal-based work	36	3	
Animal-based + management work	50	1	
Animal-based + resources work	7	0	
Animal-based + management + resources work	4	0	
	Experimental studies	Field studies	Meta-analyses
Animal-based work	4	34	1
Animal-based + management work	9	42	1
Animal-based + resources work	2	5	0
Animal-based + management + resources work	1	3	0

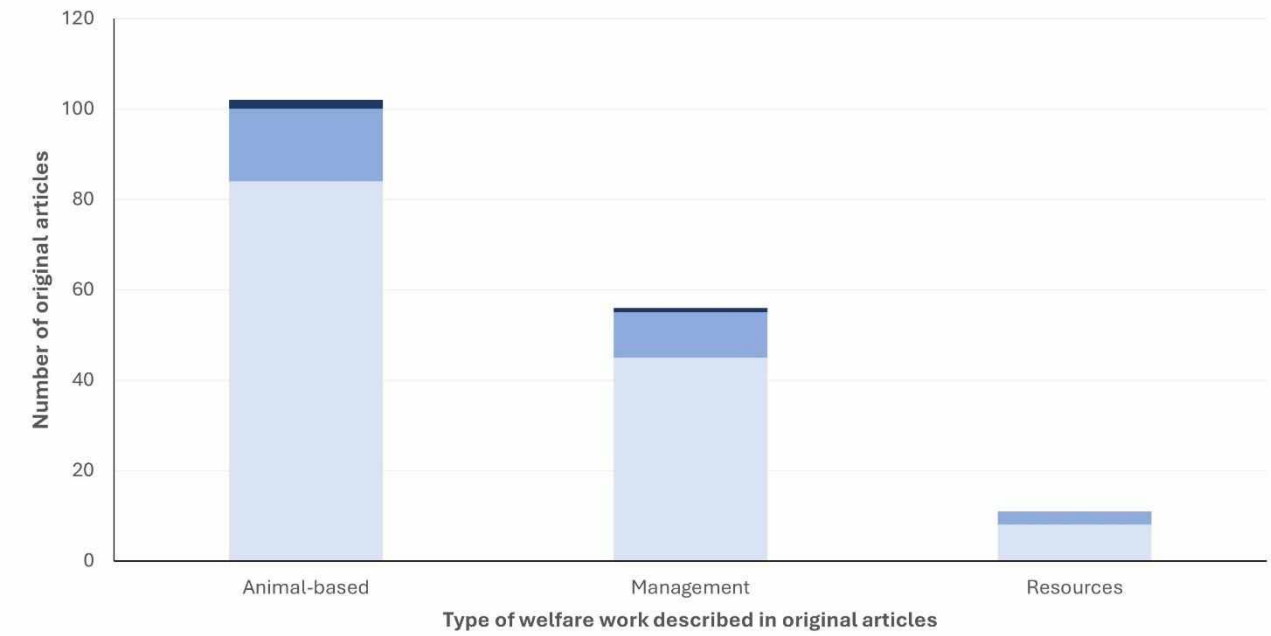

Figure 8. Type of welfare work described in papers on mastitis and welfare, in accord with type of study described therein.

Journals in which papers were published

The papers were published in a total of 57 journals. Original articles were published in 43 journals and reviews in 32 journals (Table 6, Figure 9). Among the 10 journals with most relevant papers published, there was no significant difference in the proportion of papers in accord with the production type referred to ($p = 0.22$) or type of welfare work described ($p = 0.76$) (Figure 10).

Table 6. Journals in which papers on mastitis and welfare were published and number of papers published in each.

Journal	No. of original articles	No. of reviews
Acta Agriculturae Scandinavica A Animal Science	1	0
Acta Scientiae Veterinariae	1	0
Acta Veterinaria Scandinavica	3	2
Acta Veterinaria Beograd	1	0
Agricultural and Food Science	1	0
Agriculture Ecosystems & Environment	0	1

Agriculture	3	0
Animal	3	2
Animal Production Science	0	1
Animal Science Journal	1	0
Animal Welfare	3	1
Animals	11	10
Applied Animal Behaviour Science	6	1
Archives Animal Breeding	1	1
Berichte über Landwirtschaft	0	1
Berliner und Munchener Tierarztliche Wochenschrift	0	1
Bioengineering	0	1
Biosystems Engineering	0	1
Biotechnologie Agronomie Societé et Environement	0	1
Buffalo Bulletin	1	0
Cattle Practice	0	2
Ciencia Rural	0	1
Compendium on Continuing Education for the Practicing Veterinarian	0	1
EFSA Journal	1	0
Frontiers in Veterinary Science	2	2
Genetics Selection Evolution	1	0
In Practice	0	1
Italian Journal of Animal Science	1	1
Journal of Agriculture and Food Research	1	0
Journal of Agromedicine	0	1
Journal of Animal Science	1	0
Journal of Animal Science and Technology	1	0
Journal of Dairy Research	2	1
Journal of Dairy Science	24	6
Journal of Thermal Biology	1	0
Large Animal Review	1	0
Livestock Science	6	0
Magyar Allatorvosok Lapja	1	0
Microsystem Technologies-Micro-and Nanosystems-Information Storage and Processing Systems	1	0
Milchwissenschaft	0	1
New Zealand Veterinary Journal	0	3
Pathogens	1	0
Preventive Veterinary Medicine	4	0
Research in Veterinary Science	1	0
Revista Brasileira de Zootecnia	1	0
Revista de Investigaciones Veterinarias del Peru	1	0
Revista de Medicina Veterinaria y Zootecnia de Cordoba	1	0
Scientific Reports	1	0
Small Ruminant Research	4	0
Translational Animal Science	1	0
Tropical Animal Health and Production	1	0
Turkish Journal of Veterinary & Animal Sciences	1	0
Veterinarni Medicina	0	1

Veterinary Clinics of North America-Food Animal Practice	1	1
Veterinary Record	2	1
Veterinary Research Communications	1	0
Veterinary World	1	1

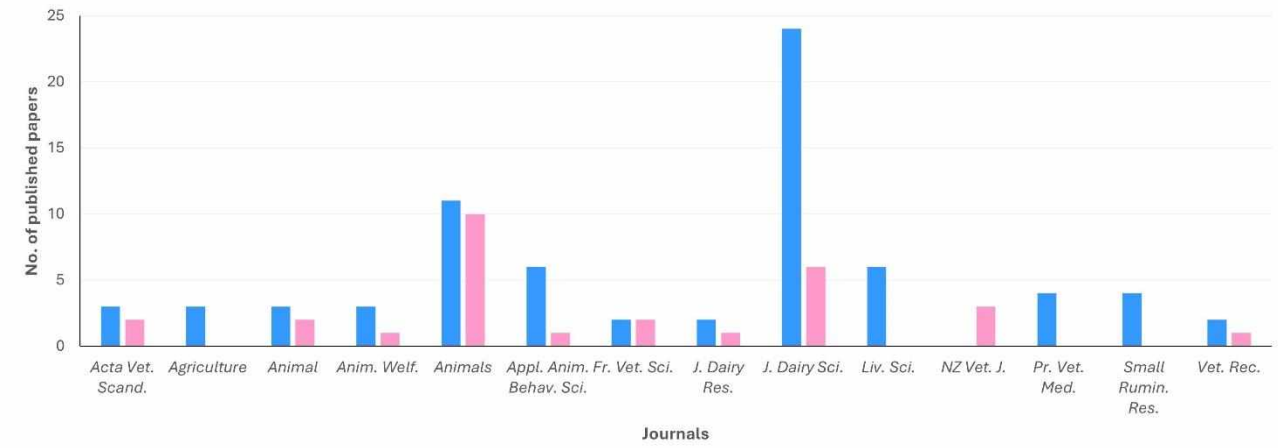

Figure 9. Number of original articles (blue) or reviews (pink) on mastitis and welfare in journals with most of these papers published.

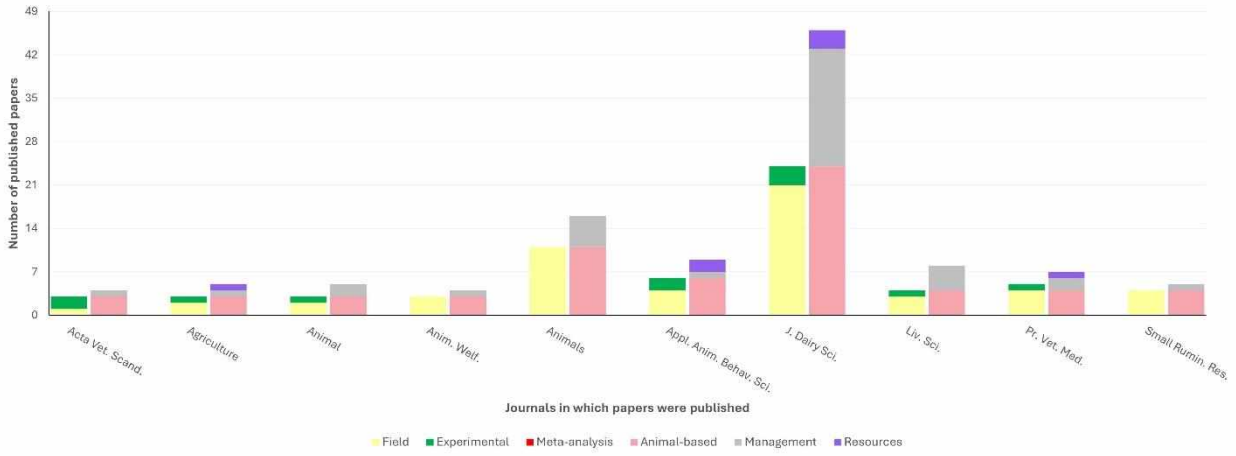

Figure 10. Number of published papers on mastitis and welfare in journals with most of these papers published, in accord with the production type referred to or type of welfare work described.

There was a significant difference in the proportion of papers in accord with the country of origin (p = 0.011) (Table 7, Figure 11). There was also a significant difference in the proportion of papers in accord with the scientific establishment of origin (p = 0.002) (Table 8).

Table 7. Journals in which papers on mastitis and welfare with origin from the 11 countries with most papers, were published.

	Country										
Journal	AUS	AUT	BRA	CDN	DNK	DEU	FRA	GBR	ITA	SUI	USA
J. Dairy Sci.	1	2	2	3	4	3	1	0	1	0	11
Animals	2	0	0	2	0	1	0	1	4	1	1
Appl. Anim. Behav. Sci.	0	0	0	2	0	1	2	1	0	0	0
Liv. Sci.	0	0	0	0	0	1	0	2	0	1	1
Pr. Vet. Med.	0	0	0	0	0	1	1	1	0	0	0
Small Rumin. Res.	0	0	0	0	0	0	0	1	3	0	0
Acta Vet. Scand.	0	0	0	0	3	0	0	0	0	1	0
Agriculture	0	0	0	0	0	1	0	1	0	1	0
Animal	0	1	1	0	0	1	0	2	0	0	0
Anim. Welf.	0	1	0	0	0	0	0	0	0	0	1
J. Dairy Res.	0	1	0	0	0	0	0	1	1	0	0
NZ Vet. J.	0	0	0	0	0	0	0	1	0	0	0
Vet. Rec.	0	0	0	0	0	0	0	3	0	0	0

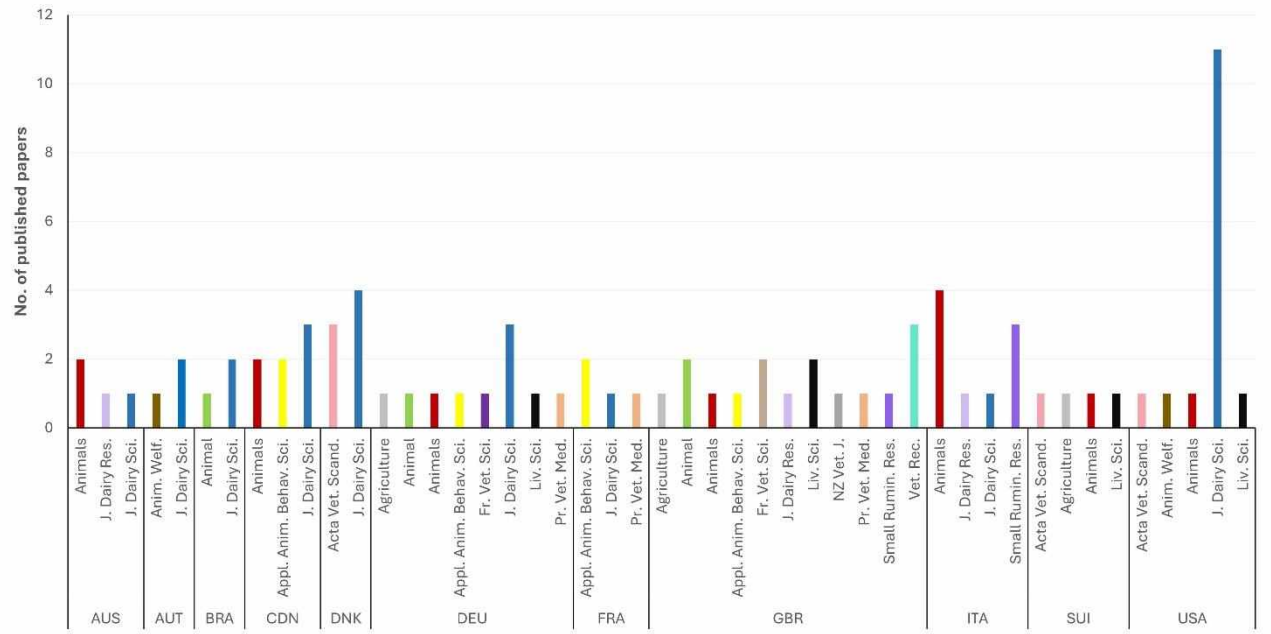

Figure 11. Number of published papers on mastitis and welfare from the 11 countries with most papers in accord with the journal in which they were published.

Table 8. Journals in which papers on mastitis and welfare with origin from the 10 scientific establsihments with most papers, were published (U. = University).

	Country									
Journal	Aarhus U.	U. of Clermont Auvergne	U. of Bristol	U. of Foggia	Guelph U.	U. of Liverpool	U. of Melbourne	U. of Minnesota	U. of Natural Resources & Life Sciences, Vienna	U. of Veterinary Medicine Hannover
J. Dairy Sci.	4	1	0	0	2	0	1	1	2	0
Animals	0	0	0	0	0	0	1	1	0	0
Appl. Anim. Behav. Sci.	0	2	0	0	1	0	0	0	0	0
Small Rumin. Res.	0	0	0	1	0	0	0	0	0	0
Acta Vet. Scand.	1	0	0	0	0	0	0	0	0	0
Agriculture	0	0	0	0	0	1	0	0	0	1
Anim. Welf.	0	0	0	0	0	0	0	0	1	0
J. Dairy Res.	0	0	0	0	0	1	1	0	0	0
Vet. Rec.	0	0	3	0	0	0	0	0	0	0
Fr. Vet. Sci.	0	0	0	0	0	0	0	0	0	1

Citations received by paper

The median number of citations received annually by the papers was 2 (3). There were no differences between original articles and reviews in the median number of citations received: 2.0 (2.9) *versus* 2.1 (4.4) (p = 0.37) (Figure 12). Also, there were no differences in citation in accord to the content of the papers (Table 9).

Table 9. Citation received annually by papers on mastitis and welfare, in accord with their content.

Animal species involved in studies							
Cattle	Sheep	Goats	Buffaloes	Pigs	Mink	Yak	p
2.0 (3.4)	1.8 (2.1)	3.1 (1.2)	11.1 (7.1)	0.8 (5.1)	0.7 (0.0)	0.0 (0.0)	0.41
Production type referred to in studies							
Dairy production			Meat production		Fur production		p
2.0 (4.4)			0.9 (5.4)		0.7 (6.4)		0.34
Type of study described in papers							
Field studies			Experimental studies		Meta-analyses		p
2.0 (5.4)			2.0 (4.4)		0.3 (6.4)		0.23

Type of welfare work described in papers			
Animal-based	Management	Resources	*p*
2.0 (4.4)	1.9 (5.4)	1.1 (6.4)	0.75

Principal component analysis for animal species involved in studies, production type referred to in studies, type of study described and type of welfare work described revealed that the two principal components accounted for 56.4% of the variation (Figures 12 and 13, Table 10).

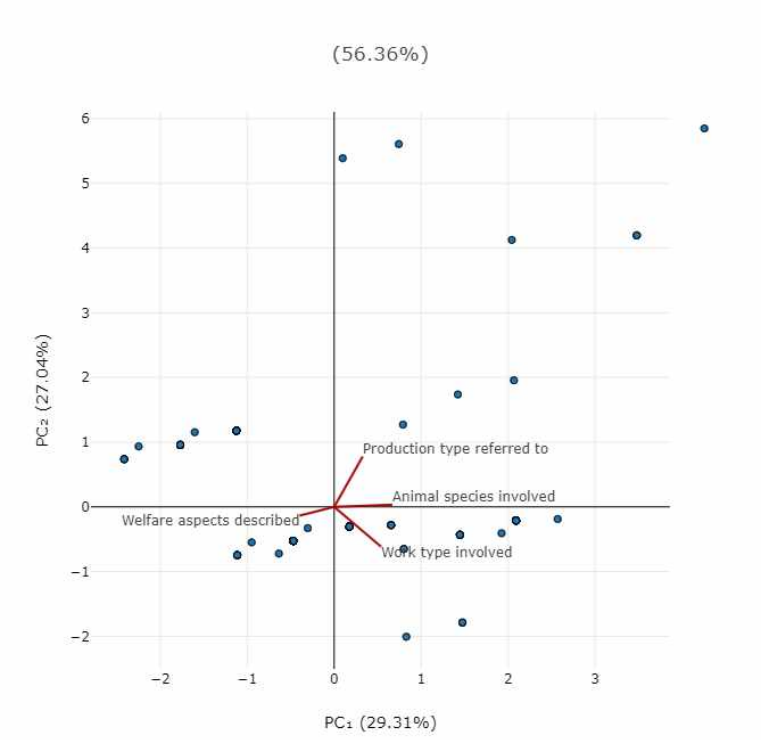

Figure 12. Bi-plot of results of principal components analysis for animal species involved in studies, production type referred to in studies, type of study described and type of welfare work described in original articles on mastitis and welfare.

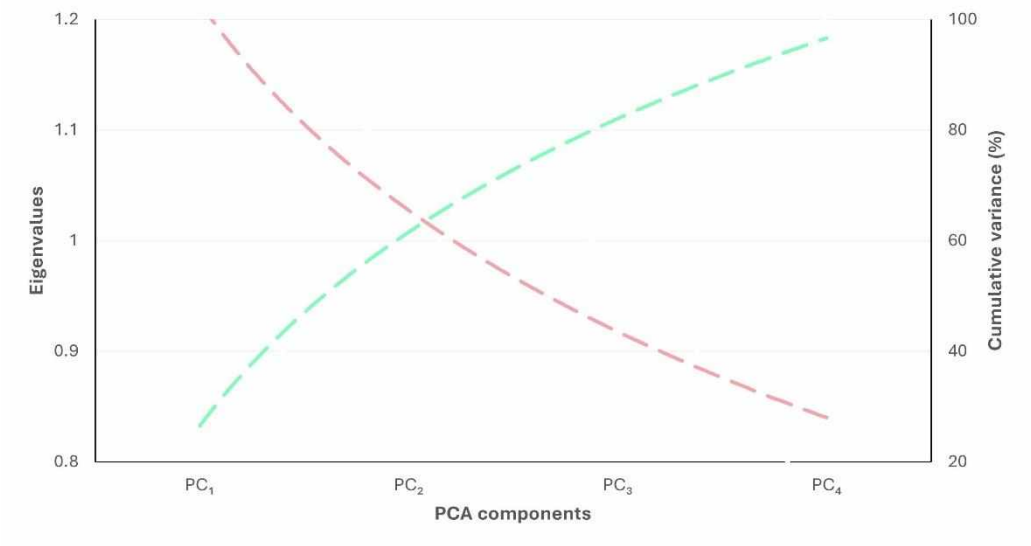

Figure 13. Scree-plot of results of principal components analysis for animal species involved in studies, production type referred to in studies, type of study described and type of welfare work described in original articles on mastitis and welfare.

Table 10. Eigenvalues for principal component analysis for animal species involved in studies, production type referred to in studies, type of study described and type of welfare work described in original articles on mastitis and welfare.

Parameter	PC1	PC2	PC3	PC4
Eigenvalue	1.173	1.082	0.988	0.757
% of Variance	29.314	27.041	24.708	18.937
Cumulative variance (%)	29.314	56.355	81.063	100

Principal component analysis for animal species involved in studies, production type referred to in studies, type of study described in papers and type of welfare work described in papers revealed that the two principal components accounted for 56.4% of the variation (Figures 12 and 13, Table 10, Figure S4).

A total of 25 combinations of animal species involved in studies, production type referred to in studies, type of study described in papers and type of welfare work described in papers were found in the original articles (Table 11). The most frequent combination referred to animal-based field studies in dairy production cattle and was found in 64 papers.

Table 11. Heat plot of combinations of animal species involved in studies, production type referred to in studies, type of study described and type of welfare work described in original articles on mastitis and welfare.

Animal species involved	Production type referred to	Type of study described	Type of welfare work described	*n*
cattle	dairy	field	animal-based	64
cattle	dairy	field	management	38
cattle	dairy	experimental	animal-based	14
sheep	dairy	field	animal-based	11
cattle	dairy	experimental	management	9
cattle	dairy	field	resources	5
cattle	meat	field	animal-based	5
sheep	dairy	field	management	5
cattle	dairy	experimental	resources	3
cattle	dairy	meta-analysis	animal-based	2
pig	meat	field	animal-based	2
sheep	dairy	field	resources	2
buffalo	dairy	experimental	animal-based	1
buffalo	dairy	experimental	management	1
buffalo	dairy	field	animal-based	1
buffalo	dairy	field	management	1
cattle	dairy	meta-analysis	management	1
cattle	meat	experimental	animal-based	1
cattle	meat	experimental	management	1
goat	dairy	field	resources	1
mink	fur	field	animal-based	1
mink	fur	field	management	1
sheep	dairy	experimental	animal-based	1
yak	dairy	field	animal-based	1
yak	dairy	field	management	1

Authors of papers

In total, there were 605 individual authors (707 co-authors) of the papers. Median number of authors per paper was 4 (3). The number of authors per paper progressively increased with time (slope: 1.366 ± 0.035; p <= 0.0003) (Figures 14, 15). The median number of authors in original articles was significantly higher than that in reviews: 5 (3) versus 3 (3), respectively (p = 0.0003) (Figure 16).

Furthermore, there were 264 individual authors who were first or last authors in the papers; among these, six authors were first or last in over two papers each (max: 4). On average,

the 6 authors with > 2 papers each were first or last authors in 83.6 ± 7.6% of the papers in which they were co-authors (min: 60.0%, max: 100.0%).

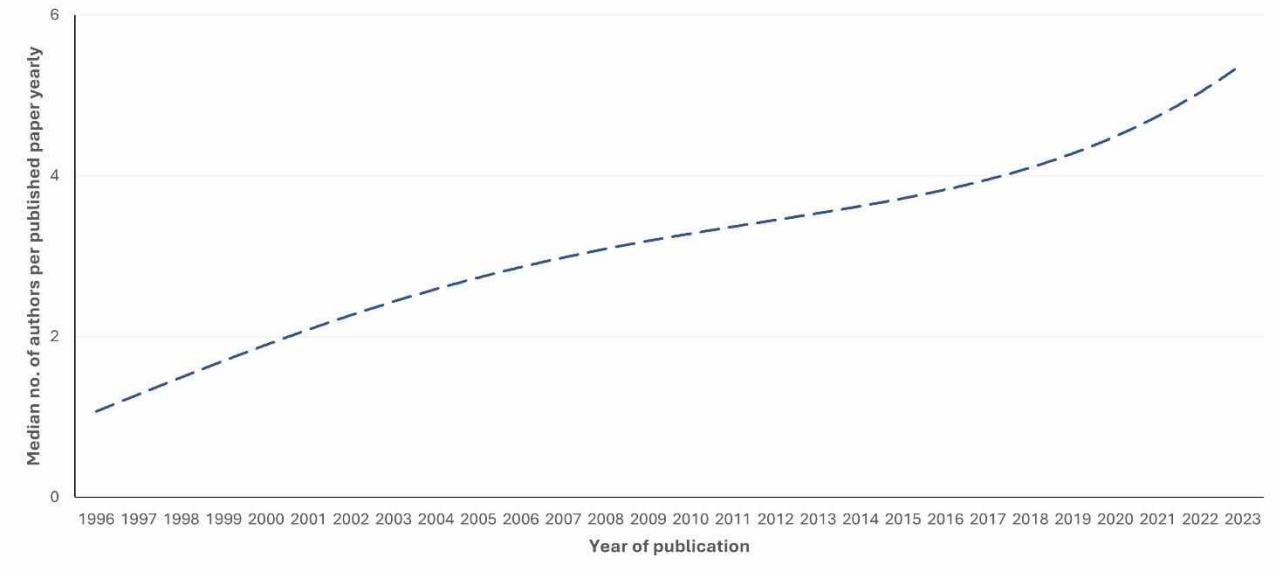

Figure 14. Median number of co-authors per published paper on mastitis and welfare, yearly (dashed line shows trendline).

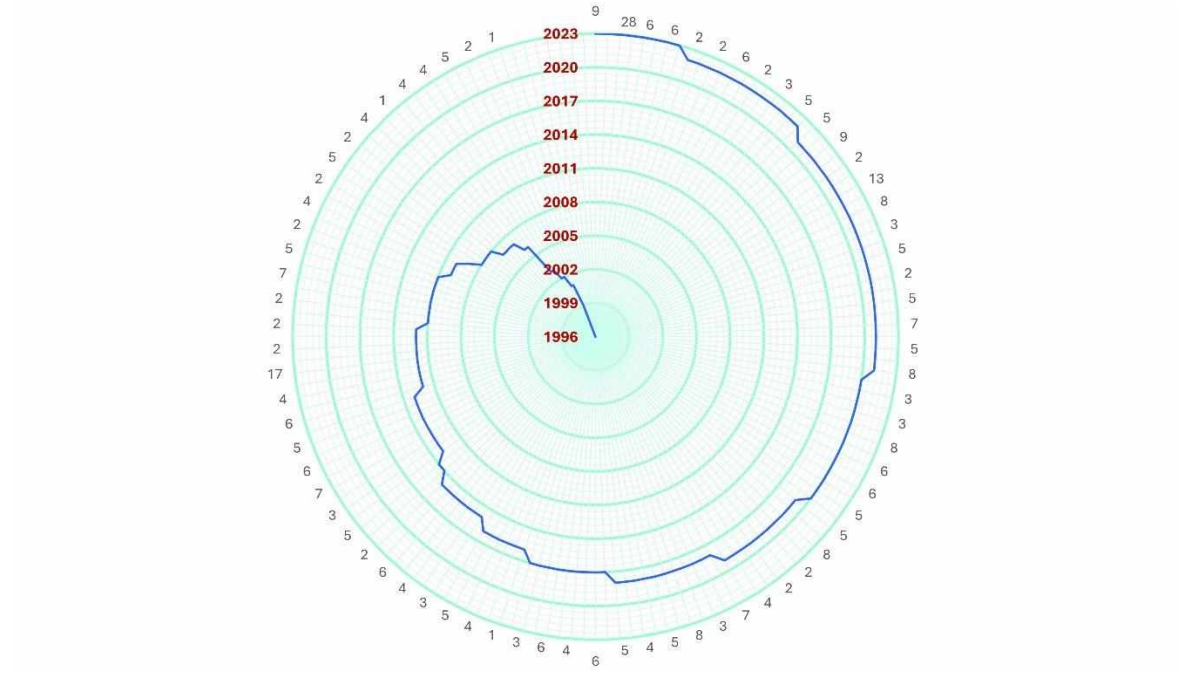

Figure 15. Number of co-authors in papers on mastitis and welfare, in accord with year of publication.

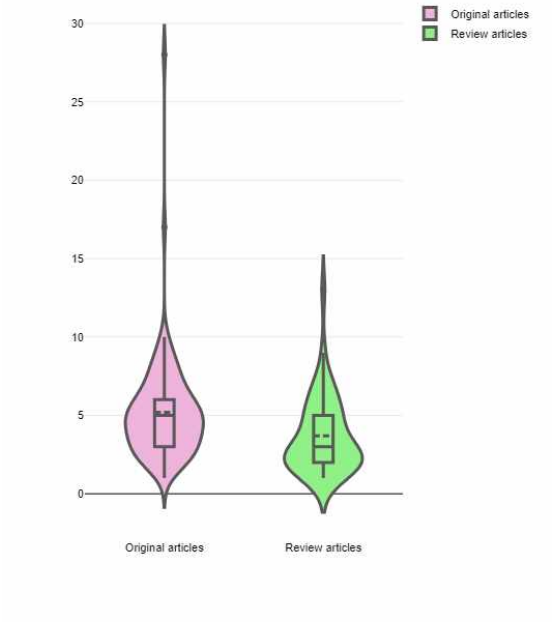

Figure 16. Violin plot of number of authors in original articles (pink) or reviews (green) on mastitis and welfare.

Authors who published > 1 papers were affiliated with scientific establishments in 12 countries (Table 12, Figure 17). One author had affiliations with establishments in two different countries.

Table 12. Number of papers on mastitis and welfare published from authors with > 1 papers as first or last author, in accord with country of origin of papers.

Country	No. of papers published
Austria	2
Canada	1
Denmark	3
Estonia	1
France	2
Germany	3
Italy	2
Lithuania	1
Spain	1
Switzerland	1

United Kingdom	6
United States of America	1

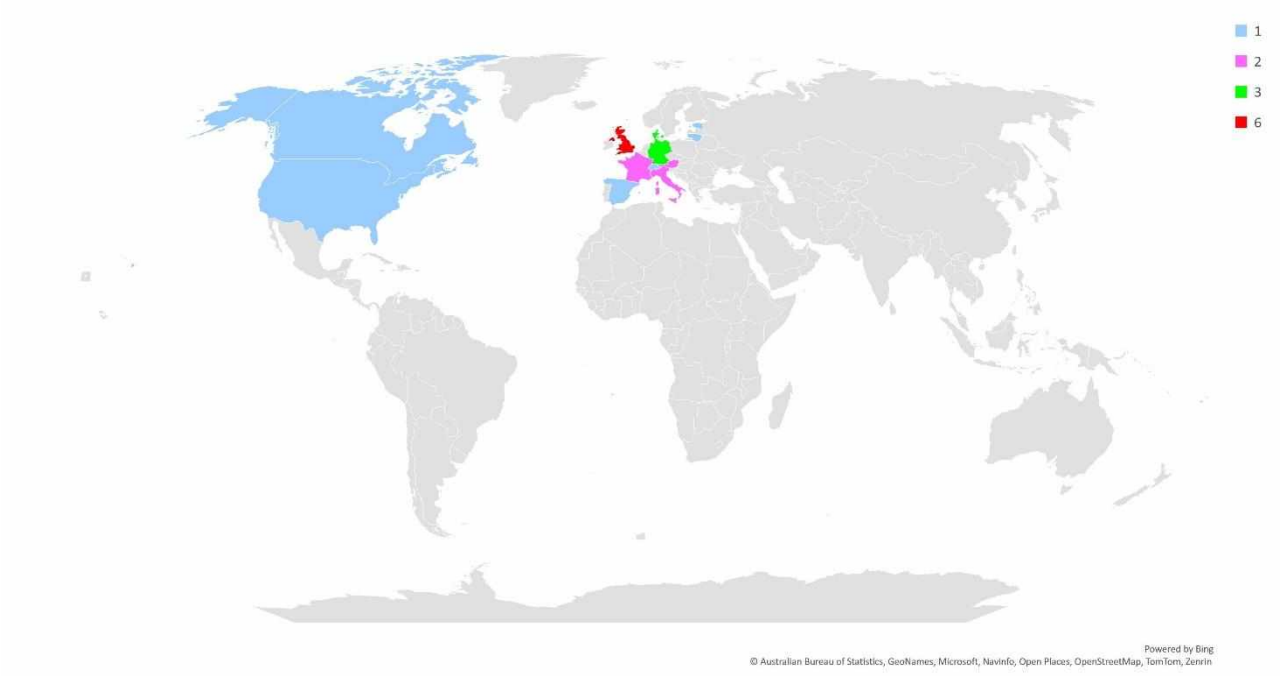

Figure 17. Map of countries in accord with the number of papers on mastitis and welfare published from authors with > 1 papers as first or last author, in accord with country of origin of papers.

There was a significant difference in the median year when papers were published between the 23 authors who published > 1 papers as first or last authors (p = 0.021) (Table 13). Further, there were interactions through the publication of joint papers by 14 of these 23 authors (60.9%) in various combinations (Figure 18).

Table 13. Association of time period with number of authors (for the 23 authors who published > 1 papers as first or last authors) with median year of publication of their papers.

Time period	No. of authors
1971-2000	0
2001-2010	6
2011-2020	13
2021-2023	4

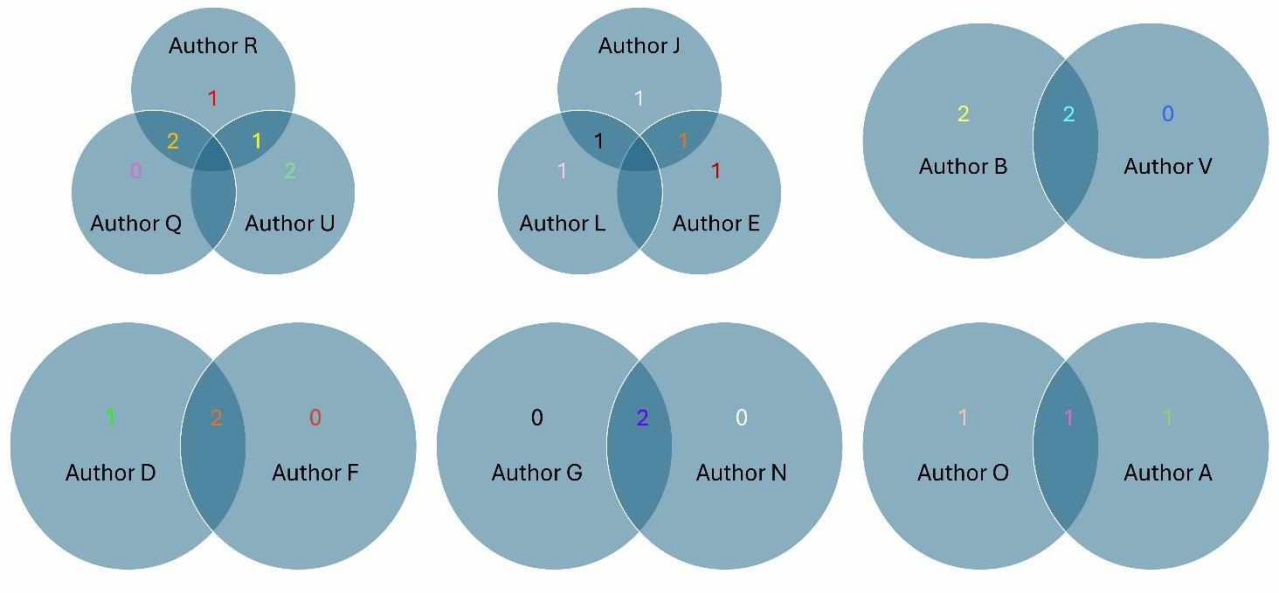

Figure 18. Venn-diagrams of joint published papers on mastitis and welfare published from 14 of 23 authors with > 1 papers as first or last author (descriptors of authors not corresponding to their names).

Accessibility of papers

Most of the papers were published under subscription only access, whilst fewer were published as open-access: *n* = 88 (58.7%) *versus n* = 62 (41.3%) (*p* = 0.003). However, the median year of publication of the latter papers was significantly more recent than of the former papers: 2020 (4) *versus* 2015 (8) (*p* < 0.0001), and the number of papers published under open access increased progressively, whilst that of papers published under subscription only access decreased (p = 0.001) (Figure 19).

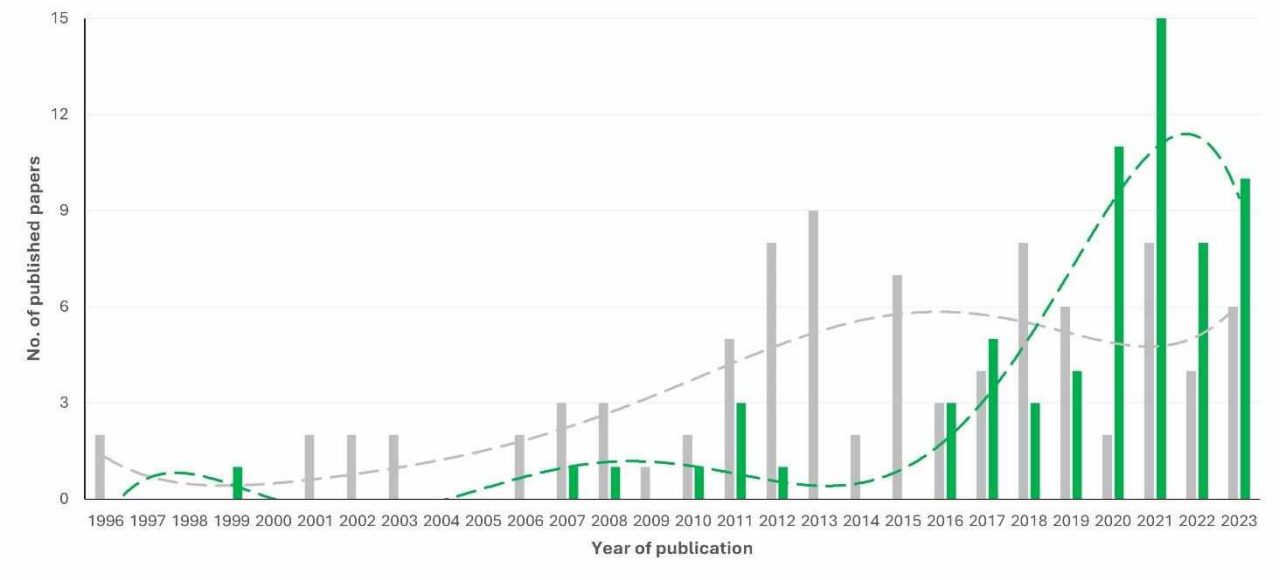

Figure 19. Number of papers published annually on mastitis and welfare of animals from 1990 to 2023 under subscription only (grey) or open (green) access (dashed lines are trendlines).

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