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Review

Lameness in Dairy Cow Herds: Disease Aetiology, Prevention and Management

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Abstract: As livestock production systems have changed to intensive commercial structures to meet the increasing demand for animal-based products, there has been an increase in food production diseases, subsequently resulting in animal welfare issues. After mastitis and infertility, lameness is one of the three major issues affecting dairy cattle globally, resulting in reduced productivity, economic losses, and animal welfare problems. Lameness is associated with reduced milk yield, lack of weight gain, poor fertility, and frequently, animal culling. Environmental (temperature, humidity) and animal risk factors contribute to disease severity, making this multifaceted disease difficult to eradicate and control. As such, prevalence rates of lameness in dairy herds ranges from 17% to 35% globally. Clinical lameness is often treated with antibiotic therapy, which is undesirable in food-producing animals, as outlined in the One Health and the European Farm to Fork food sustainability goals. Lameness is not a single disease in dairy cows but is the manifestation a range of issues, making lameness control one of the greatest challenges in dairy farming. Lameness prevention, therefore, must be a key focus of farm management and sustainable food production. There is an urgent need to establish farm-level aetiology of disease, promote the recognition of lameness, and implement effective control measures to lower incidence and transmission of disease within herds.

Keywords: dairy; foot rot; digital dermatitis; animal welfare; food production; disease control

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1. Introduction

Lameness in dairy herds continues to represent a serious issue, having detrimental impacts on animal welfare, milk production, and farm economics globally. Lameness constitutes any foot or leg condition of infectious or non-infectious origin that negatively impacts cow mobility, posture, and gait [1]. In dairy cows, the main cause of lameness is claw lesions, which are either non-infectious (white line disease, sole ulcer, sole hemorrhage, interdigital hyperplasia) or infectious, including digital dermatitis (DD), interdigital dermatitis, heel erosion, and interdigital phlegmon (foot rot) [2]. Lameness in cows ignites a negative chain, with many impacts on both the farmer and the cow, including reduced milk yield (approximately 20% reduction), loss of reproduction, lack of weight gain, and often, animal culling. Symptoms of clinical infectious lameness include fever, anorexia, reduced milk yield, pain, swelling, and loss of mobility. Lameness in subclinical cases of disease is often not present, but the level of milk production can begin to decline [3], highlighting the importance of early detection. The reduced milk yield will continue, while pain levels become more profound as feed intake declines due to an unwillingness to stand or move for food. The increasing demand for animal-based food products has promoted intensive farming systems and an increase in animal disease and reduced animal welfare [4], proliferating the issue. Lameness caused by digital dermatitis (DD) or Mortellaro (M) and foot rot is highly contagious, transmitting throughout the dairy herd and persisting chronically [5]. Both DD and foot rot are claw diseases with DD ulcers on the planar foot surfaces often extending into the interdigital space, with foot rot being a necrotic infectious disease resulting in foot decay [6]. Identifying causative agents of disease is difficult, as infections often appear polymicrobial in nature and difficult to culture for diagnosis [7]. Genetic sequencing, however, has proven useful in diagnosis where Spirochaete bacteria, specifically *Treponema,* have been repeatedly isolated from cases of invasive digital dermatitis [8]. Other species associated with lameness include *Borrelia burgdorferi*, *Bacteroides*, *Mycoplasma* spp., *Campylobacter* spp., and *Amoebophilus asiaticus* [9], with *Fusobacterium necrophorum* associated with foot rot in cattle and *Dichelobacter nodosus* in sheep. The microbial species colonize the claw and foot via sites of injury related to tissues softening from prolonged standing and walking on abrasive and rough surfaces and the presence of manure [5]. Environmental (temperature, humidity) and animal risk factors (Figure 1) contribute to disease severity, making this multifaceted disease difficult to eradicate and control. Prevalence rates of lameness in dairy herds range from 17% to 35% globally, with intensive farming systems having greater prevalence compared to grass-fed cows, who display reduced incidence of disease [6]. Alarmingly, studies have reported a lameness prevalence of 72% in European dairy herds [2]. Lameness is often treated with antibiotics, resulting in a proliferation of the use of antibiotics in food production, which is not in line with the European Farm to Fork food sustainability goals. The use of antibiotics also requires withdrawal periods where the animal is no longer productive, resulting in financial losses at the farm level. After mastitis, lameness in cattle is a major factor negatively influencing profit and economic stability in dairy farming. This review aims to outline the aetiology of lameness and to highlight suitable disease prevention and management protocols. The author aims to provide a comprehensive instructive article, informing stakeholders on effective control strategies for this challenging disease.

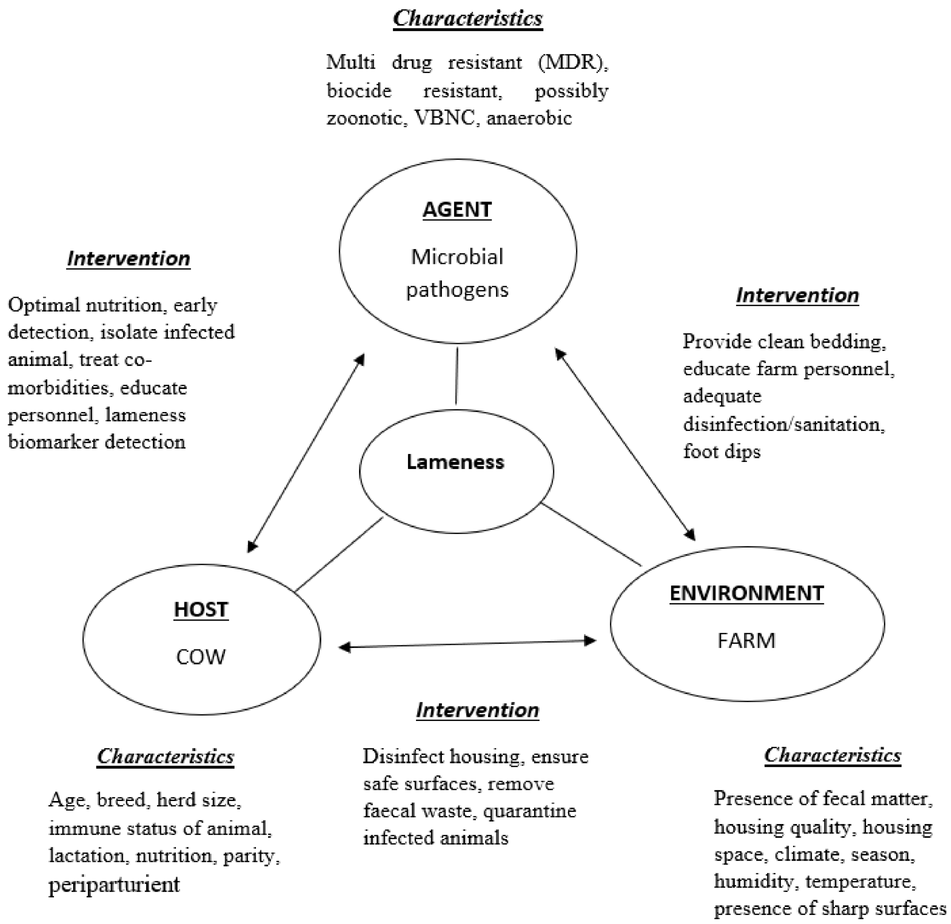

Figure 1. Factors contributing to lameness in dairy cattle, associated characteristics, and intervention methods for disease prevention on dairy farms. MDR = multi-drug resistant, VBNC = viable but non culturable.

2. Disease Aetiology

The prevalent cause of lameness in dairy herds differs depending on the farm, region, and country [10]. Advances in microbial laboratory techniques such as polymerase chain reaction (PCR) assays have provided insight into the aetiology of lameness in animals. As difficult-to-culture or viable-but-non-culturable (VBNC) organisms become easier to identify, their contribution to infectious disease becomes evident. *Treponemes*, the bacterial species historically associated with DD lameness, is extremely difficult to cultivate in a laboratory setting, prohibiting the isolation and confirmation of this pathogen in cases of lameness in the animal environment. Non-pathogenic *Treponeme* species (*T. bryantii* and *T. saccharophilum*) have been identified in cow rumen but are not associated with lameness disease in the animal [11], which also contributes to confusion. DD is typically described as a progression through stages, with the early stage, termed M1, having a small non-painful granulomatous area, M2 displaying painful ulceration, M3 being a healing stage post-treatment, and M4 an infectious chronic stage with proliferation and dyskeratosis [12]. The identification of *Treponeme* species via PCR methods varies at the different stages of DD lesion development, with six groups of *Treponemes* present: *T. denticola*, *T. maltophilum*, *T. medium*, *T. putidum*, *T. phagedenis,* and *T. paraluiscuniculi* [7]. Additionally, *Treponeme* species associated with DD appear to be encysted, allowing for persistence deep within lesions, resulting in the recurrence of clinical DD and avoidance of treatment measures [13] and suggesting that the species present relates to the severity and progression of the lesion. Acquired immunity is activated in DD with antibodies produced by dairy cows; however, this appears insufficient to prevent subsequent infections, as cows are prone to repeat infections [7]. The Gram-negative anaerobic bacterium *Fusobacterium necrophorum* associated with foot rot is present in the environment, bovine rumen, and feces making the causative link easier to establish. *F. necrophorum* produces several toxins, which are virulence factors promoting disease in the animal. In particular, leukotoxin, which is associated with liver disease in infected animals, is cytotoxic to leukocytes, macrophages, ruminal epithelial cells, and hepatocytes [14]. Septicemia is also a risk in younger animals, with infections from *F. necrophorum*. Other species potentially associated with foot rot include *Prevotella melaninogenica*, *Porphyromonas asaccharolytica,* and *Porphyromonas levii* [1]. Chronic cases of foot rot also manifest with tendon and bone tissues as well as long-standing infection, with a failure to respond to antimicrobial therapy [15].

Identifying the etiology of lameness is also hindered by farmer knowledge and perception of the issue, with severely infected animals often only recognized as lame by farm personnel [16]. This raises issues, as the prompt detection and treatment of mildly lame cows is critical in promoting recovery and preventing disease spread. The use of the manual locomotion score (LS) is the gold standard for identifying mild cases of lameness but is not implemented by farmers. The LS is a qualitive assessment of mobility, with a range of 1 (normal gait/walking) to 5 (lameness) implemented to rate lameness in affected animals (Table 1). For example, approximately 90% of DD lesions are found in the hind feet of cows, suggesting that scoring of hind legs would provide an indication of lameness in the herd. More recent techniques, including the pressure nociceptive method (PNT), physiological parameters, biomarkers (cytokines and acute-phase protein haptoglobin), and expression of inflammatory genes in clinically lame cows, have been investigated for use [17]. These novel approaches appear more sensitive and efficient at detecting lameness in cows. Proteomic-based methods, such as the shotgun proteomics approach for identifying plasma proteins, has high efficacy and rapid speed for diagnosing lameness [18].

Table 1. Locomotion score system used as indicator of lameness in cattle.

Locomotion Score	Mobility Impact	Clinical Manifestations
1	Movement is normal, equal weight on all legs [2]	None—normal gait and walking—Normal

Table 1. *Cont.*

Locomotion Score	Mobility Impact	Clinical Manifestations
2	Movement not perfect, but animal willing to move and not hindered	Gait is affected [2], limbs do not share weight, and track is affected, level back standing—Mildly lame
3	Movement is possible but seriously compromised	Lack of tracking, limp visible, short strides [2], arched back standing and lying, reduced milk yield and milkings—Moderately lame
4	Movement is greatly reduced; animal is unwillingly to move [2]	Well-defined limp, loss of tracking, always arched back, unable to put weight on affected limb [19], lying time increased, reduced milk yield and milkings—Lame
5	Movement is severely restricted; animal is unable to move	Short stride [2], unable to put weight on limb [19] and may have additional limbs affected, lying time increased, reduced milk yield and milkings—Severely lame

Risk Factors

The infectious diseases associated with clinical lameness have different etiologies; hence, identifying risk factors is essential for disease prevention [10]. Animal, herd, and farm level risk factors must be considered when determining optimal prevention measures. Risk factors that greatly impact lameness in dairy cows include farm management, nutrition management, the housing environment, animal genetics, and various breeding conditions and technologies [3]. Individual cow immunity plays a role in susceptibility to DD, as some animals can be infected repeatedly within a herd while others of the same breed and parity do not manifest with disease [7]. Holstein–Friesian cows and their cross-breeds are more prone to infection than other breeds [20]. Research shows that first parity (primiparous) increases the risk of developing DD, which may relate to environmental and biochemical changes occurring during pregnancy, with the highest risk for development of DD being in the first month after calving, perhaps related to the immune suppression in the peri-partum period [21]. Additionally, alterations in the connective tissue of the bovine foot occur in periparturient cattle, which decreases resilience to external stressors, ultimately promoting lesion development [22]. Interestingly, Calderon and Cook (2011) also determined that lameness is prevalent during the dry period via observational studies [22]. Foot rot is commonly found in cows during the first two months of lactation [1]. Cows with large bulging udders are also prone to lameness, as their gait is altered to allow movement of the back legs free of the udder, causing an uneven wear of claws [23]. As there is increased risk of hoof lesions and lameness in cows post-calving, the impact of husbandry methods relating to the periparturient cow must be assessed. A change in gait in affected cows is a result of pain caused by lesions on the cow hoof. The growth, formation, and keratinization of healthy hooves is related to animal nutrition, with minerals (calcium, zinc), vitamins, amino acids (cysteine, methionine), and fatty acids (linoleic and arachidonic acid) all essential for structurally sound hoof formation, while nutritional imbalances lead to weak horn formation prone to infectious disease [24]. Feed supplementation with sulfur amino acids, including zinc methionine, may aid in improving horn development at calving. Additionally, underweight animals are more prone to lameness than animals of a good body condition and weight [25]. Importantly, feeding of high-energy nutrition with low roughage-to-concentrate ratio can promote metabolic disease in cattle, including ruminal acidosis, which is associated with laminitis and lameness [23]. Nutritional disorders, including acidosis, promote excessive lactic acid and histamine production and the release of endotoxins, resulting in hemorrhage in the foot horn, laminitis, and ulceration of the foot [3]. Older cattle have a higher prevalence of non-DD lameness, potentially related to their higher parity (lameness increases with increasing parity) and age-related wear and stress on claws [23]. There is a lower prevalence of DD lameness in older cows, potentially due to greater cow immunity [20].

Environmental conditions including temperature and humidity may negatively impact the structural integrity of the digital skin [5], encouraging ulceration, bacterial colonization, and disease progression. Housing environmental conditions, including the absence of bedding and unclean surfaces with high content of fecal matter, is a significant risk factor for infectious lameness [26]. At herd level, housing surfaces, surface abrasions, floor bedding, and cow comfort contribute to lameness [26]. Risk factors associated with lameness in high-producing cows on farms with automated milking systems (AMSs), such as cow overstocking and traffic management [27], are somewhat different than for dairy cattle managed under grazing conditions, where cow walking tracks are a factor [26]. Risk factors associated with animal husbandry, including the presence of damaged concrete in pens and parlor entrances, grazing land also grazed by sheep, the use of automatic scrapers, and a failure to detect and treat lameness within 48 h, have also been identified [28]. The presence of infectious species in lame sheep, including *D. nodosus* and *Treponema* species, may contaminate the land subsequently grazed by dairy cattle, resulting in cow lameness. Such animal-to-animal transmission on shared grazed pasture may increase lameness prevalence in dairy herds [29]. Studies describe the association between reduced time spent lying down and the occurrence of lameness in dairy cows, with stall design in housed cows being a risk factor for reduced lying times and lameness [6]. Stall width and adequate space for lying down are also risk factors increasing standing times [27]. Poor surfaces and damaged concrete may result in hock joint ulcerations and carpal joint injuries, which can become infectious, resulting in cases of lameness [28]. Claw overgrowth and abnormalities have also been identified as a risk factor for lameness; effective claw trimming may reduce this impact [16].

3. Lameness Impact

As the frequency of lameness in dairy herds varies globally, determining the impact of such infectious disease is difficult. The economic impact relates to loss of milk productivity, animal death and culling, reduced reproductive performance, and disease treatment and prevention [30]. The stress of chronic lameness and inflammation can negatively impact ovary function, with poor cycling and ovulation and difficulty with conception.

3.1. Impact on Milk Yield

Studies have shown that reduced milk yield occurs before treatment for infectious lameness but varies with the type of lesion present [19]. Additionally, the reduction in milk yield is greater in older cows and cows with severe lameness [31]. Severe lesions, which are less common, can lead to economic losses three times greater than mild lesions [32]. Delayed treatment may further contribute to a reduction in milk yield due to increased metabolic demands and a lack of mobility, reducing caloric intake. There are contradictory reports on the effect of DD on milk yield, with decreased milk yield evident in some studies and no impact observed in other studies [7]. A possible reason for contradictory information may relate to the identification and classification of lameness. Farmer bias in identifying lame cows hinders any investigation on the impact of lameness on health, reproduction, and milk yield. Therefore, determining the full economic damage caused is problematic and probably underestimated. Importantly, cows with DD have been reported to produce more milk in the months post-treatment than prior to diagnosis, suggesting a correlation [31]. Green et al. (2002) reports that sole ulcers, white line disease, interdigital necrobacillosis, and DD were all associated with reduced milk yield in dairy cows, with a 360 kg reduction in milk yield over the 305 days of lactation [33]. Studies determined a loss of 1.5 kg per day in milk yield compared to non-affected cows [30]. Reduced milk yield occurs pre- and post-diagnosis of clinical lameness and sub-clinical lameness.

Studies assessing milk yield at varying LS determined milk yield decreased at a score of 3 and was more prominent in primiparous than multiparous cows. Dry matter intake (DMI) is a major factor in milk production, with decreasing DMI intake resulting in a poorer milk yield [34]. Lame cows are less likely to stand for feeding, and their DMI is subsequently compromised. Such changes in feeding behavior, DMI, and stress in lame animals affects rumen function and cow nutrition. Additionally, the milk yield of lame cows at the beginning and end of lactation is reduced, with a reduction in the number of daily milkings also evident in an LS of 3 to 5 [34]. High-producing cows also tend to be more prone to lameness, which means the impact of lameness in a high-producing herd can be very pronounced [35]. A reduction in milking frequently is associated with lameness, and a reduction in productivity with an increase in LS, associated with reduced trips to the milking parlor, with 0.3 fewer milkings per day [35]. Lameness due to foot rot or interdigital phlegmon has been shown to decrease milk yield by approximately 10% compared with non-lame cows and is more prominent in multiparous than primiparous cows [15]. Furthermore, protein and fat production is also affected in the milk. Such impact of milk quality will impact food production and food security, as milk is a source of fat and protein in the human diet. The reduction in milk yield from high yielding cows/herds due to lameness will greatly affect farm economics, where a repeatable, reliable assessment method of lameness is needed. Studies also suggest that a reduction in milk production could be used as an indicator of an undiagnosed claw disorder, allowing for early treatment [32]. In cases of subclinical lameness, decreased milk production often manifests prior to the diagnosis of lameness and clinical lameness [3]. Until farm personnel and veterinarians implement such a system, the impact of lameness on dairy production cannot be fully elucidated.

3.2. Additional Impacts of Lameness

The economic impact of lameness at the farm level can be divided into direct (treatment, veterinary, milk withdrawal, reduced milk yield) and indirect costs (culling and replacement, labor, extra days to calving). Studies have shown that lameness influences fertility in dairy cows, where clinical lameness in the first 70 days in milking reduced pregnancy rates by 25% compared to non-lame cows [36]. Indeed, studies report that lameness can negatively impact all aspects of cow reproduction, including delayed cyclicity, anestrus (not showing estrus), and increased rates of cystic ovarian disease [1]. Studies have shown a relationship between severe lameness and delayed estrous cycling and a failure to conceive [15]. Furthermore, when cyclicity occurs, cows with lameness are less likely to stand for mounting compared to non-lame cows and are less likely to become fertilized.

Lameness is also known to extend calving to the first service interval and calving to conception in dairy cows [26]. The average conception rate is lower in lame cows at first service, with a lame cow taking 28 days more to become pregnant [37]. The inflammation associated with infectious lameness may be associated with the increase in time to conception of lame cows. Reproductive efficiency is lower in the early stages of lameness, before, during, and after the breeding season, compared to non-lame cows [26].

Lameness is also associated with increased lying times, which increases the risk of developing mastitis and intramammary infections; this further impacts cow welfare, milk production, and farm economics [4]. If the cow opts for extended lying times post-milking, it may prevent closure of the teat canal, allowing for the entry of environmental pathogens associated with mastitis [4]. Environmental pathogens such as *E. coli*, present in the lying environment, may enter the teat, which remains open post-milking. Studies have shown that increased standing times post-milking are associated with a lower SCC in dairy herds. The incidence of clinical mastitis was found to be lower on farms where feed was provided post-milking to encourage standing [38]. Therefore, increased lying times due to lameness in dairy cows may contribute to increased incidence of mastitis and higher SCC in dairy herds. Additionally, extended lying times result in less feeding and reduced nutritional intake in lame cows. Clinically lame cows having a higher LS score have reduced feeding times, less silage intake, reduced ruminating time, and reduced feeding frequency in comparison to non-lame cows [39]. In terms of animal welfare, the emotional impact of lameness on cows is impossible to determine; the stress induced from chronic pain, however, must not be overlooked. Studies report that cardiovascular function, namely heart rate, respiratory rate, and temperature, increased in chronically lame cows, with increased levels of cortisol and haptoglobin (inflammation biomarkers) in mildly lame cows [5]. The main factors leading to the culling of dairy cows relates to health issues, including mastitis, lameness, and reduced fertility, as well as issues associated with low milk yield and productivity [3]. Lameness in cattle also results in earlier animal culling and lower carcass weight and subsequent lower carcass economic value. Epidemiological studies have shown that dairy herds with a higher prevalence of lameness had 2.9 greater odds of cow fatality compared to farms with lower lameness prevalence [15]. Culling rates appear more influenced by lameness in the mid to late lactation period, with foot rot–associated culling peaking when diagnosed between 61 to 120 days in milk [40]. As lameness is known to influence the incidence of other issues in dairy herds, the costs associated with these secondary issues (infertility, productivity, culling) should be included in the total costs determined for lameness, to provide a clearer indication of the true impact of lameness within the herd. Culling also leads to the replacement of lost animals, often from external farms, which represents a risk of bringing DD (and other infectious diseases) into the herd [37].

4. Disease Management

As with all infectious diseases, the prevention of lameness is critical to reducing its impact at the cow and herd level. For prevention of infectious lameness such as DD and foot rot, attention needs to be given to the sources of infection, methods of transmission, and the risk factors at the animal and herd level. Removing the reservoir of infection will reduce the incidence of disease and risk of transmission within herds. Biosecurity and farm management are particularly important to protect herd health and ensure optimal animal productivity. Claw trimming (CT) conducted by hoof trimmers or veterinarians is part of a farm management system to control both infectious and non-infectious lameness. Trimming aims to ensure proper weight distribution on the medial and lateral claws and is achieved by one of many methods, including the functional trimming or Dutch method, White line, White Line Atlas, and Kansas methods [16]. These procedures have similar aspects; however, they provide differences in sole thickness and so must be carefully considered when used prophylactically or therapeutically [16]. Studies have shown trimming led to lower prevalence and LS in the weeks post-trimming compared to untrimmed cows [41]. The timing of trimming also appears to be an important factor, as evidence shows a lower incidence of lameness in cows trimmed during mid-lactation, where cows trimmed before drying off had lower rates of sole ulcers in subsequent lactations [42]. Additionally, studies indicate that hoof trimming results in increased lying duration, reduced walking, and increased eating time for weeks post-trimming [43], indicating trimming induces discomfort and stress in the animal. For DD, the interdigital cleft is adjusted with trimming, to reduce exposure to environmental feces [24]; long intervals between trimmings are related to higher prevalence of DD [16]. Adequate disinfection of hoof trimming equipment is also essential to prevent pathogen transmission at the time of trimming. The literature suggests that CT is key to preventing lameness on dairy farms but is insufficient for the complete prevention and treatment of infectious lameness, such as DD as a stand-alone method [16]. The use of footbaths containing antimicrobial solutions also aids in preventing infectious lameness. Footbath solutions typically contain glutaraldehyde, quaternary ammonium compounds (QACs), formalin, copper sulphate, or organic acids to control microbial species and improve hoof health. Copper sulphate (5–10%) was used as an antimicrobial agent in replacement of antibiotics (oxytetracycline, erythromycin, and lincomycin) but was banned by the EU in 2006 according to the EU biocide directive [44]. Entire herds are walked through the foot bath, which has the advantage of treating all cows, including carrier cows and those with low grade lesions, thereby reducing transmission within the herd. For the prevention or treatment of infectious hoof disease, the antimicrobial compound will be influenced by the contact time, concentration, foot immersion, presence of organic matter in the bath, and the design and layout of the footbath itself [45]. Studies have shown that with greater footbath length, the number of foot immersions increases and so does contact time to the biocidal solution [45]. Issues arise with disposal of biocidal water containing environmentally hazardous chemicals such as QAC, formalin (toxic and carcinogenic to animals and humans), and copper sulphate, which may hinder the application of footbaths by farm personnel. Footbath water is often discarded into the manure, where it is ultimately applied to fields, leading to distribution of chemicals in soil and water where it can negatively impact terrestrial microbiota. The use of QACs and antibiotics is linked to the development of antimicrobial resistance (AMR) in bacterial species, contributing to the emergence and spread of resistant pathogens in the environment [46]. To avoid issues of using hazardous antimicrobial chemicals, which contribute to environmental pollution, there is an urgent need to develop environmentally friendly, effective biocidal options displaying activity against pathogens associated with infectious lameness. The development of vaccines against the causative agents of infectious lameness has shown little success to date [7], possibly relating to the polymicrobial nature of the infection. There has been some success with vaccination for foot rot in sheep, however, against *D. nodosus* fimbriae, but there is limited cross-protection between serogroups. Multivalent vaccines have proven less effective, with bivalent vaccines against two strains appearing beneficial.

Precision livestock farming (PLF) technologies have been developed to enhance livestock management and offer significant benefits to animal welfare assessment and management of dairy herds [47]. PLF can be applied to dairy farming to monitor animal health and welfare parameters in a continuous and automated way; this will aid in early detection of lameness, improving productivity and disease prevention. The use of automatic welfare systems assessing cow productivity, welfare, and movement data via technological monitoring and evaluation [48] offers real advantages for food production going forward and will contribute to sustainable food production methods. Systems include smart technology, such as sensors, microphones, and cameras connected directly to farm personnel phones and computers in a real-time manner [49]. PLF methods such as sensors attached to individual animals, for example, can collect data on animal movement, temperature, and position, giving indicators of issues relating to lameness and other farm management problems [50]. Injectable sub-cutaneous electronic identification systems may also provide key physiological data, allowing farmers to monitor cases of lameness and response to treatment in affected animals [51]. Accelerometer (monitoring change of velocity) sensors are currently in use as lame animal detection methods in livestock industries [39].

Controlling Lameness towards Sustainable Food Production Goals

Lameness is a devastating condition that challenges the sustainability of food production systems globally due to the substantial pain, animal welfare impact, and economic pressures put on food-producing personnel. Sustainable food production is now a global objective, with food security, climate change, and environmental impact at the core of frameworks and legislation designed to improve food production methods. As the global population increases, so too does the demand for food sources [52]. Additionally, there is increasing consumer awareness relating to animal welfare issues concerning animal health and cruelty in food production processes. These factors must be incorporated into animal welfare management systems implemented at the farm level. The control of infectious diseases including lameness in cattle is an important part of such management systems under the concept of animal welfare and animal health. Personnel involved in food production must also consider the One Health framework, which is based on the concept of an interrelated network between humans, animals, and the environment, where we must safeguard all three components in order to effectively safeguard human wellbeing. Prevention of infectious diseases, including foot rot and DD, are undoubtedly key to the One Health concept. Preventative measures will also reduce the use of antibiotics in herds, thereby reducing the amount of antibiotics in the environment and entering the food chain, improving environmental and food safety. Reducing AMR by limiting the use of antibiotics in food-producing animals is a key goal of One Health, as it recognizes the relationship between animal use and environmental pollution with antibiotics, residuals, and AMR genes [53]. Additionally, preventing infectious lameness will reduce milk wastage due to the withdrawal periods associated with antibiotic administration to dairy cows. This aligns with the Sustainable Development Goals (SDGs) outlined by the United Nations (UN), particularly relating to zero hunger (2), responsible consumption and production (12), climate action (13) and life on land (15). Furthermore, it is understood that animal and human health may be impacted by changes in the distribution and virulence of zoonotic pathogens because of climate change [54]. The Global Action Plan, which involves a group of international organizations, aligns with the SDGs and aims to establish and promote sustainable living and improve the socio-economic wellbeing of individuals through encouraging climate and environmental protection. Infectious disease in food-producing animals negatively impacts the economic status of farmers, by reducing the milk yield from livestock, decreasing trade, and increasing financial pressures relating to disease control and treatment [53]. While effective control measures including food baths must be implemented to control lameness in herds, it is important to consider the biocidal ingredients in footbath solutions in terms of environmental impact. As biocides such as QAC [52], copper sulphate, and formalin are known to have a negative impact on the environment, alternative greener options must be sought to better align with One Health and sustainable food production goals. For the control of DD, concentrations of 2.5% to 12.5% formalin are often used in food baths, with the waste being added to the manure and ultimately being spread as fertilizer [55], where it may impact soil fertility due to antimicrobial action against resident soil organisms. Formaldehyde is a known carcinogen of human and animal cells and is associated with nasopharyngeal cancer and leukemia [56] and asthma at long-term exposure exceeding 3 ppm [21]. Traditionally, copper sulfate has been used as a footbath disinfectant at 5% concentration, as it is considered safer than formalin. However, studies have described the accumulation of copper sulfate in soil, where it may negatively impact crop growth by causing damage to crop roots [57]. The use of peracetic acid or hydrogen peroxide as a greener alternative foot bath solution may offer some advantages. Peracetic acid has rapid environmental degradation and is susceptible to interference from organic matter; the high fecal load present in foot baths may inhibit its otherwise potent activity. Farm management plans should incorporate a pre-cleaning step to remove fecal matter from the hoof prior to walking through the foot bath, as the bath itself becomes loaded with microbes from fecal matter. This would aid in removing the risk of exposure of injured hoofs to large volumes of microbial species and improve the efficacy of all foot bath biocidal solutions [1]. The emergence of infectious disease in both human and animal populations is a major health issue relation to food production and food security. As governments now consider the impact of agricultural expansion and intensification on environmental systems, the full extent of their impacts on infectious disease risk has not been elucidated [58]. As we move forward under the One Health concept, monitoring infectious diseases such as lameness in dairy herds will aid in protecting the environment and its inhabitants. Both One Health and Farm to Fork systems are preventative and all-inclusive approaches and will undoubtedly reduce the risk of disease to animal and human health and, by extension, the economic burden on food producers. The COVID-19 pandemic caused by a zoonotic virus demonstrates the global threat posed by infectious disease and strengthens the need for regulatory frameworks such as One Health to safeguard animal, human, and environmental health.

5. Conclusions

Prevention and early diagnosis are key to controlling infectious disease in dairy herds. Early detection of lameness at all stages of lactation will also impact milk yield and reduce the risk of mastitis within the herd. As farmers move towards automatic milking systems, it is essential to ensure free cow movement towards the milking parlor to ensure economic stability at the farm level. Automatic milking systems implemented correctly can increase the milk yield by 12% while decreasing labor by 18%. The importance of limb health will undoubtedly become more obvious as intensive livestock farming increases globally. Digital dermatitis is the main infectious disease causing lameness, followed by interdigital phlegmon, where genetic susceptibility, immunity, parity, and animal husbandry are all risk factors associated with disease. Controlling or preventing lameness in dairy herds remains a huge challenge for farm personnel and veterinarians. The availability of effective greener biocidal solutions is a factor where current options are toxic to users and the environment. In accordance with the Global Action Plan and One Health approach to reduce AMR while safeguarding animal wellbeing, there is a dire need to develop alternative solutions to the use of antibiotics for treating such infectious diseases. Successful treatment of lame animals is dependent on the ability of farm personnel to recognize the early signs of a lame cow, with most farmers underestimating the rates of lameness in their herds. Educating and encouraging farmers in the early detection of lameness using systems such as the locomotion score are important elements in disease prevention and management. Undoubtedly smart farming technologies such as PLF will aid in moving livestock farming towards a more sustainable type of food production.

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