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Review Article

One Health Approaches to Camel Health, Milk Safety, and Food Security in Pastoral Systems: Opportunities and Challenges in Arid and Semi-Arid Regions

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Abstract

Camels are vital to the livelihoods of pastoral communities across arid and semi-arid regions, particularly in East Africa, where they serve as reliable sources of milk, meat, and income. Camel milk, which provides up to half of household nutrient intake in some areas, is nutritionally superior to bovine milk and contributes significantly to food and livelihood security. Despite their resilience, camels remain susceptible to a wide range of infectious and parasitic diseases, while challenges such as inadequate veterinary services, poor husbandry practices, and climate change further threaten their productivity. These issues also heighten the risk of zoonotic transmission, as close human animal interactions in pastoral systems facilitate the spread of pathogens. The One Health framework offers an integrative approach to address these challenges by linking animal, human, and environmental health through collaborative surveillance, biosecurity, vaccination, and community engagement. Applying One Health in camel health management not only improves milk productivity and quality but also enhances food safety, supports pastoral resilience, and contributes to broader food security goals. This review highlights the opportunities and barriers to implementing One Health strategies in pastoral contexts and underscores the importance of cross-sectoral collaboration for sustainable camel health management.

Keywords

Camel Health, Food Security, Milk Production, Pastoral Communities, One Health

1. Introduction

Camels play a vital role in the livelihoods of pastoral communities living in arid and semi-arid regions of Africa, the Middle East, and Asia. The global camel population is estimated at 35– 40 million, comprising about one million Bactrian camels (two-humped) and the rest dromedaries (one-humped). Approximately 86% of the world's dromedary camels are found in Africa, with the highest concentrations in East and Central African countries such as Somalia, Chad, Sudan, Ethiopia, and Kenya. Africa is also the leading producer of camel milk, accounting for nearly 90% of the world's fresh whole camel milk output [4, 41]. Projections suggest that the global camel population will surpass 60 million within the next 25 years [27].

Camels are increasingly recognized as sustainable livestock due to their multipurpose roles and exceptional adaptation to

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harsh climates [30, 51]. Within pastoral systems, milk production is the primary reason for camel husbandry. Unlike cattle, sheep, and goats, camels continue to provide reliable milk during dry seasons and prolonged droughts, when other livestock species drastically reduce output [4]. For many pastoral households, camel milk contributes up to half of daily nutrient intake, making it a critical source of food security [25, 63].

Despite this significance, camel health remains under-researched and poorly integrated into livestock development programs. Although camels are relatively resilient compared to other livestock species, they remain susceptible to a wide range of viral, bacterial, and parasitic infections [44]. Pastoralists also face limited access to veterinary services, drug supplies, and professional technical support, which undermines productivity and disease management [18, 72]. These health challenges are further aggravated by climate change, land degradation, and increasing human–animal interactions that heighten the risk of emerging and re-emerging zoonoses. Practices such as communal watering points and close daily contact between humans and camels facilitate the transmission of zoonotic pathogens, posing considerable risks to both animal and public health [49].

The spread of emerging diseases is accelerated by the interplay between human, animal, and environmental dynamics, compounded by rapid population growth, urbanization, intensification of agriculture, livestock wildlife interfaces, and globalization of trade [46]. Addressi ng these challenges requires a holistic approach that links human, animal, and ecosystem health. The One Health framework provides this integrated perspective, promoting collaborative prevention and control strategies at the interface of animal, human, and environmental health [35, 50].

Key strategies include camel vaccination, biosecurity measures, hygienic food handling, and public health education, all of which help to minimize zoonotic transmission risks [2]. Strengthening camel health management is therefore essential for not only improving milk productivity and food security but also for supporting both domestic and international camel milk trade [53]. Therefore, the objectives of this review are:

1) To highlight the role of one health in improving milk quality and safety in pastoral communities.
2) To explore how the one health approach can be applied to strengthen camel health for enhanced milk production and food security in pastoral communities.
3) To highlight the major health and production challenges affecting camels in pastoral communities.

2. Literature Review

2.1. Role of Camels in Livelihood and Nutrition

Camels are among the most important livestock sustaining pastoral and agro-pastoral livelihoods across the Horn of Africa, North Africa, the Middle East, and parts of South Asia [26]. In Ethiopia, they are concentrated mainly in the Somali, Afar, and Borana regions, where they provide milk, meat, transport, and cultural value, ensuring both economic sustenance and social resilience [52, 59].

Camel milk is the most significant product, serving as both a primary source of nutrition and a major income stream. In the Somali Region of Ethiopia, households obtain over 60% of their daily caloric intake from camel milk, underscoring its central role in food security [40]. Women are often at the forefront of camel milk marketing, which strengthens their economic empowerment and decision-making within households [43]. In Kenya, the commercialization of camel milk has expanded, particularly in urban centers such as Nairobi and Garissa, where women dominate informal supply chains [66].

Nutritionally, camel milk is distinct from bovine milk, with up to three times more vitamin C, higher iron levels, and protective proteins such as lactoferrin, lysozyme, and immunoglobulins [71]. Evidence from Ethiopia shows that preschool children who consumed camel milk had significantly lower rates of anemia compared to those consuming bovine milk, demonstrating its role in addressing micronutrient deficiencies [61].

2.2. Challenges in Camel Health and Production

Although camels are highly resilient and multifunctional, pastoral production systems face significant health, production, and market-related challenges that constrain their contributions to food and livelihood security [59]. A major concern is the microbial contamination of raw camel milk, often linked to unhygienic handling, absence of pasteurization, and lack of cold-chain facilities. These conditions compromise consumer safety and limit the integration of camel milk into formal markets [1].

In Ethiopia, commercialization of camel milk is further hindered by inadequate infrastructure, limited processing facilities, adulteration, and inconsistent supply [43]. By contrast, Kenya has developed stronger value chains, supported by cooperatives and semi-formal processing facilities, illustrating models that could be adapted in Ethiopia [66].

Environmental pressures compound these challenges. Climate change manifested in rising temperatures, recurrent droughts, and growing competition over rangeland intensifies stress on pastoral systems. While camels are more drought-tolerant than cattle, extreme climatic variability still reduces milk yields and heightens pastoral vulnerability [28, 36].

2.2.1. Common Diseases and Health Constraints

Although camels are more resistant to certain tropical diseases than cattle, they remain susceptible to a range of viral, bacterial, and parasitic infections [44]. Notable viral diseases include camel pox and peste des petits ruminants (PPR), while bacterial infections such as brucellosis pose both productivity losses and zoonotic risks [67]. Parasitic infections, including

trypanosomiasis and gastrointestinal helminths, are also widespread, contributing to weight loss, reduced milk yield, and higher mortality [4]. Mastitis is a further concern, as this common bacterial infection in lactating camels significantly compromises both milk quality and safety [62].

The burden of these diseases is worsened by limited access to veterinary services in pastoral areas. Many households depend on ethno veterinary remedies or informal drug markets, often leading to inappropriate or ineffective treatments [72]. Shortages of trained professionals, weak surveillance systems, and the absence of systematic vaccination programs exacerbate the challenges [18]. Consequently, camel diseases not only reduce productivity but also undermine public health and restrict the expansion of camel milk into formal markets.

2.2.2. Nutritional and Environmental Stressors

Nutrition remains a major constraint in camel production systems. While camels are efficient browsers capable of thriving on sparse vegetation, recurrent droughts and overgrazing limit the availability of quality forage [5]. During extended dry seasons, camels must travel long distances to access feed and water, leading to energy deficits, poor body condition, and reduced milk yields [26]. Water scarcity not only depresses milk production but also weakens immunity, increasing vulnerability to disease [11].

Environmental stressors intensify these nutritional pressures. Climate change has amplified drought frequency and accelerated land degradation, while the spread of invasive species such as *Prosopis juliflora* has reduced the supply of palatable browse [21, 81]. Pastoralists' traditional coping strategy mobility is increasingly constrained by settlement expansion, land fragmentation, and conflicts over rangeland resources [22]. These dynamics collectively erode pastoral resilience and undermine the sustainability of camel production systems.

2.3. Implications for Milk Yield and Quality

Although camel milk is generally safe when consumed fresh, significant food safety concerns emerge due to unhygienic milking practices, contamination during storage and transport, and the absence of formal quality control systems [1]. In pastoral settings, milk is often transported long distances without refrigeration, creating conditions that favor microbial proliferation and spoilage [27]. Studies in Ethiopia and Kenya have identified pathogens such as *Escherichia coli*, *Salmonella spp.*, and *Staphylococcus aureus* in raw camel milk, raising serious public health risks [38, 41]. The lack of structured quality assurance further restricts commercialization. In Ethiopia, informal markets dominate distribution, where adulteration with water or milk from other species is common [24]. Inadequate pasteurization facilities and poor hygiene practices across the value chain undermine both safety and consumer confidence [37]. By contrast, Kenya has developed semi-formal and formal processing plants, providing a useful model for Ethiopia to strengthen milk safety and expand market opportunities [66].

2.4. The One Health Concept: Principles and Relevance

2.4.1. Definition and Core Components

The One Health concept recognizes the interconnectedness of human, animal, and environmental health, and promotes collaborative approaches to disease prevention and control [50]. Originally rooted in veterinary public health, the framework has gained global momentum as a response to emerging and re-emerging zoonotic diseases, antimicrobial resistance, and ecosystem degradation [84].

In pastoral systems, where close interactions between humans, livestock, and the environment are routine, One Health is particularly relevant. Camels often share water sources and grazing areas with other livestock species, while herders depend heavily on camel milk for nutrition. These interconnections create opportunities for zoonotic transmission, but also pathways for integrated solutions [49].

Applying a One Health approach enables simultaneous improvements in animal health, food safety, and public health. Strategies include joint surveillance systems, cross-sectoral vaccination campaigns, antimicrobial stewardship, and promotion of hygienic milk-handling practices [35]. Beyond health outcomes, One Health fosters collaboration among veterinarians, physicians, environmental scientists, and community actors, thereby strengthening resilience in pastoral communities.

2.4.2. Core Components

The One Health framework is not only a theoretical paradigm but also a set of operational components that guide its application in research, policy, and practice. The One Health High-Level Expert Panel (OHHLEP), together with the Quadripartite agencies (FAO, WHO, WOAH, and UNEP), has outlined the core elements necessary for effective and sustainable One Health interventions [3, 30]. These include multisectoral collaboration, transdisciplinarity, systems thinking, integrated surveillance, risk management, governance, community empowerment, capacity development, research, and monitoring and evaluation [45, 80].

Multisectoral collaboration: One Health requires cooperation among human, animal, plant, and environmental health systems. Institutional partnerships support joint planning, coordinated resource mobilization, and policy alignment. Such coordination has proven effective in controlling zoonoses like avian influenza and rabies [13, 16].

Transdisciplinary engagement: Beyond sectoral coordination, One Health promotes convergence of diverse disciplines medicine, veterinary science, ecology, economics, and social sciences. This broad engagement generates solutions that address biological, environmental, and socioeconomic determi-

nants of health [20]. Importantly, it also involves non-academic actors such as policymakers, farmers, and indigenous knowledge holders [67].

Systems thinking: By recognizing dynamic interactions among animals, people, and ecosystems, systems thinking provides a holistic understanding of challenges such as climate change, food security, and disease emergence. It helps identify leverage points for interventions that address root causes rather than symptoms [15].

Surveillance and information sharing: Effective One Health practice depends on surveillance networks that integrate human, animal, and environmental health data. Such monitoring enables early detection and rapid response to zoonoses, antimicrobial resistance (AMR), and foodborne illnesses [37]. Electronic platforms and harmonized reporting systems are prerequisites for success [60].

Risk assessment and management: Joint risk assessments facilitate evidence-based prioritization of threats such as pandemics, foodborne diseases, and climate-related risks. Tools like the Quadripartite's Joint Risk Assessment (JRA) enable structured decision-making across sectors. Risk management emphasizes prevention, preparedness, and resilience, shifting action from reactive to proactive measures [24].

Policy and governance: Strong governance frameworks are vital for institutionalizing One Health. The Quadripartite One Health Joint Plan of Action provides a roadmap for mainstreaming One Health into national plans, aligning financing mechanisms, and ensuring accountability. Political will, policy coherence, and global–local coordination are essential for sustainability [6].

Community engagement and equity: Local actors—including pastoralists, farmers, and communities are central to One Health implementation. Their participation ensures culturally appropriate, equitable, and sustainable approaches. Community-based surveillance and grassroots governance strengthen early warning systems and foster trust in interventions [22].

Research, innovation, and evidence generation: Interdisciplinary research on zoonotic spillover, AMR, food systems, and ecological change underpins evidence-based practice. Socioeconomic and behavioral research further enhances understanding of human–animal– environment interactions and supports creative interventions [20, 79].

Monitoring, Evaluation, and Learning (MEL): Systematic monitoring and evaluation are crucial for assessing the effectiveness of One Health programs. Indicators of success include reduced zoonotic outbreaks, improved AMR stewardship, and greater ecosystem resilience. MEL processes strengthen accountability, adaptive learning, and continuous improvement [60].

2.5. Applications in Camel Health

2.5.1. Prevention and Control of Zoonotic Diseases

Livestock serve as reservoirs for over 60% of zoonotic pathogens transmitted to humans [47]. Applying One Health in animal systems supports integrated surveillance and vaccination programs targeting diseases such as brucellosis, anthrax, and Rift Valley fever [13]. Integrated livestock–human vaccination campaigns, including those for dog-mediated rabies, have proven cost-effective and health-beneficial [41]. One Health also emphasizes understanding the factors that increase human wildlife contact, enabling predictive approaches to disease emergence and early identification of potentially zoonotic pathogens [14].

2.5.2. Antimicrobial Resistance (AMR)

Animal husbandry practices in different livestock production systems and increased livestock– wildlife interactions are thought to be primary drivers of antimicrobial resistance (AMR) in Arid and Semi-Arid Lands (ASALs). Despite a tenfold increase in the camel population within the last decade, paired with widespread use of camel products, there is a lack of comprehensive information concerning antimicrobial resistance within these production systems [73]. One Health strategies in livestock in general include antimicrobial stewardship, biosecurity measures, and alternatives such as vaccines and probiotics [68]. The Quadripartite's Global Action Plan on AMR advocates integrating veterinary and human antimicrobial surveillance to curb resistance [30].

2.5.3. Food Safety and Security

Safe and sustainable livestock production underpins nutrition and public health. Foodborne pathogens including Salmonella, *E. coli*, and *Campylobacter* are closely linked to livestock and require cross-sectoral interventions [39]. One Health promotes farm-to-fork surveillance, good husbandry practices, and environmental management to reduce contamination risks. Healthier livestock enhance food security and strengthen trade opportunities [32].

2.5.4. Climate Change and Environmental Pressures

Climate change exacerbates camel health challenges by altering disease vectors, water availability, and forage quality. One Health addresses these pressures through ecosystem-based adaptation, including sustainable grazing, rangeland restoration, and integrated livestock– wildlife health monitoring [73]. By combining livestock health measures with environmental sustainability, One Health strengthens the resilience of pastoral and mixed farming systems [56].

2.6. Benefits for Human, Animal, and Environmental Health

2.6.1. Benefits to Human Health

One Health principles offer substantial benefits to human health. Preventing zoonotic diseases is critical, as over 70% of human zoonoses originate from animals [47]. Integrated hu-

man–animal vaccination programs, such as rabies control, reduce mortality and are cost-effective [13]. Coordinated antimicrobial stewardship across human and veterinary medicine minimizes resistant infections [79]. Enhanced surveillance and pathogen control in livestock production reduce foodborne diseases like Salmonella and *Campylobacter* [39]. One Health approaches also improve early detection of spillover events and outbreak responses, as evidenced during COVID-19 [22].

2.6.2. Benefits for Animal Health

One Health improves animal health through preventive and integrated measures. Structured surveillance identifies disease outbreaks in livestock and wildlife, reducing morbidity and mortality [16]. Mass vaccination against brucellosis and anthrax enhances livestock productivity and farmer income [83]. Policies promoting biosecurity, husbandry, and nutrition improve welfare and reduce economic losses, while strengthening food security and enabling trade [32, 68].

2.6.3. Benefits to Environmental Health

One Health extends beyond human and animal health to support ecosystems. By reducing excessive use of antibiotics, pesticides, and poor waste management, OH minimizes ecological disruption [60]. Integration with climate-smart agriculture improves resilience in livestock and crop systems [56]. Healthy ecosystems provide essential services pollination, clean water, and disease regulation thereby safeguarded through OH practices [15]. Both OH and planetary health promote sustainable resource management and acknowledge environmental determinants of disease [77].

2.7. Applying One Health in Camel Health Management

Camel health has historically received less attention than cattle, sheep, and goats, despite their crucial roles in arid and semi-arid regions for milk, meat, transport, and income [26]. Camels are reservoirs for zoonotic pathogens such as Middle East Respiratory Syndrome coronavirus (MERS-CoV), brucellosis, Rift Valley fever, and trypanosomiasis, posing significant risks to both animal and human health [58]. The One Health approach integrates environmental, animal, and human surveillance to establish early-warning systems and implement effective disease control measures [3].

2.7.1. Integrated Disease Surveillance and Control

Integrated surveillance enables simultaneous monitoring of camels, humans, and wildlife, facilitating early outbreak detection [31]. The Integrated Disease Surveillance and Response (IDSR) strategy strengthens disease monitoring and response at community, district, and national levels. One Health strategies research and surveillance, policy development, capacity building, and community engagement support sustainable camel health programs [9, 78].

Event-based surveillance and standardized reporting systems connecting veterinary laboratories and human health structures improve outbreak mapping and guide unified interventions [65, 80]. Community participation in surveillance design further enhances responsiveness and inclusion of One Health principles [8].

In Ethiopia, the IDSR strategy is incorporated into the National One Health Strategic Plan, enhancing the country's capacity to prevent, detect, and respond to infectious diseases. Transboundary camel movements necessitate regional IDSR systems for diseases like Rift Valley fever. IGAD's Animal Health Strategy promotes One Health coordination for transboundary zoonoses, reinforced through IGAD/ILRI forums focusing on cross-border surveillance and knowledge sharing on camelid health [43].

2.7.2. Cross-Sector Collaboration: Veterinary, Public Health, and Environment

Effective camel health management relies on collaboration among veterinary, public health, and environmental sectors. Traditional practices often operate in isolation, neglecting the interconnections between human, animal, and environmental health. One Health provides a framework for integrated management, enabling joint surveillance, timely outbreak detection, and coordinated interventions [69, 80, 42].

Veterinary Sector: Veterinarians are central to camel health, overseeing disease surveillance, diagnosis, vaccination, and treatment. They detect zoonotic diseases at the animal–human interface, ensure hygienic production of camel products, and facilitate transboundary livestock trade through veterinary certification aligned with global standards [84].

Public Health Sector: Public health programs integrate human health outcomes into camel health initiatives, implementing combined vaccination campaigns against brucellosis or Rift Valley fever, managing antimicrobial use, and promoting health education to enhance disease prevention and treatment-seeking behaviors among pastoralists [65, 79].

Environmental Sector: Environmental monitoring addresses ecological determinants of camel diseases, such as vector-borne diseases influenced by climate and habitat conditions [85]. This sector supports outbreak prediction, climate adaptation, habitat preservation, and risk assessment for emerging zoonoses [55].

2.7.3. Socio-Economic and Policy Dimensions

Effective camel health management requires enabling governance, policy coherence, and stakeholder engagement. Participatory epidemiology combines traditional knowledge with scientific methods to improve pastoralist surveillance systems [12]. Sustaining One Health programs depends on public–private partnerships and intersectoral funding arrangements [84].

2.8. One Health and Food Security Linkages

2.8.1. Milk Production as Food and Income Source

Camel milk is critical for livelihoods in arid regions of Africa and Asia, providing nutrition and income [25]. For desert-dwelling and nomadic populations, camel milk may supply up to 50% of nutrient intake, often serving as the primary motivation for camel husbandry [63, 70]. Fresh and fermented camel milk offers unique nutritional and medicinal benefits [48]. Despite challenges like water scarcity and limited pasture, pastoral households continue producing diverse livestock products year-round [23].

2.8.2. Gender and Equity Considerations

Pastoralism supports global food security and resource conservation but faces challenges including poverty and resource degradation [19, 51]. Pastoralist women experience compounded marginalization due to gender roles, household responsibilities, and limited decision-making authority [9, 29, 34]. While men typically manage herd movements, women oversee household care and remaining livestock, bearing a disproportionate workload. Women's critical contributions to livestock management are often overlooked, and they have limited access to resources and income opportunities, particularly with high-value livestock [76, 74].

2.9. Challenges and Barriers to One Health Implementation

2.9.1. Institutional and Policy Gaps

Despite recognition by agencies like WHO and APHA, One Health implementation faces socio-political challenges. Many countries emphasize reactive treatment over proactive prevention, with weak governance hindering coordination and resource mobilization [15, 82, 17]. Decentralized governance often fragments sectoral efforts, with misaligned policies and regulations reducing synergy [20]. Strong stakeholder partnerships, political commitment, sustainable financing, capacity building, and community engagement are essential for effective One Health programs [10, 75].

2.9.2. Community Awareness and Participation

Limited community engagement and low awareness of One Health principles impede effective implementation. Education initiatives enhance understanding, encourage behavior change, reduce mistrust, and improve stakeholder buy-in [33, 64]. Capacity building for health workers in zoonotic disease diagnosis, environmental monitoring, and risk assessment is critical in developing countries [57].

2.9.3. Resource and Infrastructure Limitations

Resource scarcity is a major barrier in low- and middle-income countries, restricting delivery of essential human, animal, and environmental health service [7, 54]. Financial and human resource shortages hinder effective execution of One Health interventions, delaying or interrupting implementation and limiting professional networks across sectors [24, 82].

3. Conclusion and Recommendations

Camel health is central to the livelihoods, nutrition, and food security of pastoral communities, especially in arid and semi-arid regions. This review demonstrates that while camels are highly resilient animals, they remain vulnerable to a range of infectious, parasitic, and management-related health challenges. These issues not only undermine milk productivity but also pose risks of zoonotic disease transmission, directly impacting human health. The One Health framework provides a holistic and effective strategy to address these challenges by integrating human, animal, and environmental health interventions. Strengthening camel health through this approach can significantly improve milk yield and quality, enhance household nutrition, reduce poverty, and build resilience against the impacts of climate change. However, successful implementation requires multisectoral collaboration, adequate resources, and the engagement of pastoral communities in disease prevention and control.

Based on the findings of this review, the following recommendations are proposed:

1) Strengthen veterinary services, improve access to veterinary infrastructure, trained personnel, and camel-specific health interventions such as vaccination and parasite control.
2) Enhance one health collaboration foster partnerships between animal health, human health, and environmental sectors to improve surveillance, early warning, and response systems for emerging zoonotic diseases.
3) Promote community engagement involve pastoralists in participatory training and awareness programs that improve husbandry, biosecurity, and milk hygiene practices.
4) Support research and innovation encourage research on camel-specific diseases, climate adaptation strategies, and milk processing technologies to enhance productivity and safety.
5) Policy and investment governments and development partners should integrate camel health into broader livestock and food security policies, while allocating resources for one health-based interventions in pastoral regions.

Abbreviations

AMR	Antimicrobial Resistance
CSA	Central Statistical Agency
FAO	Food and Agriculture Organization
ILRI	International Livestock Research Institute

NGO	Non-Governmental Organization
OIE	World Organisation for Animal Health (now WOAH)
SDG	Sustainable Development Goal
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNICEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International Development
ZDs	Zoonotic Diseases

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Olana Merera: Formal Analysis, Investigation & Validation

Conflicts of Interest

The authors declare no conflicts of interest.

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