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Emerging and re-emerging Zoonotic Viral Diseases Affecting Farm Animals in the Sultanate of Oman: A review of Current Situation

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ABSTRACT

In recent years, the emergence and re-emergence of zoonotic viral diseases have posed a growing threat to Oman's agricultural sector, significantly impacting farm animal health and productivity. This review provides an in-depth examination of the current status of zoonotic viral diseases affecting farm animals in the Sultanate of Oman. Utilizing a comprehensive analysis of existing data and scientific literature, it details the prevalence and impact of these diseases on animal populations and the broader agricultural landscape. The paper specifically focuses on key zoonotic viruses such as Crimean-Congo hemorrhagic fever, rabies, and Middle East Respiratory Syndrome coronavirus, highlighting their modes of transmission and the challenges they pose to both animal and public health. It underscores the critical need for a coordinated and integrated One Health approach, which encompasses human, animal, and environmental health, to effectively manage and prevent the spread of these zoonotic viruses. By addressing current gaps in knowledge and outlining future research priorities, this paper aims to inform policymakers and stakeholders about the necessary strategies to enhance surveillance, prevention, and control measures in Oman's agricultural sector.

Keywords: Emerging; zoonotic; viral diseases; Oman; Farm animals.

INTRODUCTION

Climate has changed throughout history, and most of these changes are attributed to the amount of solar energy obtained as a consequence of alteration to Earth's orbit.

(Callery 2019; Rupasinghe, Chomel, and Martínez-López 2022). An outcome of climate change - as well as globalization - is increasing people worldwide's exposure to emerging and re-emerging zoonotic diseases. In addition to these, changes in human traveling and behavior in the consumption and processing of food, animal housing, and management (Gebreyes et al. 2020; Hedger, Barnett, and Gray 1980). Emerging viral diseases are defined as viral diseases whose incidents have increased in the past two decades, or threaten to increase shortly (Howard and Fletcher 2012). They are the causative agents of new or previously unrecognized infections that represent a public health risk by spreading pathogens with potential zoonotic, and they pose a growing threat to global health, economy, and safety. (Vonesch et al. 2019).

The Sultanate of Oman possesses a hot and dry climate, except for Dhofar province, which enjoys relatively cool and rainy weather during the monsoon season. In Oman, the veterinary practice has its role in public health through animal health, medical research, and environmental health. Furthermore, in areas of zoonotic disease prevention and control veterinary epidemiologists contribute -as well- to both public and animal health research with a wide range of methodological approaches and via networks working in the area (Sargeant 2008). Notable diseases are reported to the Ministry of Agriculture and Fisheries via veterinary officials and to the World Organization for Animal Health (OIE). These diseases include bacterial pathogens such as tuberculosis, brucellosis (endemic in Dhofar), acute gastroenteritis, and some viral pathogens such as viral hepatitis, Human immunodeficiency virus, influenza, leprosy, rabies, and Crimean-Congo hemorrhagic fever. (Scrimgeour, Mehta, and Suleiman 1999; Talbot, Kulkarni, and Colautti 2021). Farm and agricultural laborers, veterinarians, butchers, animal handlers, healthcare professionals, and military personnel comprised most of the occupational risk groups. Despite having a low death rate and accounting for only 8% of Oman's notifiable diseases, travel-associated infections have the potential to generate epidemics that could overwhelm the country's healthcare system (Al-Abri et al. 2015).

This review focuses on the status of zoonotic viral illnesses affecting farm animals in Oman over the past eight years. It aims to highlight One Health initiatives for disease inquiry, prevention, and management. Given the limited number of published studies on the prevalence of newly emerging viral infections in farm animals in Oman, a knowledge gap exists on this topic. The data collected over the past eight years will offer insight into the current situation concerning these diseases in the Sultanate.

Selected diseases were chosen for their potential zoonotic transmission, including

Crimean-Congo hemorrhagic fever (CCHF) swRabies, and Middle East Respiratory Syndrome Coronavirus (MERS-CoV). To identify the factors influencing the selection of control measures, clinical manifestations in humans and animals, as well as the mode of transmission, were documented. This comprehensive approach aims to provide a better understanding of the dynamics of zoonotic viral illnesses in Oman and inform strategies for their prevention and control.

MAJOR EMERGING ZOONOTIC VIRAL DISEASES AFFECTING FARM ANIMALS IN OMAN:

Crimean-Congo Hemorrhagic Fever (CCHF)

Crimean–Congo hemorrhagic fever (CCHF) stems from a virus classified as a member of the genus Orthonairovirus within the Nairoviridae family in the order Bunyavirales. The Bunyaviridae family, encompasses various genera including Orthobunyavirus, Hantavirus, Phlebovirus, and Tospovirus. Bunyaviruses, ranging from 90 to 120 nm in diameter, exhibit a spherical structure. The viral envelope comprises two glycoproteins (G1 and G2) surrounded by three unique negative-sense RNA segments linked with protein structures termed nucleocapsids. These nucleocapsids consist of large (L), medium (M), and small (S) RNAs associated with the RNA-dependent RNA polymerase (L protein), alongside two nonstructural proteins (NSs and NSm). Unlike other negative-sense RNA viruses, bunyaviruses lack matrix protein. Historically, the classification of bunyaviruses relied on antigenic relationships, with serogroups grouping viruses based on their reactivity in serologic tests (Fields et al. 2001; Contigiani, Diaz, and Tauro 2017).

Epidemiology and Pathogenesis

Human cases of CCHF were reported in Oman from 1995 to 2017, with a notable mortality rate of 36.4% (32 out of 88 cases) during that period. Many cases emerged during the Eid-Al-Ahda, which falls in the summer months. Factors related to climatic conditions, particularly tick activity, were identified as pivotal contributors to the seasonal variations in human infection risk, as observed in other parts of the world. Contrary to earlier assumptions, sporadic cases were not solely linked to the importation of infected livestock. Although a substantial number of animals is imported to Oman annually, this connection was less direct than previously thought (Alam et al. 2017).

Vaccines and Control

Despite ongoing efforts, no controlled efficacy studies have been conducted on the CCHF vaccine, leading to its lack of licensure by the European Drug Agency and the US Food and Drug Administration. This situation has spurred research into vaccines globally, yet a licensed vaccine is unavailable. Ribavirin is the sole

antiviral drug accessible, but its efficacy remains unconfirmed nonetheless recent studies reported new RNA vaccine approaches that were successful in delivering immunization (Leventhal et al. 2024; Dai et al. 2021). In Oman, no vaccination has been implemented for either humans or farm animals (Al-Abri et al. 2019).

2. Rabies

Rabies virus, a member of the lyssavirus genus and a prominent pathogen within the Rhabdoviridae family, belongs to the extensive Mononegavirales order. These enveloped RNA viruses have a widespread presence in the world, infecting various vertebrates, invertebrates, and even plant species. Rhabdoviruses possess a bullet-like appearance, enveloped virions sized between 50 to 95 nm in diameter and 130 to 380 nm in length. Notably, the virus's surface is adorned with spikes formed by glycoprotein (G) trimers. Serving as the viral attachment protein, the G protein also triggers the production of neutralizing antibodies. Enclosed within the envelope, the helical nucleocapsid is symmetrically coiled into a cylindrical structure, resulting in striations. The nucleocapsid consists of non-segmented stranded, negative-sense RNA, nucleoprotein (N), and Large (L) and nonstructural (NS) proteins (Murray, Rosenthal, and Pfaller 2013; Fields et al. 2001).

Epidemiology and Pathogenesis

Various closely related viruses, including rabies virus, can be found within the Lyssavirus genus. Among these, Mokola virus, Lagos bat virus, and Duvenhage virus are noteworthy. Rabies, a zoonotic disease often underestimated in Middle Eastern nations, demands greater attention due to its significant threat to both human and animal well-being in the region (Baghi, Bazmani, and Aghazadeh 2018; El-Neweshy et al. 2020; Hussain et al. 2013).

Neglected across Middle Eastern countries, rabies remains underreported in animals. The lack of surveillance and diagnostic facilities, coupled with the unfortunate demise of many victims without laboratory confirmation, contribute to this underreporting. Although sylvatic rabies has endemic roots in Oman, with eight human rabies cases documented since 1990, scant and outdated information persists regarding the rabies situation among animals during 1990-2000 and 2006-2010 (El-Neweshy et al. 2020).

Vaccines and Control

Effective vaccination options for both humans and farm animals are accessible in Oman.

Table 1. CCHV antigen/antibody detection among different animal species in Oman during 2016 – 2023.

Year	Animal species	RT-PCR Positive	RT-PCR Negative	ELISA Positive	ELISA Negative
2016	Camel	0	0	0	7
	Cattel	0	2	5	42
	Goat	0	0	5	68
	Sheep	0	0	0	18
Total		**0**	**2**	**10**	**135**
2017	Camel	0	0	2	1
	Cattel	5	12	0	13
	Goat	8	2	2	4
	Sheep	9	14	1	9
Total		**22**	**28**	**5**	**27**
2018	Camel	0	0	0	2
	Cattel	0	0	2	22
	Goat	0	0	2	22
	Sheep	0	0	0	9
Total		**0**	**0**	**4**	**55**
2019	Camel	0	0	0	0
	Cattel	6	156	0	0
	Goat	10	105	0	0
	Sheep	1	70	0	0
Total		**17**	**331**	**0**	**0**
2020	Camel	0	0	0	0
	Cattel	11	6	0	0
	Goat	6	12	0	0
	Sheep	0	15	0	0
Total		**17**	**33**	**0**	**0**

Table 1. CCHV antigen/antibody detection among different animal species in Oman during 2016 – 2023. Continue

Year	Animal species	RT-PCR Positive	RT-PCR Negative	ELISA Positive	ELISA Negative
2021	Camel	0	0	0	0
	Cattel	1	8	0	0
	Goat	0	0	0	0
	Sheep	2	4	0	0
Total		**3**	**12**	**0**	**0**
2022	Camel	0	0	0	0
	Cattel	4	39	0	0
	Goat	19	92	0	0
	Sheep	17	0	0	0
Total		**40**	**131**	**0**	**0**
2023	Camel	2	0	0	0
	Cattel	9	3	0	0
	Goat	5	0	0	0
	Sheep	20	8	0	0
Total		**36**	**11**	**0**	**0**
Grand Total		**135**	**548**	**19**	**217**

According to the Ministry of Agriculture and Fisheries update report 2024.

3. Middle East Respiratory Syndrome Coronavirus (MERS-CoV)

Coronaviruses are Betacoronaviruses, within the Othocoronavirinae subfamily of the Coronaviridae family which is a part of the order Nidovirales. characterized by their solar crown-like appearance under an electron microscope, are enveloped viruses with long helical nucleocapsid and glycoprotein projections on the envelope's surface. These viruses possess positive-sense single-stranded RNA and are the second most frequent cause of the common cold (Fields et al. 2001; Murray, Rosenthal, and Pfaller 2013).

Table 2. Rabies reported cases among farm animals during 2016 – 2023.

Year	Animal species	RT-PCR Positive	RT-PCR Negative	FAT positive	FAT Negative
2016	Camel	0	0	0	0
	Cattle	0	0	0	0
	Fox	0	0	0	0
	Goat	0	0	0	0
	Sheep	0	0	0	0
Total		**0**	**0**	**0**	**0**
2017	Camel	0	0	7	2
	Cattle	0	0	2	2
	Fox	0	0	2	0
	Goat	1	0	46	18
	Sheep	0	0	3	3
Total		**1**	**0**	**60**	**25**
2018	Camel	0	0	2	0
	Cat	0	0	0	1
	Cattle	0	0	1	1
	Dog	0	0	0	1
	Fox	0	0	1	0
	Goat	0	0	25	12
	Kangaroo	0	1	0	0
	Sheep	0	0	3	3
Total		**0**	**1**	**32**	**18**
2019	Camel	0	0	4	0
	Cattle	0	0	0	3
	Fox	0	0	1	0
	Goat	0	0	9	32
	Sheep	0	0	0	8
Total		**0**	**0**	**14**	**43**
2020	Bat	0	0	0	3
	Camel	0	0	3	3
	Cat	0	0	1	0
	Cattle	0	0	1	2
	Dog	0	0	0	1
	Fox	0	0	2	0
	Gazelle	0	0	1	0
	Goat	0	0	17	10
	Sheep	0	0	3	3
	Equine	0	0	1	0
Total		**0**	**0**	**29**	**22**

Table 2 continue. Rabies reported cases among farm animals during 2016 – 2023.

Year	Animal species	RT-PCR Positive	RT-PCR Negative	FAT positive	FAT Negative
2021	Camel	0	0	1	1
	Cat	0	0	0	1
	Cattle	0	0	3	0
	Fox	0	0	1	0
	Goat	0	0	9	5
	Sheep	0	0	3	3
Total		**0**	**0**	**17**	**10**
2022	Camel	0	2	0	0
	Cattle	0	1	0	0
	Fox	0	1	0	0
	Goat	2	6	6	10
	Human	0	0	2	0
	Sheep	0	1	3	8
Total		**2**	**11**	**11**	**18**
2023	Camel	0	0	0	1
	Fox	0	0	0	2
	Goat	0	0	16	10
	Sheep	0	0	5	1
Total		**0**	**0**	**21**	**14**
Grand Total		**3**	**12**	**184**	**150**

According to the Ministry of Agriculture and Fisheries update report 2024.

In June 2013, Oman recorded its initial laboratory-confirmed instance of MERS-CoV. Between January 27 and February 12, 2019, Oman reported 13 human cases of MERS-CoV, confirmed through real-time reverse transcription polymerase chain reaction (real-time RT-PCR). Seroprevalence studies have revealed MERS-CoV exposure in all sampled domestic camels across Oman. Healthcare workers infected with MERS-CoV may not display symptoms, but serious infections can occur, potentially facilitating virus spread within healthcare settings (Salah and Faryal 2019).

As of December 2, 2013, the World Health Organization (WHO) has received reports of 163 laboratory-confirmed cases, including 71 deaths, with all cases connected to the Middle East region (Salah and Faryal 2019; Haagmans et al. 2014).

Vaccines and Control

Current research on MERS-CoV vaccines and antivirals has made significant steps in

recent years. Several vaccine candidates have shown promise in preclinical and early clinical trials, including DNA vaccines, viral vector-based vaccines, and subunit vaccines targeting the spike protein of MERS-CoV (Andrei 2021) but no vaccines are yet approved for human use. However, Oman has not conducted any vaccination campaigns for either farm animals or humans concerning MERS.

One health system

The One Health approach recognizes the interaction of human, animal, and environmental sectors. By working together, healthcare professionals alongside the other two divisions (managed by Agriculture and Municipality) can detect and respond to health issues, promoting better overall health and well-being. In Oman, establishing strong collaboration and coordination mechanisms faced challenges such as governmental barriers, data sharing, and national capability for rapid and effective investigation of emerging and reemerging infections. Continuous coordinated surveillance is necessary, especially in monitoring zoonotic diseases among animals. Inter-sectoral collaboration among these sectors is essential to prevent, control, and eliminate zoonoses sustainably. In addition, research is crucial for developing diagnostic, therapeutic, and preventive measures to address critical knowledge gaps in these emerging zoonoses (Mostafavi et al. 2021; Farag et al. 2019; Awaidy and Al Hashami 2019).

DISCUSSION

The emergence and re-emergence of epidemic and pandemic diseases has become a great threat to the world, especially after the SARS-CoV-2 pandemic. These diseases originate from imported cases and spillover of zoonotic diseases from different hosts. Climate change, urbanization patterns, transgression of human dominions in sylvatic areas, random use of land and water, increased global mobility, and socioeconomic factors are crucial in the spread of infectious diseases and emergence dynamics. Habitats and weather alteration by climate change led to pathogen emergence and animal movement closer to human facilitate zoonotic transmission risks (Ganter 2015). In addition, climate change enhances arthropod-borne viruses such as Dengue virus, Chikungunya virus, Zika virus, West Nile virus, equine encephalitis virus, and Mayaro virus transmission dynamics in the Americas through its effects on insect vectors life cycles, breeding patterns, and migration routes causing higher transmission rate of these viruses among the population than previously (Organization 2024). The emergence of infectious diseases due to geographic changes attributed to genetic mutations in the pathogens infect animals, especially wild animals enabling them to transmit to humans and the possibility of human-to-human transmission may occur (Ogden, AbdelMalik, and Pulliam 2017). Over 3 billion persons are at risk of CCHFV infection,

with annual infectivity of 10,000–15,000 and 500 deaths (WHO, 2019). The data shown in Table (1) demonstrates the prevalence of CCHFV zoonotic viral disease among domesticated animals (camels, cattle, goats, and sheep) samples in Oman from 2016 to 2023. A total of 135 samples out of 683 were positive for CCHFV nucleic acid while antibodies for CCHFV were detected in 19 out of 236 samples. Cattle, goats, and sheep were the most predominant hosts for CCHFV where nucleic acid and/or antibodies were detected in their samples in most years. In camel samples, virus antibodies and nucleic acids were detected in 2017 and 2023, respectively. Domesticated animals such as cattle, sheep, goats, and camels are amplifying hosts to CCHFV showing no clinical signs and facilitating its spread among ticks through their feeding on viremic animal blood. Humans are infected through tick bites or contact with infected animals and their products (Spengler, Bergeron, and Rollin 2016). International trading is introducing tick vectors to new geographical regions and climate change facilitates Haylamma tick species, the main vector and reservoir of CCHFV, to expand as far north as Sweeden leading to a possible expansion of the CCHFV geographical range (Rainey et al. 2018; Grandi et al. 2020). CCHFV cases were detected in Oman from 2013 to 2017 among people with 43/80 persons Oman citizenship while others were of different nationalities with 58 deaths and most of the CCHFV-positive persons were either working at a slaughter-house or directly handling the animals (Awaidy and Al Hashami 2020). This indicated high public health risks due to the prevalence of CCHFV among domesticated animals for animal caring and handling people.

Rabies is a fatal zoonotic viral disease transmitted to humans through rabid animal biting, mainly dogs. Globally 60,000 deaths have been estimated annually from Rabies virus infection with over 95% of rabies deaths occurring in Africa and Asia. The fluorescence antibody technique (FAT) is a sensitive (96%) and specific (99%) diagnostic test with credible results on fresh specimens (WOAH 2023.). As shown (Table 2) a detailed overview of rabies cases was diagnosed in various farm animals (Camels, Cattle, Goat, Sheep, and Equine), pet and wild animals (Dogs, Cats, Foxes, Kangaroos, Gazal, and Bats), and humans in Oman over eight years from 2016 to 2023. The data are categorized by year, animal species, and diagnostic tests, specifically RT-PCR and FAT. A total of 184 out of 334 samples were RABV positive using FAT, while 3 out of 15 were RABV nucleic acid positive by RT-PCR. Goats showed a higher number of rabid cases diagnosed by FAT (128/235) and RT-PCR (3/9) compared to other species (camel, cattle, equine, gazelle, kangaroo, fox, dog, cat, and bat) followed by sheep (20/41). FAT was more frequently used in RABV diagnosis than RT-PCR, indicating its prevalent use in detecting rabid cases in Oman.

Table 3. Prevalence of MERS-CoV infection among Camels during 2016 – 2023.

Year	Animal species	RT-PCR Positive	RT-PCR Negative
2016	Camel	8	9
Total		**8**	**9**
2017	Camel	0	3
Total		**0**	**3**
2018	Camel	0	18
Total		0	18
2019	Camel	1	123
Total		**1**	**123**
2020	Camel	0	0
Total		**0**	**0**
2021	Camel	0	20
Total		**0**	**20**
2022	Camel	3	7
Total		**3**	**7**
2023	Camel	0	1
Total		**0**	**1**
Grand Total		**12**	**181**

According to the Ministry of Agriculture and Fisheries update report 2024.

The data indicated fluctuated trends in rabies cases among different species over the years, with notable increases in certain years, particularly in 2017 (61/86), 2018 (32/51), 2020 (29/51), and 2023 (21/35). Interestingly, all samples collected from foxes during 2017 – 2021 (7/7), where RABV cases are prevalent, were FAT positive. These results are consistent with (Al-Abaidani et al. 2015) who reported that goats and sheep were more susceptible to RABV infection than other animal species in Oman during 2006 – 2013. On the other hand, no positive samples were detected for dogs, kangaroo, bats, and humans either by FAT or RT-PCR.

Dromedaries are the main reservoir host of MERS-CoV which infects humans directly or indirectly and human-to-human transmission. Globally, MERS-CoV reported cases were 2603 with fatality cases 935 in December 2022. In Oman, MERS-CoV has been recorded in 26 persons with 7 deaths from Jun 2013 – May 2022 (WHO, 2023). As shown in Table 3 the high prevalence of MERS-CoV was detected in camels from 2016 to 2023 in Oman. A total of 12 samples out of 193 MERS-CoV nucleic acids,

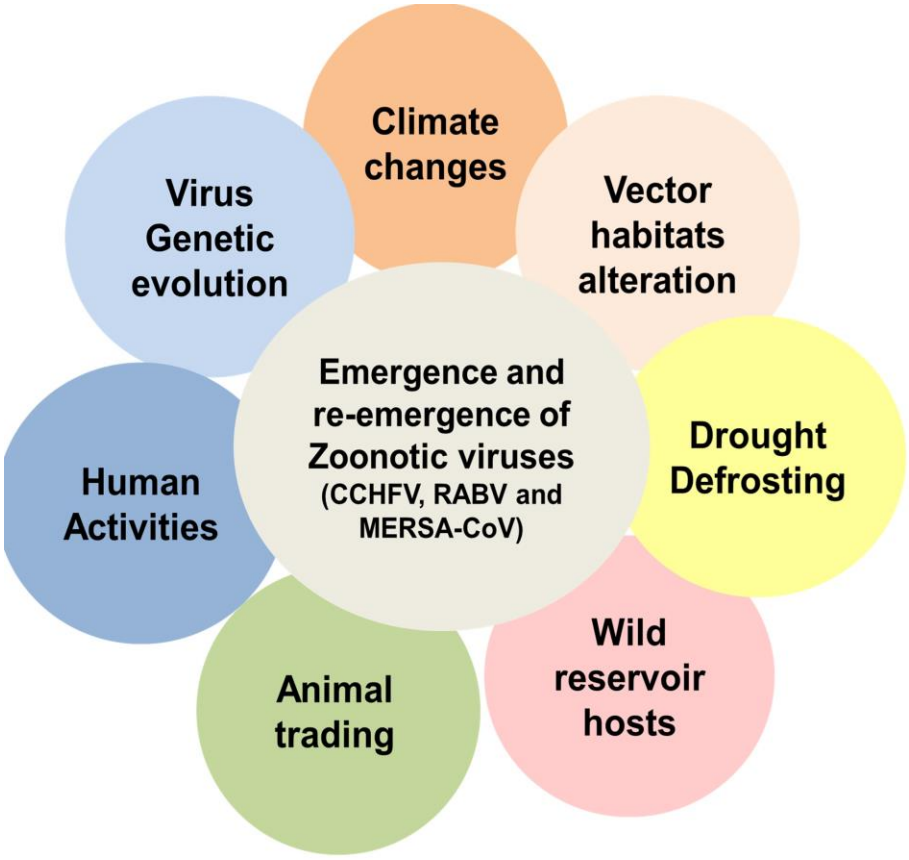

Figure 1. *The diagram shows the interaction and correlation of different risk factors that directly affect the emergence and re-emergence of zoonotic viruses such as CCHFV, RABV, and MERS-CoV investigated in Oman during 2016 -2023.*

representing 6.2%, were detected by RT-PCR in camels, which are well-known reservoirs for MERS-CoV. This indicated that camels play a significant role in the epidemiology of MERS-CoV. The number of RT-PCR positive cases was the highest in 2016, with a total of 8/17 positive cases followed by that was detected in 2022 (3/10 positive cases) while only one case out of 124 was positive in 2019. There were no positive cases detected in 2017, 2018, 2020, 2021, and 2023. Over the eight years, 193 camels were examined for MERS-CoV, with 12 confirmed positive cases, of the tested population.

Some viral diseases have shown sporadic occurrences, while others have exhibited consistent patterns. The interconnectedness of animal health, human health, and the environment necessitates a multidisciplinary approach to effective disease management (Fig. 1). So, continuous exploration of Emerging Infectious Diseases (EIDs), and Re-emerging Infectious Diseases (RIDs) such as CCHF, RABV, MERS-CoV and others of public health concern

is necessary to gain a comprehensive understanding of the epidemiological landscape. This knowledge, with insights into other contributing risk factors, is crucial for mitigating the risk of disease transmission to humans.

Efforts to control mosquito-borne diseases should focus on transparently conveying the severity of these diseases and outlining methods of control and prevention. Strategies aim to promote individual and collective awareness and behavior modification must be tied to achieve maximal impact. It is essential to acknowledge that, for the majority of EIDs and RIDs, effective therapeutics or vaccines remain absent. Consequently, some countries in the region may lack the governmental impetus to invest in preventive measures for these high-risk pathogens (Büyüktuna and Doğan 2021).

Conclusion

This review highlights the dynamic nature of zoonotic viral diseases affecting farm animals in Oman. Consistent surveillance, early detection, and collaborative efforts across sectors are crucial for preventing and managing these diseases. The One Health approach, encompassing veterinary medicine, public health, and environmental considerations, is pivotal in addressing the complex challenges posed by these emerging and re-emerging zoonotic viral diseases. As viruses continue to evolve, comprehensive strategies are essential to safeguard both animal and human well-being in Oman.

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CONFLICT OF INTEREST

All authors declare that there is no conflict of interest.

DATA AVAILABILITY APPROVAL

We confirm that the sample collection process was done according to the Animal Welfare Act and all data are available under permission from the Directorate General of Animal Wealth, the Ministry of Agriculture, Fisheries Wealth and Water Resource, Sultanate Oman on October 13, 2024, and they have no objection to publishing the data.

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