International Journal of Multidisciplinary Comprehensive Research

Microbes that infect animals: A Review

Ghufran Mohammed Sadee Merie [1], Ali Younis Saleh [2], Rafal Moufaq Ismael [3], Ali M Saadi [4*]
[1-2] Department of Medical Laboratory Technologies,Mosul Medical Technical Institute, Northern Technical University, Iraq
[3] Radiology Techniques Department, Mosul Medical Technical Institute, Northern Technical University, Iraq
[4] Department of Anesthesia Techniques, Mosul Medical Technical Institute, Northern Technical University, Iraq

* Corresponding Author: **Ali M Saadi**

Article Info

ISSN (online): 2583-5289
Volume: 03
Issue: 04
July-August 2024
Received: 13-04-2024
Accepted: 18-05-2024
Page No: 01-05

Abstract
Microorganisms are widespread microbes in nature, and there are many types of them such as bacteria, fungi, molds and parasites, and most of these organisms infect humans and animals and cause many health problems. In this article, we highlight the microbes that infect animals and cause diseases for them, as they cause contamination of meat and milk, in addition to infecting animals with diseases that need veterinary interference to treat them.

DOI: https://doi.org/10.54660/IJMCR.2024.3.4.01-05

Keywords: Microbes, Animal, Bacteria, Viruses, Fungi, Protozoa

1. Introduction

The study of wildlife diseases has a long and distinguished history but has received increased attention in the scientific literature with the recent emergence of new infectious diseases, some of which have had a direct impact on wildlife conservation. There is an increasing body of evidence, much of it circumstantial, for the role of infectious diseases in causing population declines and negatively affecting the health and welfare of free-ranging wild mammals. History has shown us that new diseases often have a devastating impact on indigenous wildlife species. Consequently, diseases of wildlife are included as part of animal health and welfare programs in many instances and are becoming increasingly important in the context of environmental management and ethics. This contribution takes a close look at the most important pathogens that infect animals. Although the pathogens have been grouped according to the group of animals they infect, they are capable of infecting multiple classes of animals. This is a review of these pathogens (excluding prions) which potentially cause cross-species infections. Parasitic and viral diseases are the most common; however, there are some bacterial and fungal ones as well. (Trimmel & Walzer, 2020, Valenzuela-Sánchez *et al*. 2021, Cohen *et al*., 2020) [40, 42, 10].

2. Types of Microbes Infecting Animals

Although many types of microbes can cause diseases in animals, the most common are bacteria, fungi, viruses, and protozoa. Researching and understanding these disease-causing agents in animals can help researchers determine ways to stop transmission, design drugs that fight the infection, and identify the best vaccines to protect animals. (Dhagat and Jujjavarapu 2022, Abdugheni *et al*. 2023) [13, 2].

All animals (including humans) are natural hosts to bacteria, which means that bacteria can live and replicate in their bodies. Many bacteria help animals by doing things like helping the gut digest food or by competing with disease-causing germs for a place to live in the gut. It's when bad bacteria make the jump from "harmless" to "pathogen" that they pose problems for either people or animals. Some common bacterial infections include infections caused by E. coli, Brucella abortus (brucellosis), and Chlamydophila abortus (enzootic abortion of ewes). Microbial resistance to antibiotics can make bacterial infections harder to treat. (Bonner, 2024, González-Espinoza *et al*. 2021) [6, 19].

Viruses are tiny infectious agents that are only able to replicate inside the living cells of other organisms. Most viruses can't be seen in even the most powerful microscope. Viruses are technically not alive because they depend on a host cell to replicate. They typically consist of two or three simple parts: nucleic acid (DNA or RNA) and a protein coat. Some diseases caused by viruses include porcine reproductive and respiratory syndrome, porcine circovirus, and foot and mouth disease. Some of the viruses that infect animals can also infect humans too, like avian flu. Fungi are eukaryotic organisms, which means that they have cells with a true nucleus, and in their reproductive stage form zygospores. Some parasites are fungi. (Cowan, 2021, Botacin *et al*. 2022, Meessen, 2020) [11, 7, 30].

2.1. Bacteria

Microbes that infect animals: This is a review documenting the range and diversity of types of microbes that can infect animals. This is likely to be influenced both by the physical make-up and immune status of the animal host infected. We have divided them into categories by type and then - for brevity, in many cases - drawn examples from, or made reference to available reviews and book chapters. (MacInnes *et al*. 2022, Sarkar *et al*. 2020, Sepulveda & Moeller, 2020) [28, 35, 37].

Bacteria are ubiquitous throughout the environment and are one of the most diverse groups of living organisms on Earth. It is perhaps not surprising that there are a considerable number of bacterial infections and diseases of domestic large animals, pets, and wildlife. These bacteria often take various forms ranging from intracellular parasites to free-living microorganisms. Infections can either be picked up incidentally following the consumption of contaminated food or water, for example, via the fecal-oral route, through the bite of an infected vector, by droplet inhalation, or following physical contact with other infected animals. Bacteria can infect many different tissues and organs of their animal hosts. The range of clinical signs and pathology seen in natural infections, together with the possible range of treatments, varies according to the bacterial pathogen and the species affected. In general, the most common clinical signs of infection are wasting, mild fever, dehydration, inflammation, and diarrhea (in animals where both species are compared), with typical histopathology characterized by raised antigen-specific antibody levels (although often disease or pathology does not occur). Actinobacillosis: Infectious cattle disease that can cause pneumonia abscesses in more advanced cases. Brucellosis: Abortion and infertility in cattle and sheep which can be acquired by consuming unpasteurized milk. (MacInnes *et al*. 2022, Abebe *et al*., 2020, Nicoletti, 2020) [28, 3, 31].

2.2. Viruses

Most epidemiology and infectious disease textbooks introduce viruses as the most common types of infectious agents. It is estimated that viruses not only cause the majority of animal infections but likely also have potent impacts on ecosystem function, either directly through pathogenesis of hosts or indirectly through effects on the abundance and behaviors of animals following infection. In the following sections, we briefly review some of the major types of viruses that infect animals, followed by select primary literature focusing on how they can affect different host species. (Abdel-Moneim & Abdelwhab, 2020, Haake *et al*., 2020) [20, 21].

Viruses are small infectious particles that are parasitic in living cells. They can infect animals, plants, protozoa, fungi, mosses, and bacteria. There are two phases of the viral infection cycle, including one in which the host cell replicates millions of virus particles and the other in which the virus particles are released from the host cell into the surrounding environment in order to infect new host cells. Within the animal kingdom, both invertebrates and vertebrates are targeted by viruses, including parasites. Viruses only replicate in living cells, and they can enter them through three pathways. Firstly, a virus can be ingested, and the virus particles can then bind to host cells in the gut of the host. Once viruses enter host cells, they are often taken up into membrane-bound organelles, where the cellular membranes aid in targeting parts of the virus to replicative areas of the cell. Media and distributions. Viruses are often directly transmitted from one animal to another animal by ingesting virus-contaminated food, either through social interactions or through predation for scavenging. The health consequences of a viral infection in an animal host are often a function of how virus particles get from the infectious agent to the host cell. (Harvey & Holmes, 2022, Iwama & Moran, 2023, Forni *et al*. 2023) [22, 25, 15].

2.3. Fungi

Some animal fungal infections can also be seen in humans (zoonotic infections). Therefore, these fungal infections can be seen within the scope of public health as well as veterinary medicine. Zoophilic fungi such as Trichophyton, Microsporum, and Malassezia may cause infections. Although it is not a significant source of human infection worldwide, it is an important health concern. Fungal agents are mostly transmitted to animals as environmental pathogens. However, they are not widespread in nature because the six species are very sensitive to environmental conditions. These fungi can also be transmitted through close contact with both carrier animals and infected animals. (Gnat *et al*. 2021, Gnat *et al*. 2021, Carpouron *et al*., 2022) [17, 18, 8].
Environmental infection is one of the ways of infection. It is an infectious agent that is relatively difficult to unaccompanied individuals being around. On the other hand, the animal itself should have factors that allow infection to occur, primarily in the immune system. The impact of fungal infections on the health and welfare of the infected ones is significant. Here, it varies according to the age, gender, genetic factors of the breeder animal, and animal species, as well as parasitic infections whether there are other accompanying diseases. Common symptoms of diseases with zoonotic potential are generally non-specific. It is important to be diagnosed in order to prevent the mutation of the infection together with the disease and to determine its spread. It is not only a direct infection mechanism, but carrier and wildlife animals play a role in the spread of zoonotic infections. However, the factors affecting zoonotic threats within the animal society remain to be researched further. (Gnat *et al*. 2021, Fisher *et al*. 2020, Rodrigues and Nosanchuk 2021) [17, 14, 33].

2.4. Protozoa

Protozoa can cause infections in animals. Many different species can potentially infect vertebrates, and the phylogenetic diversity is considerable. The major ways of transmission are faecal-oral routes and external uptake by a

vector. Some species can be sexually transmitted. These species have complex life cycles and can be found in various tissues. Symptoms of protozoal infections consist of weight loss, poor growth, and general symptoms of disease. Tissues affected by infestation may become more sensitive to bacterial infection. Upper respiratory symptoms are also described, especially in feline rhinitis. Other symptoms of protozoal infestation consist of localized symptoms like PES, which causes lesions in the trachea and soldiers showing localized inflammation, especially in the thyroid area. Inflammatory responses on the flat may also be caused by vascular damage. Phillansporum enteritis is associated with bloody feces, probably because of cell destruction in the gut or the liver. (McDougald *et al*. 2020, Ceylan *et al*., 2021, Al-Malki, 2021) [29, 9, 4].

Protozoans that can primarily infect pets include fungi and bacterial infections. Clostridial diseases are abundantly described in the can side, especially in guinea pigs. Overfeeding, obesity, and chemical exposure may cause clostridial infection. The parasites may contribute by producing toxins, which cause low weight and ill thrift. Infected small animals show CNS symptoms such as epilepsy and progressing paralysis. Birds show stiff wing syndrome and tensile tetanus symptoms. Other symptoms may include anemia. Uterine tetanus, produced by cytotoxoplasma, can be progging and has been described with high mortality rates in mice. It has a line abortive effect, especially in pregnant animals' glands. Restrict kelts with few knots per litter are often seen. Lyme disease leads to abortive lesions in cows but seems to have no effect on other farm animals. Listeric nervous symptoms and a decrease in cerebellar score are seen in affected vertebrates. Lyme disease has a serious effect on elk populations in many countries. (Pignon and Mayer 2020, Grenda *et al*. 2023, Tissue, 2020) [32, 20, 39].

3. Routes of Transmission

There are various modes of varying efficacy through which a microbial infection can be transmitted directly between animals: i) contact, direct or indirect, incorporated through aggressive interactions, sexual contacts or through normal social behaviour. For example, dermatophytoses, sarcoptic mange shared by direct contact or indirectly through pets or on hay. Whereas, streptococcosis, pestiviruses, foot rot or worm infections shared through normal flock activities of mutual grooming. ii) Aerosol transmission of Leonard's disease or Chicken guinea. iii) Water, for example giardiasis, Leptospirosis. iv) Ingested via food: Salmonellae, Bacillus anthracis GWSS, Salmonelloses, Tyzzer's disease, Camphylobachaerosis, histomoniasis. The ability to transmit is always biologically linked to the micro-organism and any risk is compounded by managemental practises too. Transmission may be air-borne or by physical contact involving infected skin, urine, faeces, milk, saliva, secretions and grooming by normal social contacts. (MacInnes *et al*. 2022, Sarkar *et al*. 2020, Ikhimiukor *et al*. 2022) [28, 35, 24].

The introduction of a new pathogen to a new population can involve several interactions. As potential new hosts, camels may aggregate and adapt to local climatic and grazing conditions, as highlighted by the increase of their populations in the face of decreasing water supplies and restraints placed introduced a protozoon, Theileria lestoquardi, through transplanting infected African cattle into a naive camp with competent Rhipicephalus (Boophilus) and Hemophysalis ticks. The camel population quickly amplified the infection, allowing tick-borne transmission cycles to become established. Thus, the agro-ecological niche plays a critical factor, and a high pathogen load could easily be established through the introduction. Bushmeat markets could introduce trichostrongylid and helminths of impala, bushbck and eland. (Urban *et al*. 2020, Baker *et al*. 2022, Klein & Hultgren, 2020) [41, 5, 26].

4. Impact on Animal Health

Animals - wild and domestic alike - require robust, well-functioning immunological systems in order to survive and thrive in their environments. Microbial infections can, at best, detract from the quality of life of individual animals, and, at worst, result in their premature death. Populations can also be affected by a high prevalence of certain pathogens, particularly where immunity to a particular pathogen is weak or temporary within a population. Furthermore, some microorganisms that naturally infect animals can also infect humans (zoonoses) and can indirectly affect issues such as food safety and the animal-human bond. (MacInnes *et al*. 2022, Swelum *et al*. 2021, Ibrahim *et al*. 2020) [28, 38, 23].

It is particularly important from the perspective of wild and free-ranging animals to consider the effects of infection not only at the individual level, but also in terms of its potential impact on the population, as certain parasites and pathogens have the capacity to seriously reduce population size and even lead to extinction in extreme cases. The greater the number of susceptible animals (via a naive immune system) living together in relatively high densities in any particular area, the greater the chance that pathogens from within a population or that cross into a population (carried by other animals, humans or fomites) will find hosts in which to initiate or complete their respective life cycles. Feral and wild birds and mammals are susceptible to many pathogens, and some can act as vectors that might transmit these to 'clean' farming environments and domestic pets. Furthermore, if a relatively high density domestic or farmed animal population is infected with a particular microorganism, the resultant high numbers of infective stages (e.g. helminth eggs, fluke cysts, or oocysts) shed into the local environment can easily lead to an increase in soil or water contaminant levels. (Van Oosterhout, 2021, Deksne *et al*. 2020, Baker *et al*. 2022) [43, 12, 5].

5. Prevention and Control Strategies

No control or prevention of emergent pathogens, or pathogens already present, can occur until the pathogens are detected. Had the pathogens in this review not caused obvious clinical disease, their presence may have gone unnoticed or exacerbated the problem. In addition to overt clinical signs, the recognition of some diseases may be further obscured when the symptoms are confused with those of another disease, which may be more widely known. (MacInnes *et al*. 2022, Abebe *et al*. 2020) [28, 3].

The heterogeneous nature of the animals affected allows for a rational approach to incorporate appropriate measures. There are a number of possible control strategies, such as therapeutic forthcoming with medication, withdrawal periods, disease exclusion zones to prevent the spread of pathogens and encourage immune response, vaccination, biosecurity, outbreak management after diagnostic analysis, and post mortem holding for toxicological examination, among others, which veterinary researchers and practitioners can use in order to curb the considered pathogens. The

prompt and correct use of some of these approaches may avoid disease issues, such as economic and public welfare problems. These are only some of the strategies that can be initiated; however, due to the limitations of this review, the possible methods of control and prevention are not exhaustive. Many reports did not specify the use of control and preventative techniques, which is a cause for concern due to potential infection spread in addition to animal suffering. This emphasizes the importance of preventing poor health using a proactive approach. Additionally, other efforts to limit infection risk, spread, and prevent disease alongside control, surveillance, and management decrease the emergence of undesired products and the wider economic impact of poor animal health. (Kock *et al*., 2021, Scannapieco & Gershovich, 2020, Garrigou *et al*. 2020, Rodríguez-Ardura and Meseguer-Artola 2020) [27, 36, 16, 34].

6. Conclusion and Future Perspectives

Some of the above-discussed animal infectious agents depend on associations with plant materials for their survival, and hence, their discovery is dependent on the inclusion and study of the relevant plant microbiomes. In several cases, we have no knowledge of the animal reservoirs of the discovered organisms, which means that their role in animal diseases is uncertain. For this reason, we propose using the term "infectious agent" rather than "pathogen" when reporting such associations in order to avoid drawing conclusions about the impact of a given microbe on a host. We hope that reports of this kind will contribute to a more comprehensive understanding of the agents that infect animals as well as the means through which they are transmitted. Finally, it should be acknowledged that some of the sequences cataloged in this study may originate from environmental contaminants (e.g., due to sample collection and processing), as has been reported for microorganisms of medical and biotechnological significance.

In order to fully understand the microbial world, particularly the agents that infect animals, it will be important to differentiate between microbes that cause diseases and those that do not. This will allow a closer look at the majority of enteric viruses that do not yet have known hosts, as well as the potential to carry them. It should be interesting to consider, for example, the possibility that bacteria found in association with insects might be infectious to humans or their livestock. Future work will attempt to gauge the extent to which the human, wildlife, and livestock fecal microbiomes contribute to and overlap with one another in host genetic studies that incorporate 16S rRNA sequences from various combinations of humans, livestock, and other animals.

7. References

1. Abdel-Moneim AS, Abdelwhab EM. Evidence for SARS-CoV-2 infection of animal hosts. Pathogens; 2020. mdpi.com
2. Abdugheni R, Li L, Yang ZN, Huang Y, Fang BZ, Shurigin V, Li WJ. Microbial risks caused by livestock excrement: Current research status and prospects. Microorganisms. 2023;11(8):1897. mdpi.com
3. Abebe E, Gugsa G, Ahmed M. Review on major food-borne zoonotic bacterial pathogens. Journal of Tropical Medicine; 2020. wiley.com
4. Al-Malki ES. Toxoplasmosis: stages of the protozoan life cycle and risk assessment in humans and animals for an enhanced awareness and an improved socio-economic. Saudi Journal of Biological Sciences; 2021. sciencedirect.com
5. Baker RE, Mahmud AS, Miller IF, Rajeev M, Rasambainarivo F, Rice BL, Metcalf CJE. Infectious disease in an era of global change. Nature Reviews Microbiology. 2022;20(4):193-205. nature.com
6. Bonner JT. Why size matters: from bacteria to blue whales; 2024. [HTML]
7. Botacin M, Domingues FD, Ceschin F, Machnicki R, Alves MAZ, de Geus PL, Grégio A. Antiviruses under the microscope: A hands-on perspective. Computers & Security. 2022;112:102500. github.io
8. Carpouron JE, de Hoog S, Gentekaki E, Hyde KD. Emerging animal-associated fungal diseases. Journal of Fungi; 2022. mdpi.com
9. Ceylan O, Xuan X, Sevinc F. Primary tick-borne protozoan and rickettsial infections of animals in Turkey. Pathogens; 2021. mdpi.com
10. Cohen JM, Sauer EL, Santiago O, Spencer S, Rohr JR. Divergent impacts of warming weather on wildlife disease risk across climates. Science; 2020. nih.gov
11. Cowan TS. Breaking the spell; 2021. rodscontracts.com
12. Deksne G, Davidson RK, Buchmann K, Kärssin A, Kirjušina M, Gavarāne I, Jokelainen P. Parasites in the changing world–Ten timely examples from the Nordic-Baltic region. Parasite Epidemiology and Control; 2020:10. sciencedirect.com
13. Dhagat S, Jujjavarapu SE. Microbial pathogenesis: Mechanism and recent updates on microbial diversity of pathogens. Antimicrobial Resistance: Underlying Mechanisms and Therapeutic Approaches; 2022:71-111. [HTML]
14. Fisher MC, Gurr SJ, Cuomo CA, Blehert DS, Jin H, Stukenbrock EH, Cowen LE. Threats posed by the fungal kingdom to humans, wildlife, and agriculture. mBio. 2020;11(3):10-1128. asm.org
15. Forni D, Pozzoli U, Cagliani R, Clerici M, Sironi M. Dinucleotide biases in RNA viruses that infect vertebrates or invertebrates. Microbiology Spectrum; 2023:11(6). asm.org
16. Garrigou A, Laurent C, Berthet A, Colosio C, Jas N, Daubas-Letourneux V, Judon N. Critical review of the role of PPE in the prevention of risks related to agricultural pesticide use. Safety Science. 2020;123:104527. sciencedirect.com
17. Gnat S, Łagowski D, Nowakiewicz A, Dyląg M. A global view on fungal infections in humans and animals: opportunistic infections and microsporidioses. Journal of Applied Microbiology. 2021;131(5):2095-2113. wiley.com
18. Gnat S, Łagowski D, Nowakiewicz A, Dyląg M. A global view on fungal infections in humans and animals: infections caused by dimorphic fungi and dermatophytoses. Journal of Applied Microbiology. 2021;131(6):2688-2704. wiley.com
19. González-Espinoza G, Arce-Gorvel V, Mémet S, Gorvel JP. Brucella: Reservoirs and niches in animals and humans. Pathogens. 2021;10(2):186. mdpi.com
20. Grenda T, Jarosz A, Sapała M, Grenda A, Patyra E, Kwiatek K. Clostridium perfringens-opportunistic foodborne pathogen, its diversity and epidemiological significance. Pathogens. 2023;12(6):768. mdpi.com
21. Haake C, Cook S, Pusterla N, Murphy B. Coronavirus

infections in companion animals: virology, epidemiology, clinical and pathologic features. Viruses; 2020. mdpi.com
22. Harvey E, Holmes EC. Diversity and evolution of the animal virome. Nature Reviews Microbiology; 2022. nature.com
23. Ibrahim M, Ahmad F, Yaqub B, Ramzan A, Imran A, Afzaal M, Ahmed S. Current trends of antimicrobials used in food animals and aquaculture. In: Antibiotics and Antimicrobial Resistance Genes in the Environment. Elsevier; 2020:39-69. nih.gov
24. Ikhimiukor OO, Odih EE, Donado-Godoy P, Okeke IN. A bottom-up view of antimicrobial resistance transmission in developing countries. Nature Microbiology. 2022;7(6):757-765. nature.com
25. Iwama RE, Moran Y. Origins and diversification of animal innate immune responses against viral infections. Nature Ecology & Evolution; 2023. [HTML]
26. Klein RD, Hultgren SJ. Urinary tract infections: microbial pathogenesis, host–pathogen interactions and new treatment strategies. Nature Reviews Microbiology; 2020. nih.gov
27. Kock F, Berbekova A, Assaf AG. Understanding and managing the threat of common method bias: Detection, prevention and control. Tourism Management; 2021. [HTML]
28. MacInnes JI, Van Immerseel F, Boyce JD, Rycroft AN, Vázquez-Boland JA. Pathogenesis of bacterial infections in animals. In: Prescott JF, editor. John Wiley & Sons, Incorporated; 2022. [HTML]
29. McDougald LR, Cervantes HM, Jenkins MC, Hess M, Beckstead R. Protozoal infections. In: Diseases of Poultry; 2020:1192-1254. [HTML]
30. Meessen A. Virus destruction by resonance. Journal of Modern Physics; 2020. scirp.org
31. Nicoletti PL. Relationship between animal and human disease. In: Brucellosis; 2020. [HTML]
32. Pignon C, Mayer J. Guinea pigs. In: Ferrets, Rabbits, and Rodents: Clinical Medicine and Surgery. Elsevier; 2020:270-297. [HTML]
33. Rodrigues ML, Nosanchuk JD. Fungal diseases as neglected pathogens: A wake-up call to public health officials. In: Advances in Clinical Immunology, Medical Microbiology, COVID-19, and Big Data. Jenny Stanford Publishing; 2021:399-411. plos.org
34. Rodríguez-Ardura I, Meseguer-Artola A. How to prevent, detect and control common method variance in electronic commerce research. Journal of Theoretical and Applied Electronic Commerce Research. 2020;15(2):1-5. mdpi.com
35. Sarkar A, Harty S, Johnson KVA, Moeller AH, Archie EA, Schell LD, Burnet PW. Microbial transmission in animal social networks and the social microbiome. Nature Ecology & Evolution. 2020;4(8):1020-1035. up.ac.za
36. Scannapieco FA, Gershovich E. The prevention of periodontal disease-An overview. Periodontology 2000; 2020. researchgate.net
37. Sepulveda J, Moeller AH. The effects of temperature on animal gut microbiomes. Frontiers in Microbiology; 2020. frontiersin.org
38. Swelum AA, Elbestawy AR, El-Saadony MT, Hussein EO, Alhotan R, Suliman GM, Abd El-Hack ME. Ways to minimize bacterial infections, with special reference to Escherichia coli, to cope with the first-week mortality in chicks: an updated overview. Poultry Science. 2021;100(5):101039. sciencedirect.com
39. Tissue GAL. Small intestine. In: Ferrets, Rabbits, and Rodents: Clinical Medicine and Surgery; 2020. [HTML]
40. Trimmel NE, Walzer C. Infectious wildlife diseases in Austria—a literature review from 1980 until 2017. Frontiers in Veterinary Science; 2020. frontiersin.org
41. Urban M, Cuzick A, Seager J, Wood V, Rutherford K, Venkatesh SY, Hammond-Kosack KE. PHI-base: the pathogen–host interactions database. Nucleic Acids Research; 2020:48(D1). oup.com
42. Valenzuela-Sánchez A, Wilber MQ, Canessa S, Bacigalupe LD, Muths E, Schmidt BR, Cayuela H. Why disease ecology needs life-history theory: a host perspective. Ecology Letters. 2021;24(4):876-890. ucl.ac.uk
43. Van Oosterhout C. Mitigating the threat of emerging infectious diseases; a coevolutionary perspective. Virulence; 2021. tandfonline.com