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Bacterial and viral rodent-borne infections on poultry farms. An attempt at a systematic review

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Abstract

Introduction: Rodents are quite common at livestock production sites. Their adaptability, high reproductive capacity and omnivorousness make them apt to become a source of disease transmission to humans and animals. Rodents can serve as mechanical vectors or active shedders of many bacteria and viruses, and their transmission can occur through direct contact, or indirectly through contaminated food and water or by the arthropods which parasitise infected rodents. This review paper summarises how rodents spread infectious diseases in poultry production. **Material and Methods:** The aim of this review was to use PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) principles to meta-analyse the available data on this topic. Three databases – PubMed, Web of Science and Scopus – and grey literature were searched for papers published from inception to July 2022 using the established keywords. **Results:** An initial search identified 2,999 articles that met the criteria established by the keywords. This number remained after removing 597 articles that were repeated in some databases. The articles were searched for any mention of specific bacterial and viral pathogens. **Conclusion:** The importance of rodents in the spread of bacterial diseases in poultry has been established, and the vast majority of such diseases involved *Salmonella*, *Campylobacter*, *Escherichia coli*, *Staphylococcus* (MRSA), *Pasteurella, Erysipelothrix* or *Yersinia* infections. Rodents also play a role in the transmission of viruses such as avian influenza virus, avian paramyxovirus 1, avian gammacoronavirus or infectious bursal disease virus, but knowledge of these pathogens is very limited and requires further research to expand it.

Keywords: PRISMA, rodent, transmission, poultry diseases.

Introduction

The European Union is the world's third largest producer of poultry. The output is greater than 15 million tonnes per year, with Poland (17%), the UK (13%) and Germany (10%) among the largest producers (https://ec.europa.eu/eurostat/). The economic viability of such farming depends on the health and maintenance conditions of the animals, and modern farms have numerous safeguards to mitigate threats to this viability. However, sometimes there are certain failures in maintaining standards that negate the efforts made. Among the various causes, rodents are quite common. They can not only damage the structure of buildings and thereby affect normal farming procedures, destroy and contaminate food, but can also injure animals and/or transmit various diseases. It should also be added that the threats from rodents vary from one farm to another, mostly depending on the farm's production system but also on its location. The species of rodents and their numbers differ in various parts of the European continent, and the threats posed by rodents on farms near bodies of water or near forests are also a distinct set.

The animals of order *Rodentia* are characterised by a single pair of continuously growing incisors in the maxilla and mandible. This order comprises about 40% of mammalian species and its members occur in large numbers on all continents except Antarctica. The most common rodents found on farms are rats and mice, and among them the most frequent species are the house mouse (*Mus musculus*) and brown (Norwegian) rat (*Rattus norvegicus*); slightly less common are the black rat (*Rattus rattus*) and bank vole (*Myodes glareolus*).

The smallest of them, the house mouse is particularly adaptable, and able to eat practically any kind of food. It most often lives in close vicinity to humans, in colonies with an established hierarchy. A feature of mice is also their remarkably high reproductive capacity. The brown rat prefers to live in close proximity to water sources (*e.g.* cellars or sewers) and to food (feed stores, *etc*.). It is an omnivorous rodent that likes to build burrows in which it makes its nests. The brown rat has no subspecies and is common throughout Europe. The black rat, a little smaller than its relative, usually feeds indoors, in roof areas, and unlike the brown rat prefers dry areas. Also unlike the brown rat, the black rat digs burrows only occasionally. It mainly inhabits western Europe, and in Poland it is found in large numbers in seaports and in the west of the country, along the course of the Oder. There are three subspecies of this rat differing in coloration, but they can interbreed. The bank vole is found primarily in forests, so it may be a problem for farms located next to them. It builds a system of tunnels under the ground, usually near food sources. It feeds on mixed foods, such as fruits, seeds, and invertebrates and is active mainly at night (https://informatordrobiarski.pl/gryzonie - na-fermie/higiena-i-zywienie/ (source in Polish)).

Among the many disease threats to a poultry farm brought by rodents are diseases caused by bacterial, viral or parasitic infections (41). Although we currently have quite good methods to solve rodent problems in rodenticides, it seems that the problems may soon grow, mainly because of the expected legal regulations (a ban on the use of poisons), the emerging resistance of some rodents to the agents used in their control and climate change, which may influence rodent population sizes and their behaviour. The importance of these animals in spreading poultry diseases has been well known for years and many manuscripts, including reviews, have been published on the subject. The aim of this review was to use PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) principles to meta-analyse the available data on this topic (51).

Material and Methods

Search strategy. Three databases including PubMed, Web of Science and Scopus were searched for papers published in English from inception to July 2022. The first group of keywords used comprised ‘rat’, ‘rats’, ‘mouse’, ‘mice’, ‘rodent’ or ‘rodents’. The second group contained ‘chicken’, ‘chickens’, ‘turkey’, ‘turkeys’ or ‘poultry’. There was a third group, made of ‘disease’, ‘diseases’, ‘infection’ or ‘infections’. The final group was a list of ‘transmission’, ‘transmissions’, ‘vector’ or ‘vectors’. The databases were interrogated for entries containing at least one keyword from each group. In addition, grey literature from national and international authorities and sectorial organisations was searched using the above criteria in the Google search engine.

Selection criteria. The data obtained was then searched for duplicates, which were removed, and then further criteria were applied to analyse the data collected. To narrow the number of papers, inclusion criteria were applied such that the articles needed to describe the role of rodents specifically in bacteria or virus transmission. In the next step, the obtained datasets were searched using the specific name of the poultry pathogen in question as a criterion. The searches included mostly epidemiological studies as well as experimental ones that described the susceptibility of certain rodent species to particular pathogens.

Exclusion criteria. The use of rodents, especially mice, in the study of the expression of various genetic constructs caused manuscripts describing such research to be drawn into the dataset despite their irrelevance to poultry farm disease spread. Articles were excluded from the collected base of material that contained data concerning expression or genes. This was done automatically and manually.

Results

An initial search of three scientific databases identified 2,999 articles that met the criteria established by the keywords. This number remained after removing 597 articles that were repeated in some of these databases. The rest of the articles were searched for any mention of specific bacterial and viral pathogens. The most numerous group were articles that contained the word “virus”. A total of 366 such papers was found, which was then manually reduced to 99 by excluding articles unrelated to the searched topic. For example, despite the automatic exclusion of articles containing the word “expression”, there were still articles in the dataset with descriptions of recombinant vaccine constructs tested in a mouse model or of obtaining monoclonal antibodies in mice. Of the publications in which the words “virus”, “transmission” and any rodent species appeared, those concerned with the influenza virus dominated (74 articles). Mentions of other individual viral pathogens of poultry in terms of rodent transmission appeared in single publications. Bacterial infections, on the other hand, have been known to be transmitted by rodent vectors for years. Such publications describing interactions between various bacterial pathogens of poultry and different species of rodent were found in a total of 386 articles, most of which were excluded for the reasons indicated earlier, and, as a result, a total of 85 such remained. The vast majority concerned infections with *Salmonella* (43), followed by *Campylobacter* (28) and *Escherichia coli* (9).

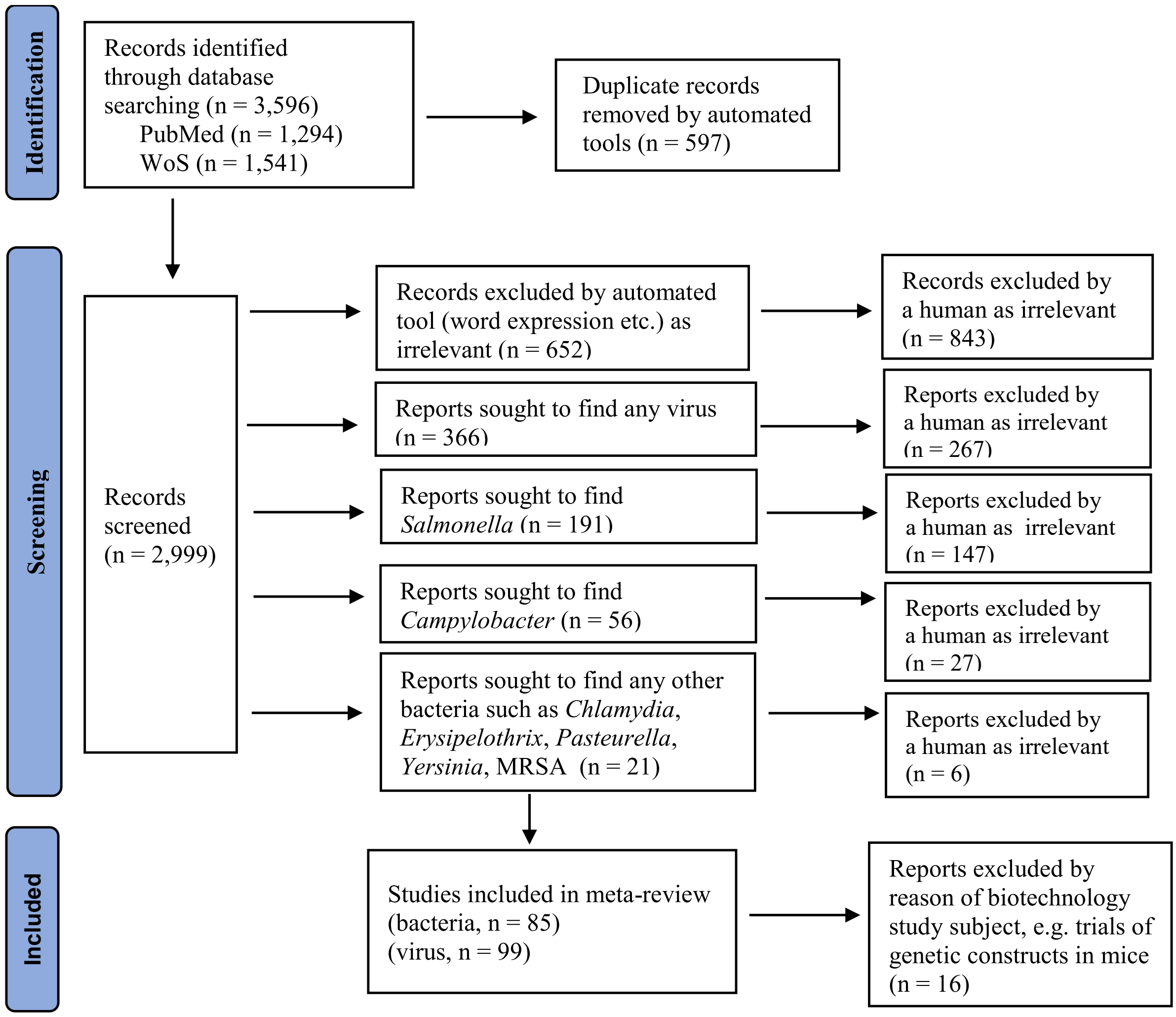

Fig. 1. Diagram of the process used to obtain relevant articles from the literature

Infections with other rodent-borne pathogenic bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA), *Pasteurella*, *Erysipelothrix* or *Yersinia* were described in lesser numbers in the articles (1–8 articles) (Fig. 1). The grey literature search results could not be counted so accurately. The rule of thumb was that after typing a search term into the Google search engine, up to five consecutive screens of results were reviewed manually, where an average of 10 consecutive web page links appeared per screen.

Discussion

In the presented review study, various scientific databases as well as grey literature on the role of rodents as risk factors for the health of poultry were searched. Rodents are highly mobile and also have a short reproductive cycle, which creates ideal conditions for the rapid spread of various pathogens among birds on farms. The appearance of rodents on a farm can be recognised by damaged feed bags, chewed wires, or a damaged layer of building insulation. In addition, they mark their presence with contaminants from the body (urine, blood, dander and droppings) on feed and grain. Another signal of rodent infestation is general uneasiness among birds. In addition to spreading diseases, rats can damage livestock housing by digging networks of tunnels in its walls or under its floor. Moreover, adult rats are capable of killing chicks. Unfortunately, rodent control on a poultry farm typically comes rather late, as farmers usually only notice rodent presence when the animals are already adults, and their population has multiplied (https://swiatrolnika.info/hodowla/drob-i-jaja/zwalczanie-gryzoni-na-fermie-drobiu-deratyzacja-i-zabezpieczenie-ferm.html (source in Polish)). Transmission of pathogens to birds on a farm occurs in a variety of ways: from direct contact with rodents; from the environment and *via* food and water contaminated with rodent faeces, urine or secretions containing pathogens; or from the mediation as disease vectors of arthropods parasitising rodents. Moreover, rodents can also be asymptomatic carriers in which some pathogens can successfully multiply. Circulation of pathogens among rodents in a particular area results in endemicity there and the persistence for years of animal and human infections despite preventive and control measures. In Poland, for example, the Kłodzko Basin had been an endemic area for leptospirosis in humans and animals for many years (23).

Rodents and bacteria. Our search revealed that the most publications on rodent-borne bacterial infections in farmed birds involved different serotypes of *Salmonella*: Enteritidis, Infantis, Livingstone, Mbandaka, Potsdam and Corvallis (37, 38). Rodents play a major role in the epidemiology of *Salmonella*, both of the serotypes with zoonotic potential and of those pathogenic to poultry which cause pullorum disease (3, 5). First of all, they are a reservoir and amplifying host of *Salmonella* infections in poultry flocks. Rodents can be a source of *Salmonella* infection and poultry can be persistently infected even if the facilities are thoroughly cleaned and disinfected and if replacement stocks are obtained from *Salmonella*-free breeders and rearing units (66). It has been shown that *S.* Enteritidis can be present in a large proportion of the mouse population on infected laying and broiler farms (up to 86%) (16). Other studies revealed that *S.* Enteritidis persisted at least for 10 months in an infected mouse population on such a farm (26). Salmonella in mouse droppings retains its infectious properties for two months (16). Black rats may also be involved in lifting certain serotypes to dominant positions on farms. Such a situation was recently observed in Japan. The relative prevalences of *Salmonella* serotypes changed over time; first, *S.* Potsdam gradually replaced *S.* Infantis in rats. The same shift in dominant serovars was then observed in the poultry house environment and in eggs (10). This environment needs the protection afforded by the important and effective tool in managing and controlling *Salmonella* infection in laying flocks which rodent control programmes are (66). On the other hand, farm animals appear on occasion to be the source of *Salmonella* infection for wild ones. In a Danish study, wild animals tested positive only during periods when *Salmonella* was detected in production animals, and the low prevalence of *Salmonella* in mice on farms coincided with negative results in farm animals (42, 52, 61).

Escherichia coli is a physiological component of the intestinal microbiome of many animal species and humans. The prevalence of this bacteria in the environment, and contamination food and water with faeces containing *E. coli* contribute to the rapid spread of infection. Some strains of E. coli have acquired virulence factors and cause diarrhoeal disease in humans. Enterohaemorrhagic *E. coli* (EHEC) causes haemorrhagic colitis, which is characterised by acute abdominal cramps and bloody diarrhoea, and may progress to life-threatening clinical symptoms such as haemolytic uraemic syndrome (46). Some EHEC could be harboured by poultry, rather rarely by chickens but often by turkeys. Only sporadically is such *E. coli* carried by rodents (20). Avian pathogenic *E. coli* (APEC) is the main causative agent of avian colibacillosis, which is an important systemic disease of economic and clinical consequence for the poultry industry worldwide. In the past, APEC has mainly been considered a secondary pathogen requiring predisposing factors for disease outcomes; however, recently a primary role was assigned it in disease outbreaks. Among the different vectors of APEC such as houseflies, beetles and wild birds are also rodents, and they need to be kept out of poultry houses (12). Studies of APEC in chickens, wild animals with habitats on farms (including rats), and in the environment in Vietnam revealed complex transmission of *E. coli* from chickens to wild animals including rodents and to the environment and *vice versa* (47, 48). Although the most important reservoir of verotoxigenic *E. coli* (VTEC) strains are ruminants, especially cattle, another important reservoir are also rodents, especially rats. There is a possibility of bidirectional transfer of VTEC strains between cattle, sheep, goats, pigs, birds and rats (20). It should be mentioned that rats and mice could be a reservoir of *E. coli* strains that are resistant to many antibiotics (11, 24). It seems that rodents can also be a source of such antibiotic-resistant *E. coli* for poultry. The faeces of rats caught on a Canadian poultry farm were infected with avian pathogenic *E. coli* and more than one quarter of the rats were carrying multidrug resistant strains of these bacteria (27). Moreover, the strains of *E. coli* carried by the farm rats were very similar to those found in chickens, and totally different from *E. coli* strains found in urban rats (67). These findings supports the conclusion that rodents are involved in the circulation of pathogens on a farm.

Over several decades, *Campylobacter* species have been the most commonly reported cause of enteritis in humans in developed countries, where poultry and poultry meat are considered a common source of this infection (32). Among the multiple factors that increase the risk of poultry flocks becoming infected with the bacteria are rodents, although how potent a factor they are is not clear. The presence of rodents in a poultry house was identified as a risk factor for *Campylobacter* infection in a Swedish and a Spanish study (7, 64). On the other hand, in Norway the observed effect of rodent presence on a farm on *Campylobacter* infection in broilers was described as not significant. Also, a similar study in France revealed no significant association between rodent control and the incidence of *Campylobacter* spp. in broiler flocks (2, 34, 50). Rodents are susceptible to *Campylobacter* infection, and this was demonstrated in experimental studies on mice and water voles. After infection, both species were colonised and excreted the bacteria for up to nine weeks (7, 50). Nonetheless, a study on the occurrence and molecular characteristics of *Campylobacter* in wildlife including house mice and brown rats on livestock farms in the United States revealed no rodent infection with *Campylobacter* (60). The presence of *C. jejuni* and *C. coli* was found in wild rodents caught on Swedish chicken farms, although the prevalence was not high (up to 28%) (5). However, it should be added that insects have been studied as a reservoir of *Campylobacter*. For example, flies have been suggested to play a role in the transmission of *Campylobacter* from contaminated sources to broiler chickens, and the lesser mealworm beetle, *Alphitobius diaperinus*, may act as a reservoir for *C. jejuni* (30, 62). Thus, it cannot be ruled out that rodents may be a mechanical vector carrying arthropods, and these constitute the source of infection for poultry.

Avian pseudotuberculosis is a worldwide distributed disease caused by *Yersinia pseudotuberculosis* affecting various species of poultry, to which the highest sensitivity is in young turkeys; a wide variety of wild birds and rodents are also sensitive to it besides poultry. Yersiniosis, the disease caused by this bacterium, is also reported in humans but rather rarely and is usually linked to the consumption of food contaminated by birds or rodents. *Yersinia pseudotuberculosis* was found in mice, moles and barn rats in Japanese studies (21, 33). Rats infected with *Y. pseudotuberculosis* could be the source of water contamination with this bacterium (22). On the other hand, surveys of Swedish livestock farms and rodents caught near them indicated no such infection in either group of animals (4, 5). Only one mouse out of 120 caught on a livestock farm and tested was infected with this bacterium (5). Poultry meat products can also be a source of another species of this genus, *Y. enterocolitica*, and its presence has been identified in many studies. However, it most likely originates from sources other than the poultry itself, as a result of inappropriate meat handling, processing, and storing of meat causing its cross-contamination from bacteria-laden material or surfaces. The known reservoir of *Y. enterocolitica* are farmed pigs. In the studies of a Swedish group of livestock and rodents mentioned above, *Y. enterocolitica* was only detected in rodents on pig farms (8% prevalence) and was more likely to be transmitted to rodents from pigs or the environment on infected farms (5). Recent studies of the prevalence of *Yersinia* spp. in animals in China revealed the presence of *Y. enterocolitica* in 4.5% and 3.4% of studied chickens and wild rodents, respectively; no *Y. pseudotuberculosis* in chickens; and only 0.86% prevalence in rodents (39).

Erysipelas is generally an acute, fulminating infection and occurs mainly in turkeys but also in laying hens, although outbreaks sometimes occur in other bird species, *e.g.* geese (8). The aetiological agent, *Erysipelothrix rhusiopathiae*, is a worldwide distributed bacterial pathogen of swine and sheep but has also been isolated from cattle, horses, dogs, cats, mice, rats, fish, marine mammals, a variety of wild birds and mammals, biting flies and ticks. Most of these animals are asymptomatic carriers of pathogenic and/or nonpathogenic *Erysipelothrix* and disseminate the organism that contaminates feed, water, soil and bedding (https://vetmed.iastate.edu/vdpam/FSVD/swine/ index-diseases/erysipelas). Monitoring results of the past decades have shown that outbreaks of erysipelas in poultry occur mainly in the autumn and early winter months, both in free-range birds and in aviaries or poultry houses. During this time, rodents look for easy sources of food and shelter from low temperatures, likely bringing *E. rhusiopathiae* at the same time. Chickens can then acquire the bacteria from rodent droppings, and further spread is caused by birds pecking at and cannibalising animals that have died of septicaemia. The infection is then difficult to eradicate from the farm because of the presence of infected blood from lice, rats and mice, and the resistance of the bacteria to drugs (https://www.gdanimalhealth.com/en/News/2022/03/Erysipelas-in-poultry-and-humans). However, in studies of poultry house environments during erysipelas outbreaks in organic laying hen flocks in Sweden, the presence of bacteria was found in manure, dust and swabs from water nipples. Samples from mice and arthropods were negative, which was interpreted to indicate that these populations were not heavily infected (18).

Another bacterium with worldwide spread, causing disease not only in various domestic animals and wild birds but also in other animals and humans, is *Pasteurella multocida*. The disease it causes in representatives of the *Aves* class, known as avian cholera (or pasteurellosis), can be acute or chronic, generalised or local and is characterised by a sudden onset with high morbidity and mortality. Birds that recover from an infection become lifelong carriers. However, many non-avian animals found on the farm, such as cats or rats, can become asymptomatic carriers of *P. multocida* (https://www.michigan.gov/dnr/managing-resources/wildlife/wildlife-disease/fowl-cholera). The role of rats as maintenance hosts has been documented previously. Thirty-four rat carcasses from 11 poultry farms were examined for the presence of *P. multocida* and 41% of them were positive. Poultry pasteurellosis was present on two farms with infected rats and the same serotype was present in rats and poultry in those cases (15). An epidemiological investigation in Nigeria found that black rats were the cause of recurrent pasteurellosis on a quail farm. The same *P. multocida* subspecies and serotype was identified in both birds and rats, and the rats were indicated as the carrier of the bacterium (45). The presumed cause of the repeated outbreaks of avian cholera that have been occurring in seabirds on Amsterdam Island for 30 years, threatening the populations of three endangered seabird species, may be rats (29).

Rodents and viruses. The participation of rodents in avian influenza (AI) outbreaks on poultry farms generates the most discussion (68). Avian influenza virus (AIV) is one of the most important poultry pathogens. The virus exists as two pathotypes, low and highly pathogenic (LPAIV and HPAIV), and wild birds of the *Anseriformes* and *Charadriiformes* orders are recognised as the natural reservoir for LPAIV (69). The virus can be introduced into domestic poultry *via* direct or indirect contact with infected wild birds or contaminated food and water, or by human activities (1). It is believed that rodents could serve as mechanical vectors or active shedders of AIV (68). Although numerous studies of rodents caught near infected farms did not reveal the presence of the virus, serological tests indicated that these animals had had contact with it (25, 56, 58). During the HPAIV H5N8 outbreak in the Netherlands, the virus was detected in a dead mouse found in an infected chicken house, so it is possible that rodents die quickly after infection, becoming dead end hosts for AIV (68). Such a course of infection is suggested by experiments on BALB/c mice – typical laboratory animals. Inoculation of such mice with AIV caused morbidity, mortality and high virus replication, but their high susceptibility to AIV could result from the specific geno- and phenotype of this mouse line (17, 31, 36, 44). Infection of wild-caught house mice with various LPAIV subtypes did not cause disease, but the viruses replicated efficiently in their bodies and were shed into the environment (59). On the other hand, HPAIV infection of laboratory Sprague Dawley rats was asymptomatic and the animals shed only a small quantity of the virus (57). Similarly, infection of bank voles with the H5 and H7 subtypes of HPAIV caused no disease symptoms, but in this case resulted in shedding of high amounts of the virus (53). It is reasonable to assume that whether the outcome of infection is the disease state depends on the species, subspecies, genetic line, age and general health status of the infected organism, but also on the virus itself – its subtypes, lineage of haemagglutinin (HA), dose or route of infection. In addition to the possibility of rodents' introducing the virus onto a poultry farm as active shedders, it is also possible for rodents to introduce the virus on their coats (70). A recent study on the prevalence of IAV in wild brown rats originating from a dense urban location (Boston) revealed 11% positivity. Moreover, a seasonal trend in IAV-status was observed, with the highest prevalence occurring in the winter months (December–January) and the lowest in September (14). Such results further suggest that wild rats play some role as reservoirs or mechanical vectors of IAV circulation in environments.

Virulent strains of avian paramyxovirus 1 (APMV-1), from the *Orthoavulavirus* genus infect at least 236 species of wild birds and poultry species, leading to Newcastle disease. The disease is found worldwide and affects the respiratory, gastrointestinal, nervous, and reproductive systems with up to 100% mortality in unprotected chickens. Infections of poultry species are reportable to the World Organisation for Animal Health. Horizontal direct or indirect transmission is the main route of virus spread (43). As the virus is shed through saliva and faeces from infected birds, indirect spread is likely through contaminated fomites, so rodent fur may be also contaminated. Additionally, recent results suggest that a virulent APMV-1 strain as well as strains of other AMPV serotypes (2–9 excluding AMPV-5) could replicate in BALB/c mice with minimal disease and pathology when inoculated intranasally. All of the mice infected with the APMVs except APMV-5 produced serotype-specific serum antibodies in a haemagglutination inhibition assay (35). Similarly, intranasal inoculation of Syrian golden hamsters induced mild or inapparent clinical signs, gross lesions in pulmonary surfaces and also replication of viruses in respiratory tissue (54).

The current Covid-19 pandemic in humans has stimulated interest in the study of coronaviruses and their adaptation to a new host (63). Numerous studies have found chickens and Muridae rodents (mice and rats) to be insensitive to SARS-CoV-2, unlike some Cricetidae rodents (such as hamsters), which are susceptible (9, 13, 55). However, the first coronavirus discovered in the world was avian gammacoronavirus, also known as infectious bronchitis virus (IBV). It causes a highly contagious disease of the respiratory, reproductive, excretory and digestive systems, and despite intensive immunoprophylaxis, is still a major economic problem for the poultry industry worldwide. Transmission can occur by inhalation or ingestion of live virus through direct contact between infected and susceptible birds; or through indirect contact by exposure to virus-contaminated fomites, such as clothing, shoes and tools (28). A Brazilian study investigated whether rodents near poultry farms may be involved in the transmission of avian coronavirus. After infection of BALB/c and A/J mice with Massachusetts and Brazilian strains of IBV, moderate or marked histopathological changes in the experimental animals' respiratory systems were found. In addition, viral antigens were detected in the tissues of infected mice and low-level antibody production was observed shortly after infection. Later, at 10 days post infection, the antigens were no longer detected, which suggests that viral replication occurred for a short time (40). However, similarly to the study of the AIV susceptibility of inbred mice, their genotype and phenotype may be responsible for this: one characteristic of BALB/c mice exemplifying how their genome may hold the explanation is their lack of the Mx1 gene, which encodes an important antiviral protein. In view of the rapid spread of IBV between poultry farms, the possibility should be considered that other animal species, such as rodents living on these farms, might not only be able to transport IBV mechanically but may also actively multiply the virus.

Another viral pathogen that rodents may be involved in transmitting is infectious bursal disease virus (IBDV). It causes an immunosuppressive disease of young chickens of worldwide prevalence, which can result in high morbidity and mortality. Additionally, the immunosuppressive effect of the disease diminishes the bird's resistance to other pathogens and reduces responsiveness to vaccines (19). The virus particles are highly resistant to harsh environmental conditions. It was shown that water, feed and faeces collected from infected pens were infectious by 52 days (6). It cannot be ruled out that IBDV deposited on rodent fur would also remain infectious for some time and that the disease may also be spread in this way. In addition, there is circumstantial evidence that the virus can also actively multiply in the bodies of rodents. Antibodies to IBDV were detected by the agar-gel precipitin test in 6 out of 23 tissue samples from rats found dead on four poultry farms that had histories of IBDV infection (49).

Rodents such as mice, rats and voles are found in large numbers in rural areas, especially around farms where high numbers of animals are kept, but also in cities, and serve as vectors and reservoirs for many infectious organisms that can cause disease in both animals and humans. Although rodents cannot be considered the main cause of transmission of avian pathogens, they may represent a risk factor in the spread of different infections among poultry farms as indicated above. The database search method used (PRISMA) and applied criteria did not identify other poultry pathogens that can be transmitted by rodents. Nevertheless it seems very likely that they are also involved in the transmission of other pathogens, such as astroviruses, rotaviruses and reoviruses. The lack of publications in the dataset linking rodents with these pathogens seems to lie not in misapplied criteria, but rather in the fact that no one has studied them in this transmission aspect to date.

Rodents can play a role in pathogen transmission as their mechanical vectors or as active shedders. Unfortunately, there is very limited data on the survival of poultry pathogens in rodents. Viral and bacterial pathogens are excreted by birds with droppings or faeces, sometimes in very large quantities, and thus contaminate surfaces in the poultry house, equipment, *etc*. It is likely that the fur or paws of rodents can be contaminated when the animal contacts those surfaces or equipment. In this way, pathogens can travel certain distances and be passed on to subsequent facilities or animals. Many different poultry pathogens can also successfully asymptomatically multiply in the bodies of rodents. There are even theories indicating that rats act as a "pathogen sponge" absorbing bacteria (perhaps also viruses) from their environment (67). However, shortcomings of the existing literature are its sufficiency in data on the susceptibility of "wild" rodents to infection with and the disease caused by a given bacteria or virus, and deficiency in evidence that they are able to maintain the bacteria or virus in the environment. Most of the information is derived from experimental studies using typical laboratory rodents such as BALB/c mice, which are known to be especially sensitive to such infections (65). It seems that useful supplementary data would be provided by studies on field rodents sampled directly on a poultry farm.

Considering all the negative aspects of the presence of rodents on the farm, it is recommended to optimise rodent control, especially in autumn, when the number of these animals on the farm rises significantly. Prevention and control of rodents is difficult and still not very effective. An important approach has always been the use of rodenticides. However, concerns about the environmental safety of the most common of them have led to changes in European and national regulations which restrict their use. There is also the problem of rodent resistance to these poisons, so only combining biological control methods with chemical ones and mechanical restriction of access by rodents to dwellings, farm buildings and food warehouses may bring measurable results.

This review of the role of rodents in the transmission of poultry diseases has attempted to use PRISMA principles as a reporting guideline. The review's topic is extremely broad and there are many publications on the subject in the databases searched. Depending on the keywords used, the number of records in the query outputs ranged from 60,000 to 120,000, an amount which would have been physically impossible to review. The breadth of information contained in this review is therefore a compromise, and perhaps for this reason the review may have some shortcomings. Further efforts should be made using other search algorithms to review the main topic more fully. Understanding the role of rodents in disease transmission to poultry, other livestock, and to humans still requires further study.

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