COACTION

Rodents on pig and chicken farms – a potential threat to human and animal health

Annette Backhans, VMD, PhD* and Claes Fellström, VMD, PhD

Department of Clinical Sciences, Faculty of Veterinary Medicine and Animal Science, Swedish University of Agricultural Sciences, Uppsala, Sweden

Rodents can cause major problems through spreading various diseases to animals and humans. The two main species of rodents most commonly found on farms around the world are the house mouse (*Mus musculus*) and the brown rat (*Rattus norvegicus*). Both species are omnivorous and can breed year-round under favourable conditions. This review describes the occurrence of pathogens in rodents on specialist pig and chicken farms, which are usually closed units with a high level of bio-security. However, wild rodents may be difficult to exclude completely, even from these sites, and can pose a risk of introducing and spreading pathogens. This article reviews current knowledge regarding rodents as a hazard for spreading disease on farms. Most literature available regards zoonotic pathogens, while the literature regarding pathogens that cause disease in farm animals is more limited.

Keywords: *rodents*; *infections*; *zoonoses*; *pigs*; *chicken*

Rodents can cause major problems due to destruction and contamination of food, and also by the spread of various diseases. This review describes the occurrence of pathogens in rodents specifically on pig and chicken farms. The emphasis is on zoonotic pathogens that are indirectly transmitted to humans through contaminated food, or pathogens that cause important diseases in pigs. The order *Rodentia* (L. *rodere*, to gnaw) constitutes the most successful mammalian group, both in terms of the number of species and individuals (1). Two commensal (L. *cum mensa*, sharing a table) species are common inhabitants on farms worldwide: the house mouse (*Mus musculus*) and the brown rat syn. norwegian rat (*Rattus norvegicus*). Both species originated from Asia, from where they spread over the world along with the development of agriculture, which provided shelter and supplies of food. They are underground dwellers, omnivorous and can breed year-round when conditions are optimal (1, 2). The house mouse weighs 12–30 g, eats vegetables or any available food, and is active at any hour of the day. It manages well without water for a substantial time and can adapt to temperatures down to 10 °C (1). Its home range is less than 10 m² and daily movement of an individual mouse is only a few square or cubic metres. A female can produce up to 10–14 l, each containing 3–12 puppies per year (2). The brown rat usually weighs 200–400 g and lives in territorial colonies with population densities on farms of 50–300 individuals. Compared with the house mouse, it has a rather large home range of 25–150 m in diameter, but individual rats can move 3 km away and back in one night (2), and rats are more active during night time (3).

Rodents as carriers of zoonotic disease

On farms, the risk of rodent-borne spread of pathogens to production animals is obvious due to the difficulty of excluding rodents from animal houses. Several studies have focused on rodents as possible carriers of various pathogens. Table 1 shows selected studies regarding rodents as carriers of zoonotic pathogens. Included in the table are studies published in international peer-reviewed journals, on rodents caught on pig or chicken farms and their surroundings. Results regarding rodent species other than brown rats, black rats, and house mice have been excluded.

Zoonotic bacteria

The three most commonly reported zoonoses in the EU are the foodborne enteric diseases campylobacteriosis, salmonellosis, and yersiniosis (4). Most cases of

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Table 1. Selected studies on rodents as carriers of human pathogens on pig and chicken farms

Pathogen studied	Reference	Rodent species	Country	Location	Detection method	Detection rate
Salmonella Enteritidis	Davies and Wray (14)	Mice	Great Britain	Broiler & layer breeder flocks	Culture	29/84
Salmonella Enteritidis	Lapuz, Tani et al. (106)	*R. rattus*	Japan	Layer farms	Culture	113/851
Salmonella Infantis						158/851
Salmonella Livingstone	Meerburg, Jacobs-Reitsma et al. (11)	*R. norvegicus*	Ns	Organic farms	Culture	0/8
		M. musculus				1/83
Salmonella spp.	Pocock, Searle et al. (18)	*M. musculus domesticus*	UK	Mixed farms	Culture	0/341
Salmonella Enteritidis	Henzler and Opitz (16)	*M. musculus*	USA	Poultry farms	Culture	116/715
Salmonella sp.	Le Moine, Vannier et al. (107)	*R. norvegicus*	France	Pig farms	Culture	1/40
		M. musculus				2/34
Campylobacter spp.	Meerburg, Jacobs-Reitsma et al. (11)	*R. norvegicus*	ns	Organic farms	Culture	1/8
		M. musculus				8/83
Campylobacter jejuni	Le Moine, Vannier et al. (107)	*R. norvegicus*	France	Pig farms	Culture	16/40
		M. musculus				4/34
Yersinia spp. biotype 1A	Pocock, Searle et al. (18)	*M. musculus*	UK	Mixed farms	Culture	21/354
Yersinia (Y.) enterocolitica O:3	Aldova, Cerny et al. (24)	*R. rattus*	Czechoslovakia	Pig houses	Culture	16/96
Y. enterocolitica O:3	Pokorna and Aldova (108)	*R. rattus*	Czechoslovakia	Pig houses	Culture	5/36
Y. enterocolitica 4/O:3	Kaneko, Hamada et al. (25)	*R. norvegicus*	Japan	Slaughter-house, barn, zoo	Culture	2/270
		R. rattus				
Y. enterocolitica 4/O:3	Backhans, Fellström et al. (26)	*R. norvegicus*	Sweden	Pig farm	TaqMan PCR	7/56
		M. musculus				2/120
Y. pseudotuberculosis	Pocock, Searle et al. (18)	*M. musculus*	UK	Mixed farms	Culture	1/354
Y. pseudotuberculosis	Kaneko, Hamada et al. (35)	*R. norvegicus*	Japan	Barn	Culture	8/259
		R. rattus				0/11
Y. pseudotuberculosis	Aldova, Cerny et al. (24)	*R. rattus*	Czechoslovakia	Pig houses	Culture	16/178
		R. norvegicus				
Y. pseudotuberculosis	Backhans, Fellström et al. (26)	*R. norvegicus*	Sweden	Pig farm	TaqMan PCR	0/56
		M. musculus				1/120

Table 1 (*Continued*)

Pathogen studied	Reference	Rodent species	Country	Location	Detection method	Detection rate
Cryptosporidium parvum	Quy, Cowan et al. (65)	*R. norvegicus*	UK	Farms	IFAT	105/438
Cryptosporidium parvum	Webster and MacDonald (66)	*R. norvegicus*	UK	Rural	Modified Ziehl-Nielsen	46/73
Leptospira spp.	Webster, Ellis et al. (40)	*R. norvegicus*	UK	Mixed farms	MAT, ELISA, cultivation	37/259
Listeria spp.	Webster, Ellis et al. (109)	*R. norvegicus*	UK	Rural	Cultivation	5/44
Trichinella spiralis	Stojcevic, Zivicnjak et al. (61)	*R. norvegicus*	Croatia	Pig farms	ns	18/2287
Trichinella spiralis	Leiby, Duffy et al. (110)	*R. norvegicus*	USA	Pig farm	Peptic digestion	188/443
Toxoplasma gondii	Kijlstra, Meerburg et al. (50)	*R. rattus*	Netherlands	Organic pig farms	TaqMan PCR	4/39
		M. musculus				2/31
Toxoplasma gondii	Smith, Zimmerman et al. (56)	*R. norvegicus*	USA	Pig farms	Serology (MAT)	0/9
		M. musculus				2/588
Toxoplasma gondii	Webster (111)	*R. norvegicus*	UK	Rural	ILAT ELISA	84/235
Hantavirus	Webster (111)	*R. norvegicus*	UK	Rural	ELISA	5/173

R, Rattus; *M*, Mus; ns, not specified; IFAT, indirect immunofluorescent antibody test; MAT, microscopic agglutination test; ELISA, enzyme-linked immunosorbent assay; ILAT, indirect latex agglutination test.

campylobacteriosis are caused by *Campylobacter jejuni*, followed by *Campylobacter coli* and *Campylobacter lari*. Humans become infected by consuming contaminated meat, especially poultry meat, which is commonly contaminated by *C. jejuni*. Pigs, in particular growing pigs, are commonly colonised by *Campylobacter* spp., mostly by *C. coli,* but also by *C. jejuni* (5, 6). However, results from genotyping studies indicate that isolates from pigs differ genetically from human isolates to a larger extent than poultry isolates (7). There are just a few studies on the subject of rodents as a risk of transmission of campylobacter, but one study concluded that occurrence of rodents was one of the risk factors for high *Campylobacter* prevalence in broiler chicken flocks (8), and a similar tendency, although not significant, was described by in another study (9). Mice experimentally infected with *C. jejuni* become colonised and excrete bacteria for several weeks (10). One study found that isolates from pig manure and rodents on organic pig farms differed genetically (11), but these isolates originated from different farms, so the results may simply reflect biodiversity within the species.

Non-typhoidal salmonellosis is the second most reported zoonosis, and also the most frequently reported cause of food-borne outbreaks within the EU (4). The majority of cases worldwide are caused by *Salmonella* serovar Enteritidis, of which the most important sources are eggs and poultry meat (4, 12). The second most common, and in North America the most common serovar, is *Salmonella* Typhimurium, which is usually derived from pig, poultry, or bovine meat (4). Infected pigs are usually subclinical carriers of zoonotic *Salmonella*, although some serovars cause disease in the pig (13). The source of infection of *Salmonella* to poultry or other farm animals, except for the introduction of infected animals, can be anything from a broad range of wild animals including birds and rodents, to cats, feed, and the environment. Salmonella persists for years in suitable conditions, surviving both freezing and dryness (13). Davies and Wray (14) showed that *Salmonella* Enteritidis could be cultured from a large proportion (19–86%) of mice on infected layer and broiler farms, and that droppings from infected mice were infective for pullets up to 2 months after inoculation. Liebana et al. (15) further emphasised mice as the most common finding in their study of vast numbers of environmental and vector samples on *S*. Enteritidis-contaminated farms. Henzler and Opitz (16) found that mice amplify the bioconcentration of *S*. Enteritidis, resulting in an isolation rate three times higher than from the environment. Mouse population density has also been shown to be an important factor for the transmission of *Salmonella* between chicken and mouse. In a study from Denmark, a strong correlation was indicated between *Salmonella* in production animals and wildlife, including rodents.

However, wildlife animals tested positive only during periods when *Salmonella* was detected in production animals, indicating the production animals as the source of infection (17). Similarly, two other studies showed that low prevalence of *Salmonella* in mice on farms coincided with negative farm animals (11, 18).

Yersiniosis is the third most frequently reported zoonosis in Europe, with the majority of human cases caused by *Yersinia* (*Y*). *enterocolitica* bioserotype 4/O:3 (19), with occasional outbreaks especially in the northern hemisphere caused by *Yersinia pseudotuberculosis* (20, 21). The reservoir of human pathogenic *Y. enterocolitica* is the domestic pig (22). One study found *Y. enterocolitica* in about 8% of wild rodents in Scandinavia, but no human pathogenic biotypes (23). House mice on farms are colonised mainly by *Y. enterocolitica* serogroup 1A (18), but serotype O:3 has been isolated from black rats (*Rattus rattus*) in pig houses (24), and serotype 4/O:3 from brown rats in a slaughterhouse (25) and brown rats and house mice in pig houses, of similar genotypes as pig isolates from the same farms (26).

Yersinia pseudotuberculosis appears to circulate between animals and the environment in wild birds (27), various free-living mammals such as deer, hare, marten, and racoon dog (28) and water (29), but has also been isolated from domestic pigs (30, 31) and from wild boars (32). In Finland, recent outbreaks of *Y. pseudotuberculosis* were traced to carrots and iceberg lettuce stored in such a way that they were accessible to rodents and other wildlife. The same authors identified pest animals as a risk factor for high prevalence of *Y. pseudotuberculosis* on pig farms (20, 21, 33). Furthermore, *Y. pseudotuberculosis* has been found in mice, moles, and barn rats (34, 35). Identical restriction endonuclease patterns were found in isolates from rat and a patient within the same area in Japan where transmission through rodent-contaminated water was suspected (29). Rats were also strongly suspected of being the source of infection in a breeding monkey outdoor facility (36).

Leptospirosis is a zoonotic disease of worldwide distribution which causes subclinical to severe cases of icteric leptospirosis with renal failure, often called Weil's disease (37). Animals of different species, including rodents, act as maintenance hosts for different serovars of *Leptospira* (38). Several studies show that wild rodents are common carriers of leptospires, including feral rodents (39), rodents on farms (40), and rodent pets (41). A high proportion of sewer rats in Copenhagen were recently found to be infected with serovars Pomona, Sejroe, and Icterhaemorrhagiae (42).

In the Netherlands, black rats on pig farms were found to be carriers of methicillin-resistant *Staphylococcus aureus* (MRSA) of a multilocus sequence type 38 strain that has emerged as a cause of hospital-acquired infections (43).

Zoonotic parasites

The parasite *Toxoplasma gondii* is a coccidium that infects all warm-blooded animals which act as intermediate hosts (44), whereas definitive hosts are cats of various species (45). In humans, infection during pregnancy can cause abortion or congenital toxoplasmosis in the foetus, with subsequent central nervous system (CNS) and ocular lesions (46). The sources of infection to humans are soil exposure (47), eating undercooked meat, especially pork (44), and cleaning cat litter boxes (48), while rodents are believed to be an important source of *T. gondii* infection to cats (49). Rodents also seem to play a role in the transmission of *T. gondii* to pigs: a correlation between *T. gondii* seroprevalence in pigs and seropositive rodents has been shown in several studies (50, 51). Prevalence studies show somewhat different results depending on methods used. Various serological methods have been used (52, 53), but also polymerase chain reaction (PCR) applied directly on brain tissue, which generally results in higher prevalences (54, 55). Murphy et al. (81) used both PCR and serology simultaneously in mice and found a PCR detection rate of 59%, whereas the detection rate by serology was only 1.0%. Thus, low sensitivity for serological methods detecting *T. gondii* could be the explanation for the low prevalence of toxoplasmosis previously reported in rodents (56, 57).

The eight recognised species of the nematode *Trichinella* are all pathogenic to humans, causing intestinal and muscular disease of varying severity (58). The most important species associated with human disease is *T. richinella spiralis,* which is most adapted to domestic and wild pigs (58), whereas other species have wild carnivores as main and intermediate hosts. In Europe, *T. richinella britova* has become more widespread due to its occurrence in sylvatic carnivores, whereas *T. spiralis* dominates in domestic pigs and wild boars (59). In Romania, for example, trichinellosis is a serious health problem, with an annual incidence of 6.2 cases per 100,000 inhabitants between 1990 and 2007 (60). Rats can be infected by *Trichinella*, but their importance in spreading the disease is unclear. Leiby et al. (22) found that a population of rats scavenging on infected dead pigs remained infected during a 25-month period after the infected pigs were removed. Stojcevic et al. (61), on the other hand, detected infected rats only on pig farms with positive pigs in an area with endemic infection of *T. spiralis* and concluded that the cause of infection in rats is improper slaughter procedures, which result in the spread of infected pork scraps in the environment.

The parasitic gastrointestinal infections cryptosporidiosis and giardiosis are common and have worldwide distributions. For both of these infections, outbreaks can often be traced to water or to food, and the infectious dose is small (62, 63). To date, there are 19 known species of the protozoan *Cryptosporidium* (64), of which two, *Cryptosporidium hominis* and *Cryptosporidium parvum*, can cause diarrhoea in humans. *C. hominis* is restricted to humans, whereas *C. parvum* is zoonotic. Before the development of molecular biology methods for genotyping isolates of *Cryptosporidium*, wild animals including rodents were considered carriers of zoonotic *Cryptosporidium* (65, 66), leading to an overestimation of their zoonotic importance. More recent studies show that most of the *Cryptosporidium* oocysts detected in rodents belong to other species or genotypes than *C. parvum*, for instance mouse genotype I, which is host-adapted to rodents, and *Cryptosporidium muris* (67), which in rare cases has been isolated from human patients (68, 69). *Giardia intestinalis* (syn. *duodenalis, lamblia*) has been described as the most common intestinal parasite in humans and livestock (70). Similarly, with the use of molecular methods, *Giardia,* an intestinal flagellate, has been divided into assemblages A–G, each of which has distinct host spectra. Assemblages A and B are zoonotic genotypes, C and D are dog genotypes, E livestock, F cat, and G are rat genotypes (71). Other *Giardia* species that have been isolated from rodents are *Giardia muris* and *Giardia microti*, species which are not zoonotic (72).

Zoonotic virus

Hepatitis E virus (HEV) belongs to the family Hepeviridae and includes four genotypes with the ability to infect humans and other animals. Besides genotypes 1 and 2, which are restricted to humans, genotypes 3 and 4 have been detected in both humans and pigs (73). Several studies have shown that occupational pig exposure is a factor for HEV infection (74), which suggests animal-human transmission of the virus. In the search for other potential reservoir animals for hepatitis E, Kabrane-Lazizi et al., 1999 found that between 44 and 90% of rats tested positive by ELISA (75). However, sequence and phylogenetic analyses of rat HEV indicate that these constitute a completely different genotype of unknown pathogenicity to humans (76).

Rodents as carriers of animal pathogens

Only a few studies have been published on rodent transmission of specific animal pathogens in pig and chicken herds, but some of the agents discussed previously as zoonoses can also affect the health of pigs, e.g. *Toxoplasma gondii*, *Leptospira,* and *Campylobacter* spp. and some serovars of *Salmonella*.

Bacteria

The genus *Brachyspira* constitutes bacteria that are found in the intestines of many species of mammals and birds. *Brachyspira hyodysenteriae* is the aetiological agent of swine dysentery (SD) (77), a pig disease that causes severe mucohaemorrhagic diarrhoea. All age groups of pigs

except for newborns can be affected (78). *Brachyspira pilosicoli* causes a milder colitis referred to as porcine colonic spirochaetosis (PCS) (79). Weaners and growers are affected with watery diarrhoea or porridge-like faeces, sometimes with mucus, resulting in reduced growth rate. In chicken, *Brachyspira* spp. colonisation, referred to as avian intestinal spirochaetosis (AIS), is associated with egg production losses and signs of disease. Intestinal spiral-shaped bacteria have been observed microscopically in both laboratory and wild-caught rodents, of which some showed the morphological characteristics of *Brachyspira* spp. (80). Isolates designated as *Brachyspira hyodysenteriae* have been detected in both wild and laboratory rodents (81, 82). Experimentally, *B. hyodysenteriae* has been shown to effectively spread between laboratory mice and pigs (83). Porcine genotypes of *B. hyodysenteriae* have been isolated from rats and mice caught in pig herds (84, 85) and porcine genotypes of *B. pilosicoli* in mice (84, 86).

The intracellular bacterium *Lawsonia intracellularis* is the cause of porcine proliferative enteropathy (PPE) (87), a very common intestinal disease with large economic impact in growing pigs (5, 88). The clinical appearance is similar to that of colonic spirochaetosis, with diarrhoea and retarded growth. *L. intracellularis* has been detected in a number of animal species other than the pig, i.e. hamster, deer, ostrich, ferret, horse, and rabbit (89–91). Rodents have been implicated as possible reservoirs for the bacteria (92), and a recent study showed that infected rats shed large numbers of bacteria in their faeces for up to 3 weeks (93).

Virus
Encephalomyocarditis virus (EMCV) is a cardiovirus of the Picornaviridae that in growing pigs causes acute myocarditis and sudden deaths (94, 95). In sows, it causes reproductive problems with abortions and dead and weak piglets (96, 97). Outbreaks occur mainly in clusters in certain areas, which in Europe have been located in Belgium, Italy, Greece, and Cyprus (98). The epidemiology is inconclusive, but wild rodents are considered a natural reservoir for EMCV (99), from which the virus is shed in faeces (100, 101). In a few cases, EMCV has been suspected of causing disease in humans (102) and seroprevalence has been found to be high in veterinarians, farmers, abattoir workers and especially hunters (103).

Porcine respiratory syndrome (PRRS), a highly contagious syndrome with reproductive failure and pneumonia in growing pigs, has spread worldwide and often remains as an endemic infection in herds (104). Several non-porcine reservoirs for this arterivirus have been suspected, but attempts at virus isolation from rodents caught on infected pig farms have failed, and transmission experiments to laboratory rodents have shown that rodents are not susceptible to the virus (105).

Conclusions and perspectives
The literature shows that wild rodents carry pathogens that can be transmitted to production animals on farms and thereby constitute an important factor in the epidemiology of these pathogens. In general, rodents are not true reservoirs of the pathogens reviewed here, but could act as transmitters of disease within a facility or in some cases between farms. In addition, rodents on farms can be a link between wild fauna and domestic animals used for consumption, and in the case of intensively reared animals kept indoors, rodents pose a danger of introducing new infections into herds. The conclusion is that rodent control should be considered an important measure to provide good bio-security on farms. Considering that climate change can be suspected to promote rodent populations in the temperate zone, in the future the problem is likely to become more difficult to combat. The use of rodent-proof buildings will thus be important when planning new facilities for production animals.

Conflict of interest and funding

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*Annette Backhans
Department of Clinical Sciences
Swedish University of Agricultural Sciences
Box 7054
750 06 Uppsala