Journal of Dairy Research

cambridge.org/dar

Zoonotic risks of pathogens from dairy cattle and their milk-borne transmission

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Invited Review

Cite this article: Holzhauer M and Wennink GJ (2023). Zoonotic risks of pathogens from dairy cattle and their milk-borne transmission. *Journal of Dairy Research* **90**, 325–331. https://doi.org/10.1017/S0022029923000730

Received: 10 February 2023
Revised: 2 March 2023
Accepted: 16 October 2023
First published online: 8 January 2024

Keywords:
Bovine; infections; milk; transmission; zoonotic risk

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Abstract

Dairy products are major sources of high-quality protein and bioavailable nutrients and dairy production contributes to local, regional and national-level economies. Consumption of raw milk and raw milk products does, however, carry a zoonotic risk, as does direct contact with cattle by farm husbandry staff and other employees. This review will mainly focus on the latter, and deal with it from the standpoint of a well-developed dairy industry, using the example of the Netherlands. With regard to dairy cattle, the main bacterial pathogens are *Salmonella* spp., *Listeria monocytogenes* and *Leptospira hardjo* as well as *Brucella abortus* and *Chlamydia abortus*. The main viral pathogens associated with dairy are Rift Valley fever virus, rabies virus, cowpox virus and vaccinia virus. The main parasitological infections are *Echinococcus granulosis, Cryptosporidium parvum* and *Giardia duodenalis*, however, the last mentioned have mainly swimming pools as sources of human infection. Finally ectoparasites such as lice and mites and *Trichophyton verrucosum* may affect employees. Some pathogens may cause health problems due to contamination. Bacterial pathogens of importance that may contaminate milk are *Campylolobacter jejuni, Escherichia coli, Mycobacterium avium* subsp. *paratuberculosis*, *Leptospira hardjo and Salmonella typhimurium*. Excretion of zoonotic viruses in milk is negligible in the Netherlands, and the endoparasite, *Toxocara vitulorum* is mainly found in suckling and fattening calves, whilst the risk in dairy cattle is limited. Excretion of transmissible spongiform encephalopathies (TSEs) or mycoses in milk are not expected and are, therefore, not of importance here.

Being aware of the risks and working according to hygiene standards can substantially limit zoonotic risks for employees. Additionally, diseased employees are advised to limit their contact with cattle and to indicate that they work with cattle when consulting a physician. To prevent zoonotic risks through excretion of pathogens in milk, standard hygiene measures are necessary. Further, using only pasteurised milk for consumption and/or processing of milk can considerably limit the risks. If these measures are not possible, well-constructed monitoring can be followed. Monitoring programmes already exist for pathogens such as for *Salmonella spp., Leptospira hardjo* and *Mycobacterium avium* subsp. *paratuberculosis*. For others, like *Campylobacter jejuni and E. coli,* programmes are not available yet as far as we know.

Introduction

Dairy production and consumption have mainly positive effects on society and individual consumers, but can have negative effects on human health also (Hawkes and Ruel, 2006). Dairy products are major sources of high-quality protein and bioavailable nutrients (eg calcium; Todd *et al.*, 2006). Dairy production can also contribute to local, regional and national-level economies and provide opportunities for employment and income generation (Hawkes, 2006), which are critical determinants of health (Marmot *et al.*, 2008). However, a number of potential health risks associated with dairy production and consumption have also been identified, such as diet-related chronic diseases like milk allergy, environmental change, food-borne and occupational hazards and zoonotic diseases (Horrigan *et al.*, 2002; Hawkes, 2006; Kimman *et al.*, 2013). Globally, there is strong demand for milk and dairy products (IDF, 2016; USDA, 2021). This is largely due to global population growth (IDF, 2016), although increases per capita in dairy intake have also driven global demand (OECD and FAO, 2016). As demand for food increases, agricultural sectors have sought to increase production to meet that demand, and the dairy sector is no exception. In 2020, more than 906 million tons of milk were produced by the global dairy sector (FAO, 2021), and global production is projected to increase by 23% in 2025, compared to years 2013–2015 (OECD and FAO, 2016).

Direct or indirect contact with contaminants such as bacteria, viruses and other pathogens is a potential risk when working with animals (WOAH, 2022). Exposure to contaminants can occur by respiration or by contact with excreta such as urine, faeces, milk and abortive fluids. Individuals may also have direct contact with the animal's coat and skin. Contact with the pathogenic agents can cause an infection or even disease and the same risk of transmission of pathogens from animals to humans applies to the consumption of raw milk products (Maunsell and Donovan, 2008). Fortunately, not all infectious agents and infections lead to health problems for cows and humans, though some pathogens unmistakably contain a markedly increased zoonotic risk. The objective of this paper is to provide an overview of the micro-organisms that may affect dairy cows under Dutch circumstances, the risk that these micro-organisms are presented to herd mates and to the employees working with dairy cattle and their effect on safety of the milk. Based on this overview, the pathogens with the highest zoonotic risk are identified and listed in the database. A distinction is made between pathogens that pose a risk to employees that work with dairy cattle and those that threaten the safety of milk and milk products. Reviewing the health impacts associated with dairy production and consumption will enhance understanding of the potential consequences associated with intensification of the dairy sector. To the authors' knowledge, no other comprehensive reviews of the potential health impacts of bacterial, viral, parasitological and mycotic infections associated with dairy production and consumption have been published.

With these objectives into mind, a broad review was undertaken in an effort to provide a comprehensive overview of the linkages between the dairy sector and public health. Specifically, the review aimed to identify the potential public health risks associated with dairy production. The content of this review can be used to support improved decision making for the future development of the dairy sector, from a public health perspective. Such decisions include:

- Prioritisation of potential health hazards associated with the dairy sector that require specific risk communication and management actions;
- Resource allocation for the management of specific hazards associated with dairy production and consumption and
- Identification of knowledge gaps that require further research to improve understanding and management of the public health impacts associated with dairy production and consumption.

There are several methods that can be used to support these decision-making processes by providing systematic assessments of the public health impacts of dairy production and consumption at a wide range of spatial and temporal scales and with varying levels of detail. This inventory covered the clinical symptoms in cattle, the impact on animal welfare, the route and estimated risk of transmission to herd mates and to humans, the excretion in milk, the production of endotoxins, possible biosecurity measurements, vaccinations, diagnostic tools and the prevalence in our country (The Netherlands) as an example of a developed dairy sector.

Materials and methods

The infectious contaminants that may be found on Dutch dairy farms for now and in the near future were identified and listed in a database. Next, relevant background information for these micro-organisms was added, including their prevalence, the risk of excretion in milk, available diagnostic tests and preventive measures that can be taken to minimise the risk of infection. The relevant information was obtained from the literature, specialists of and the diagnostic results from the Royal GD laboratory in the last decade.

The pathogens with the highest zoonotic risk were identified based on the following criteria: causes of diseases of infectious origin in dairy cattle, characteristics of the agents, zoonotic aspects of the agents, route and risk of transmission to herd mates and humans, prevalence or the risk that the disease will be introduced in the Netherlands, laboratory diagnosis and excretion in or contamination of milk.

Scope of the literature review to support the risk analysis

First, lists were composed of micro-organisms including bacteria, viruses, parasites, TSEs, mycoses and emerging diseases that may be found on Dutch dairy. The following information was included in the list for each micro-organism:

- Species
- General information including size, RNA- or DNA, presence of an envelope (viruses), Gram status and production of endotoxins (bacteria), route of transmission (all pathogens).
- Prevalence in Dutch dairy herds as known from the literature (in case not known from the literature, a best guess was made by Royal GD experts).
- If an emerging disease, the likelihood of occurrence in the Netherlands in the next decade.
- Likelihood of pathogen to be found in milk.
- Zoonotic potential, including possible route(s) of transmission and estimated risk to humans by direct contact or contact with raw milk.
- What can be done to prevent disease, including biosecurity measures, vaccination, testing and others.
- The harmfulness to animal welfare and animal health.
- Testing possibilities, including available tests, frequency of testing and materials required.

This information was obtained from the literature, experts and laboratory staff employees of Royal GD Animal Health. The Dutch information was combined with papers about zoonotic infectious diseases from other countries with modern dairy production systems. Attention was given to TSEs and viral, bacterial, parasitological and mycotic infections. Specific attention was paid to list A diseases (ie diseases regulated by the EU Animal Health Law: https://eur-lex.europa.eu/EN/legal-content/summary/the-eu-animal-health-law).

Literature regarding production systems other than the dairy system (suckler cows, for example) was not included in this study. A comprehensive literature search was conducted in July–August 2021 to identify all relevant publications addressing infectious diseases in dairy cows, excretion of agents in milk, faeces and urine, as well as zoonotic risks. Literature search terms included specific phrases such as 'salmonella', 'trichophyton' and 'dairy cows' in the title, abstract, or as a keyword. The search terms were entered into the following three search databases:

- Web of Science (http://apps.webofknowledge.com).
- PubMed (https://www.ncbi.nlm.nih.gov/).
- ScienceDirect (http://www.sciencedirect.com/science/search).

To complete this systematic review in a reasonable period of time, we included literature published in the last five years as far as possible, thus, publications between January 2015 and August 2021. An exception was made in the case of high-quality reviews published before 2015 or where there were no publications in period

https://doi.org/10.1017/S0022029923000730 Published online by Cambridge University Press

mentioned. The database search of scientific articles resulted in papers published predominantly in Western countries. All of the information was presented in an Excel file data base that distinguished between bacterial, mycotic, parasitological and viral infections as well as TSEs.

Risk analysis

The pathogens with the highest zoonotic risk were identified based on the following criteria:

- Causing diseases of infectious origin in dairy cattle
- Characteristics of agents
- Zoonotic aspects of agents
- Route and risk of transmission to herd mates and humans
- Prevalence in the Netherlands or the risk of being introduced
- Laboratory diagnosis
- Excretion in or contamination of milk

The prioritisation of the pathogens in this report is based on knowledge and discussion with the scientific staff of the Bovine Health Department and the Laboratory of Royal GD, which manages diseases in cattle with zoonotic consequences on a daily basis. Among the 223 publications identified in the literature, 119 were not considered useful because better or more recent examples or reviews of a given pathogen were consistently identified. In total, 104 papers provided usable information, but the pathogens discussed were either not all present or not emerging in the Netherlands. Ultimately, about 60 papers were selected to support the conclusions presented in this paper.

Results

An alphabetic overview of the pathogens of importance in the Netherlands or from regions important for the Netherlands was compiled. Viral, bacterial and parasitological infections are presented in Tables 1–3, respectively. Mycoses are presented in Table 4 transmission of pathogens from cattle to humans is especially possible through direct or indirect contact with the skin or excreta, and through faecal contaminated milk produced by clinically healthy animals. Transmission by excretion of pathogens in the milk is considered to be very limited (with exception of Salmonellae), especially if milk from sick cows is treated with care.

Viral infections

There are said to be a total of 42 viruses, including Toro or Breda virus, that are causing serious infections in cattle and are of potential zoonotic risk in The Netherlands (Hoet and Saif, 2004). Many viruses are species-specific, in which case the risk for transmission to humans is considered to be minimal. Other viruses (such as Enterovirus) have a low zoonotic potential but currently (January 2022) are limited present in the Netherlands. They are also found in other European regions and in the US (Gomez and Weese, 2017) and may become a concern in the near future in our region.

Rabies and Rift Valley fever (RVF) were identified as viral infections with the highest risk to employees working with cattle. Rabies can occur in all warm-blooded animals and is principally transmitted *via* direct contact with the saliva of an infected animal. Infection with rabies can be fatal without rapid intervention, which is the main reason for it being classified as a high-risk pathogen. Rabies is found in wildlife in Eastern Europe, in Africa, Asia, Indonesia, Bolivia, Mexico and Cuba (WHO, 2019). RVF, genus *Phlebovirus*, order Bunyavirales, is most commonly seen in domestic animals in sub-Sahara Africa and considered a serious risk to animals by the World Organisation for Animal Health (WOAH, 2022), with high economic impact. The virus can be transmitted to humans by contact with the body fluids of infected animals or through bites from infected mosquitoes (*Culicoides)*. Most infected humans do not show signs of clinical illness or have only mild symptoms. However, a small percentage develop severe symptoms such as eye disease, haemorrhage and encephalitis (Wright and Kortekaas, 2019). The risk of future RVF introduction in Europe is relatively high given intercontinental traffic and storms.

Cattle warts, caused by bovine papillomavirus, are highly prevalent in Dutch cattle but appear to be species-specific and transmission to humans is unproven (Lawson *et al*., 2018). In contrast, cowpox (mainly observed in cats) and related vaccinia virus may infect humans (Lapa *et al*., 2019). These viruses usually cause skin lesions, although the ocular form may lead to serious complications. Both viruses are not present in cattle in the Netherlands, but may become a threat in the near future through worldwide travelling and trade. At present, viruses with high zoonotic risk that are excreted in the milk of dairy cows have not been identified in the Netherlands. For an overview of potential zoonotic viruses, the laboratory test to detect them, their clinical symptoms in cattle, their presence in milk, control measures and their total occurrence and importance in our region, see Table 1.

Bacterial infections

There are a total of 37 bacteria species and their various subspecies, causing infections in cattle and of which roughly 17 species present a potential zoonotic risk. Some species such as *Salmonella typhimurium*, *Bacillus cereus* and *Brucella abortus* have a high

Table 1. Potential zoonotic viruses of importance in Western Europe, DNA or RNA, the laboratory test to detect them, their clinical symptoms in cattle, their presence in milk, control measures and their importance in The Netherlands

Virus	DNA/ RNA	Detection methods	Symptoms in cattle	Presence in milk	Prevention	Importance
Rift Valley Fever	RNA	PCR	Abortion and mass death of young animal and sheep	No	Not specific, prevention of mosquito contacts	Of importance in endemic areas
Cowpox, Vaccinia virus	DNA	PCR, electron microscopy	Teat lesions	Contamination, mainly transmission by cats	Hygiene and gloves	Minor

https://doi.org/10.1017/S0022029923000730 Published online by Cambridge University Press

Table 2. Potential zoonotic bacteria of importance in Western Europe, the laboratory test to detect them, their clinical symptoms in cattle, their presence in milk, control measures and their importance in The Netherlands

Bacteria	sp.	Detection methods	Symptoms in cattle	Present in milk	Control	Importance	
Bacillus	*anthracis*	Colouring ear preparatus	Sepsis	No	Not digging close to old farm buildings	Minor	Serious in case of suspicion
Brucella	*abortus*	Culturing and serology	Abortus	Yes	Hygiene around abortion	Minor	Neth. Official free
Campylobacter	*jejuni*	culturing/ special programme for monitoring	Diarrhoea	Contaminant	Hygiene + monitoring	Most times asymptomatic, diarrhoea incidentally, relevance every time intern point of discussion	Sometimes major in case of human infections
Chlamydia	*abortus*	PCR	Abortus	Yes	Hygiene around abortion	Incidentally, mainly in small ruminants	Low
Clostridium	*botulinum*	PCR lung/liver	Paralysis	No	Not using milk of suspected cows	Symptoms dependent type of Clostr. bot. A-E	Moderate
	difficile	No diagnostics	Slight enteritis	Contaminant	Hygiene	Low	
	perfringens	Anaerobe culture	Slight enteritis	Contaminant	Hygiene	Normal present in gut of cattle	Prevalence high, but meaning is under discussion
	septicum	Anaerobe culture	Malignant oedema	No	Hygiene	Minor	Unknown
Escherichia	*coli*	Culturing/ special programme for monitoring	No symptoms	Contaminant	Hygiene + monitoring	HUS and bloody faeces in humans;	Sometimes serious in case of human infections
Leptospira	*hardjo*	Culture urine	Not serious in cattle	Contaminant	Monitoring at GD + hygiene	Incidentally serious problems with livestock farmers	Dairy herds monitored The Netherlands
Listeria	*monocytogenes*	Culturing/ serology	Abortion and mastitis	Yes	Hygiene + SCC	Hygiene around abortion	Major in case of human infections
Salmonella	*dublin*	Culturing/ serology	Abortion, pneumonia, sepsis	Contaminant	Monitoring at GD	Incidentally serious problems with farming personal	Major in case of human infections
	typhimurium	Culturing/ serology	None-bloody diarrhoea, increased mortality	Contaminant	Monitoring at GD	Incidentally serious problems with farming personal	Major in case of human infections
Mycobacterium	*tuberculosis*	Mantoux test, PCR	Pneumonia	Seldom	Prevent introduction by employees	Minor in The Netherlands but still serious in other area	

Table 3. Potential zoonotic parasitological infections, their clinical symptoms in cattle, their detection methods, their presence in milk, control measures and their importance in The Netherlands

Species	Symptoms in Cattle	Detection methods	Excretion route	Presence in milk	Prevention	Importance
Endoparasites						
Echinococcosus granulosis	Dependent affected organ	At slaughter + microsc.	At slaughter	No	Hygiene at slaughter, not feeding raw meat to pets	Minor in Western Europe
Cryptosporidium parvum	Diarrhoea	Faecal examination	Faecal, esp. young calves	Contamination	Hygiene	Moderate
Giardia duodenalis	Diarrhoea	Faecal examination	Faecal, calves 3–6 weeks	Contamination	Hygiene	Minor
Toxocara vitulorum	Fecal shedding worms	Faecal examination after primary infection	Milk	Mainly in colostrum	No introduction carriers	Minor
Ectoparasites						
Cheyletiella	Small itch symptoms	Microscopy		No	Limit contact with animals and brushes etc	
Chorioptes	More importance, mainly on the legs and back side on the cow	Microscopy		No	Limit contact with animals and brushes etc	Sometimes around the tail
Psoroptes	Crusts over whole body, sticking mites	Microscopy		No	Limit contact with animals and brushes etc	Major problem in Belgian Blue cattle
Sarcoptes	Crusts, mainly the head, the neck and tail	Microscopy		No	Limit contact with animals and brushes etc	Sometimes outbreaks in schools and Universities
Demodex bovis	Pustul. Dermatitis	Deep scraping sample and microscopy		No	Limit contact with animals and brushes etc	
Lice	Itch and crusts	Microscopy		No	Limit contact with animals and brushes etc	
Ixodes ricinus	Local dermatitis	Macroscopy		No	Wear coveralls and daily control after visiting	Mainly in special area with suckling cows

Table 4. Potential zoonotic fungal infections, their clinical symptoms in cattle, their route of transmission, their presence in milk, control measures and their risk of transmission

Fungal infections	Symptoms in cattle	Route of transmission	Presence in milk	Preventive measures	Estimated risk of transmission to herdmates
Candida subtilis	Mastitis, most time secondarily	By milk	Yes	Correct use of Antibiotic therapy	Low
Aspergillis fumigates	Respiratory problems, abortion, mastitis	Airborne	Yes	Biosecurity measures	Low, originates from contaminated corn
Trichophyton verrucosum	Dermatomycosis	By (in-)direct contact	No	Wear gloves and limit direct contact, vaccination	Serious, very infectious

potential pathogenic character. *Bacillus cereus* can cause clinical mastitis in cows. In case of clinical mastitis, milk delivery for consumption is forbidden, so the zoonotic risk for direct transmission by milk is considered low, if mastitis milk is removed and if hygiene measures are followed by employees. *Brucella abortus* can cause substantial health problems in

https://doi.org/10.1017/S0022029923000730 Published online by Cambridge University Press

humans, but the Netherlands has been declared by the European Union to be officially free of bovine brucellosis for over 20 years. In the Netherlands, salmonellosis, campylobacteriosis and possibly paratuberculosis were identified as bacterial infections with serious zoonotic risk. Other bacterial pathogens with non-negligible zoonotic risk are *Leptospira hardjo*, *Escherichia coli* and *Listeria monocytogenes*. Most of these bacterial zoonotic infections are a consequence of direct excretion in or contamination of the milk or contact with manure (eg *Salmonella* spp., *Mycobacterium avium* subsp. *paratuberculosis, E. coli* [*STEC O157*], *Campylobacter* spp.; Christidis et al. 2016; Whittington et al. 2019; Ameer *et al.,* 2021; Stevens and Kingsley, 2021). Other vectors are excreta associated with abortion (e.g. *Brucella abortus*, *Listeria monocytogenes* and *Chlamydia abortus*; Walker *et al.*, 2015; Chlebicz and Śliżewska, 2018; Whatmore and Foster, 2021), with urine (e.g. *Leptospira hardjo*; Ellis, 2015) or with cadavers (e.g. *Clostridium botulinum*; Holzhauer *et al.*, 2009).

As said before, mastitis pathogens themselves are normally not a problem in food-borne diseases because these products are not used for human consumption. In the milk of dairy cows with mastitis, endotoxins (lipopolysaccharides) may be present at the moment of bacterial death (ie after treatment with antimicrobials that kill mastitis pathogens). Experts at our company estimated that endotoxins remain in milk for roughly seven days after removal of the bacterial infection (vd Merwe, Royal GD, personal communication). These endotoxins can cause fever and local inflammatory reactions in the gastro-intestinal tract of humans if the milk of cows cured of mastitis is consumed (Wang and Quinn, 2010). However, this risk is limited because cows that contract clinical mastitis will be treated with antibiotics and the milk of treated cows is not allowed for consumption during the withdrawal period. Special attention must be paid to mastitis caused by potentially methicillin resistant *S. aureus* (MRSA; Vanderhaeghe *et al.*, 2010). However, these MRSA are mostly linked to the intensive beef industry (van Loo *et al.*, 2007). For an overview of potential zoonotic bacteria, the laboratory test to detect them, their clinical symptoms in cattle, their presence in milk, control measures and their total occurrence and importance in our region, see Table 2.

Parasitological and mycotic infections

Parasitological infections can be distinguished as being caused by endo- or ectoparasites. Endoparasites affecting host tissues and organs of live cattle include:

- In the gastro-intestinal tract, worms: *Ostertagia ostertagi* and *Toxocara ventilorum*;
- In the gastro-intestinal tract, protozoa: mostly *Cryptosporidium parvum*, *Giardia duodenalis* and various *Eimeria* spp. Recently an outbreak of cryptosporidiosis was diagnosed in Sweden (Outbreak News Today, 2022)
- In the liver: leaf-shaped worms: *Fasciola hepatica* and bladder worms: *Echinococcus granulosis*;
- In the lungs: roundworm (*Dictyocaulus viviparus)* and bladder worms *Echinococcus granulosis*;
- In the uterus, protozoa: *Neospora parvum*;
- In blood: tick-borne diseases: *Babesia divergens*.

Some of these parasites, such as *Cryptosporidium parvum* (Thomson *et al.*, 2017), *Toxocara ventilorum* (Borgsteede *et al.*, 2012), *Echinococus granulosis* (Eckert and Deplazes, 2004) and *Giardia duodenalis* (*G. duodenalis;* Geurden *et al.*, 2004*;* Olson *et al.*, 2004), are of zoonotic importance. *C. parvum* infections in humans are frequently related to contact with surface water (e.g. in swimming pools). The *T. ventilorum* parasite is known to be excreted in milk, but is mainly found in the colostrum of suckling cattle from southern Europe. The prevalence of *E. granulosis* in the Netherlands is also low and the main risk is consumption of imported raw meat of cattle from Eastern Europe (Berends *et al.*, 2009). *G. duodenalis* is predominantly found in young calves (Geurden *et al.*, 2004). Therefore, the overall zoonotic risk of endoparasites from dairy cattle in the Netherlands is estimated as low.

Ectoparasites such as lice and mites may cause problems of the coat and skin. They can be a risk for employees working with cattle, and may be principally responsible in humans for zoonotic dermatitis symptoms – red spots and itch, in the case of infection with mites (Pérez de León *et al.*, 2020). Consuming milk from cattle infected with ectoparasites does not carry a zoonotic risk.

By far the most important mycotic infection with a serious zoonotic risk is *Trichophyton verrucosum* (Lund *et al.*, 2014) which results in proliferative dermatitis with crust. The spores of this infection are highly resistant and are mostly seen in animal crusts but can also be present throughout the barn. Therefore, eliminating this infection from the herd is very challenging. *Trichophyton verrucosum* (commonly known as ringworm) can be transmitted to humans by direct contact and causes circular skin lesions (Lund *et al.*, 2014). The agent is not excreted in milk. For an overview of potential zoonotic parasitological and mycotic infections of importance in Western Europe, the laboratory test to detect them, their clinical symptoms in cattle, their presence in milk, control measures and their total occurrence and importance in our region, see Tables 3 (parasitological infections) and 4 (fungal infections).

Transmissible spongiform encephalitis

The most important TSE in the last several decades has been bovine spongiform encephalitis (BSE), which has been responsible for a considerable number of outbreaks with most economic damage in the UK (Alarcon *et al.*, 2022). The Netherlands has observed 31 clinical cases and a total of 89 confirmed cases (58 after slaughterhouse control, www.wur.nl). The last confirmed case was in 2023. Humans have been diagnosed with variant Creutzfeldt–Jacob disease, but a relationship with BSE has not been proven. Evidence does not support transmission of TSE by milk consumption. Therefore, the zoonotic risk of BSE is estimated as very low.

Conclusions and recommendations

Dairy cattle can be a source of various types of zoonotic infections. Therefore, working with cattle includes a risk that farmers or employees become infected with a pathogen. Some infections may cause serious symptoms such as fever, diarrhoea, respiratory problems or worse in humans. The risk of transmission of infectious agents from dairy cattle to humans is mainly through air, by direct or indirect contact with manure, urine or abortive material (where indirect contact is largely through contaminated milk) and by direct contact with the coat. Risks can be limited by taking good preventive hygiene measures. We advise that all employees working with cattle or milk be aware of the risks and take preventive measures, for example using coveralls, gloves and protective glasses and washing hands frequently with disinfectant soap after contact with cows or their milk. Additionally, sick dairy farm employees are advised to limit their contact with cattle and to indicate they work with cattle when consultation with a physician is required. Excluding milk from infected dairy cattle also limits the risk of pathogen transmission. Other measures include the use of cattle that are free of specific pathogens such as *L. hardjo, S. typhimurium* and *M. paratuberculosis*.

Bacterial infections caused by pathogens excreted in milk (*Salmonella* spp. and paratuberculosis) or faecal contamination of milk (eg *Campylobacter jejuni* and *E. coli*) and mycosal infections (eg *Trichophyton verrucosum)* are particular risks for farmers and employees working with cattle. They should be aware of possible risks, avoid the consumption of raw milk and take protective measures such as those just described. More extreme measures, like having lunch in dedicated rooms, must be considered as well. Dairy farms are advised to follow certification programmes for *L. hardjo, Salmonella* spp. and *M. paratuberculosis*. All these measures should result in an acceptably low risk of becoming affected by a zoonotic disease.

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https://doi.org/10.1017/S0022029923000730 Published online by Cambridge University Press