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Review

A review of the microbiological hazards of dairy products made from raw milk

C. Verraes [a,*], G. Vlaemynck [b], S. Van Weyenberg [b], L. De Zutter [c,d], G. Daube [c,e], M. Sindic [c,f], M. Uyttendaele [c,g], L. Herman [b,c]

[a] Staff Direction for Risk Assessment, DG Control Policy, Federal Agency for the Safety of the Food Chain (FASFC), Kruidtuinlaan 55, 1000 Brussels, Belgium
[b] Institute of Agricultural and Fisheries Research (ILVO), Brusselsesteenweg 370, 9090 Melle, Belgium
[c] Scientific Committee, Federal Agency for the Safety of the Food Chain (FASFC), Kruidtuinlaan 55, 1000 Brussels, Belgium
[d] Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium
[e] Faculty of Veterinary Medicine, University of Liège, Boulevard de Colonster 20, 4000 Liège, Belgium
[f] Gembloux Agro-bio Tech, University of Liège, Passage des Déportés 2, 5030 Gembloux, Belgium
[g] Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

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ABSTRACT

This review concentrates on information concerning microbiological hazards possibly present in raw milk dairy products, in particular cheese, butter, cream and buttermilk. The main microbiological hazards of raw milk cheeses (especially soft and fresh cheeses) are linked to *Listeria monocytogenes*, verocytotoxin-producing *Escherichia coli* (VTEC), *Staphylococcus aureus*, *Salmonella* and *Campylobacter*. *L. monocytogenes*, VTEC and *S. aureus* have been identified as microbiological hazards in raw milk butter and cream albeit to a lesser extent because of a reduced growth potential compared with cheese. In endemic areas, raw milk dairy products may also be contaminated with *Brucella* spp., *Mycobacterium bovis* and the tick-borne encephalitis virus (TBEV). Potential risks due to *Coxiella burnetii* and *Mycobacterium avium* subsp. *paratuberculosis* (MAP) are discussed. Pasteurisation ensures inactivation of vegetative pathogenic microorganisms, which increases the safety of products made thereof compared with dairy products made from raw milk. Several control measures from farm to fork are discussed.

Contents

1. Introduction

Consumers' attitudes show a trend towards increased consumption of foods that are not or only minimally processed such as raw milk and dairy products made from raw milk. Cheeses made from raw cow, sheep and goat milk are the most frequently

* Corresponding author. Tel.: +32 2 211 87 00.
E-mail address: claire.verraes@favv.be (C. Verraes).

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consumed type of dairy products made from raw milk; however, other types of dairy products made from raw milk are also consumed such as mozzarella made from raw buffalo milk, as well as raw milk butter made from cow milk. The consumption of raw milk can hold a risk for the consumer, due to the possible presence of human pathogenic microorganisms. The risks and benefits of the consumption of raw cow milk were described in a review by Claeys et al. (2013) and the nutritional and health benefits of the consumption of raw milk from animal species other than cows were described in a review by Claeys et al. (2014). The microbiological hazards of raw milk from animal species other than cows were described in a review by Verraes et al. (2014). Also EFSA evaluated the public health risk from the consumption of raw drinking milk (EFSA, 2015).

In the present review, a collation is made of available information in the scientific literature concerning the microbiological hazards of dairy products made from raw milk, in particular cheese, butter, cream and buttermilk. Dairy products made from raw milk from cows, sheep and goats are taken into account. Dairy products made from raw milk from other animal species are less relevant in Europe, with the exception of mozzarella made from raw buffalo milk. Only zoonotic human pathogenic microorganisms and pathogens originating from the environment have been taken into consideration. Pathogenic agents originating from human contamination due to human illness, e.g., *Salmonella* Typhi, *Shigella* spp. and noroviruses are not covered in this review.

2. Occurrence of human pathogenic microorganisms in raw milk and dairy products made from raw milk

In general, pathogenic microorganisms can contaminate raw milk in two ways. The first way is an endogenous contamination where the milk is contaminated by a direct transfer from the blood (systemic infection) to the milk or via an infection in the udder called mastitis. The second way is an exogenous contamination, where the milk is contaminated during or after milking by the faeces, the exterior of the udder and teats, the skin, the environment, etc.

Based on recent review documents (Claeys et al., 2013; EFSA, 2015; Sci Com, 2011, 2013; Verraes et al., 2014), the following human pathogenic microorganisms are considered as the main microbiological hazards associated with raw milk consumption from cows, goats and sheep: *Bacillus cereus*, *Campylobacter coli* and *Campylobacter jejuni*, enterotoxin-producing *Staphylococcus aureus*, *Helicobacter pylori*, human pathogenic verocytotoxin-producing *Escherichia coli* (VTEC), human pathogenic *Yersinia*, *Leptospira*, *Listeria monocytogenes*, *Salmonella* spp., *Streptococcus agalactiae*, *Streptococcus equi* subsp. *zooepidemicus*, *Clostridium botulinum*, *Brucella* spp., *Mycobacterium bovis*, *Cryptosporidium parvum* and *Toxoplasma gondii*. Some microbiological hazards are indicated as hypothetical because they are still not confirmed, but have the hypothetical potential to be pathogenic for humans (*Mycobacterium avium* subsp. *paratuberculosis*; MAP) or to be foodborne (*Coxiella burnetii*).

Limited systematic data were available on prevalences of human pathogenic microorganisms in dairy products made from raw milk. In a baseline study (EFSA, 2013b) performed at a European level, 1 sample from 476 raw milk cheese samples exceeded 100 cfu g^{-1} for *L. monocytogenes*. The EU summary report mentioned that non-compliance of *L. monocytogenes* primarily occurred in soft and semi-soft cheeses made from raw or low heat-treated cows' milk (EFSA & ECDC, 2015). In addition, studies in the scientific literature describing detection frequencies of human pathogenic microorganisms in dairy products made from raw milk provide an indication of prevalences. Data of such frequencies of occurrence were collected for Europe and are shown in Table 1, where the detection frequency, the type of food, the method of analysis and the country are given.

Frequencies of occurrence were found for several raw milk cheeses, butter and cream. No frequencies were found for buttermilk made from raw milk as such products are less often produced. No *Salmonella* has been detected in any tested samples of raw milk cheeses, butter and cream with the exception of one publication where the prevalence in cheese was 4.3% (n = 70 samples; Almeida et al., 2007). Concerning VTEC in raw milk cheeses, *E. coli* strains with virulence genes are detected with frequencies between 0 and 55.3%. Farrokh et al. (2013) stated that the prevalence of *vtx* genes, detected by PCR, does not necessarily reflect the occurrence of a viable *E. coli* isolate containing those genes. VTEC was also detected in butter (Messelhäusser, Beck, Gallien, Schalch, & Busch, 2008). As illustrated in Table 1, *L. monocytogenes* was detected in raw milk cheeses, butter and cream with frequencies varying between 0 and 41.9%, 3.6 and 29.9%, and 0.7 and 8.3% respectively, although in some cases the numbers were lower than 100 cfu g^{-1}. Of 70 cheese samples, 11.4% were positive for *L. monocytogenes* per 25 g, whereby 1.4% contained counts higher than 200 cfu g^{-1} and 10.0% lower than 100 cfu g^{-1} (Almeida et al., 2007). Of 474 cheese samples and 519 butter samples, respectively, 0.6% and 0.2% of the samples that were taken in Belgium by the sector of small cheese producers in the Walloon region had counts higher than 100 cfu g^{-1} (Sci Com, 2015). No *Campylobacter* were detected in 199 tested raw milk cheeses, which contrasts the higher reporting in raw milk (0–12%) (EFSA, 2015; Verraes et al., 2014). As indicated in Table 1, *S. aureus* was found in raw milk products with frequencies between 5 and 100% in cheeses, and between 1.6 and 20.3% in butter, but the possibility of the strains to produce enterotoxins varies and the share of such strains is difficult to deduce from the available information. Jørgensen, Mørk, and Rørvik (2005) also detected *S. aureus* in sour cream. *B. cereus* was detected in 28% of 25 samples of cheeses made from raw milk of several animal species. All strains were able to produce enterotoxins (Williams & Withers, 2010). MAP was detected in 4.2 and 20% of raw milk cheese samples using PCR (Stephan, Schumaher, Tasara, & Grant, 2007; Williams & Withers, 2010). *C. burnetii* was detected with PCR in 57.0% of unpasteurised cheese samples and in one of two cream samples, but the relation of these PCR results with the presence of infectious strains is not clear (Eldin, Angelakis, Renvoisé, & Raoult, 2013).

3. Reported human cases and outbreaks due to the consumption of dairy products made from raw milk

The development of a disease after consumption of contaminated dairy products made from raw milk depends on several factors such as the pathogenicity of the strain, the number of ingested microorganisms, the physiological state of the microorganism, the health condition of the consumer at the moment of ingestion, etc. Persons belonging to the YOPI group (young, old, pregnant, immunodeficient) have a higher risk of infection for certain pathogens such as *L. monocytogenes* and healthy persons can also be infected. The likelihood of developing a disease follows a dose–response curve with a higher number of cells increasing the chance of developing a disease. This relationship was categorised by the EFSA BIOHAZ Panel in the framework of a risk ranking exercise of foods of non-animal origin as follows: score 1 stands for a dose–response curve where the pathogen has to grow to high numbers (often higher than 5 log cfu g^{-1}) to produce toxins and cause illness; score 2 stands for a dose–response curve where the pathogen must grow to cause illness; and score 3 stands for a dose–response curve where the pathogen can cause illness in low numbers (Da Silva et al., 2015; EFSA, 2013a). *Salmonella*,

Table 1
Reported frequencies of occurrence of human pathogenic microorganisms in/on dairy products made from raw milk in Europe.[a]

Dairy product made from raw milk	Frequency of occurrence (%)	Number of samples	Comments	Country	References
Salmonella					
Cheese	0.0	71		Belgium	De Reu, Debeuckelaere, Botteldoorn, De Block, and Herman (2002)
	0.0	20		Belgium	De Reu, Grijspeerdt, and Herman (2004)
	0.0	334		Germany	Hahn, Walte, Coenen, and Teufel (1999a)
	0.0	75		Ireland	Coveney, Fitzgerald, and Daly (1994)
	4.3	70		Portugal	Almeida et al. (2007)
	0.0	25		Scotland	Williams and Withers (2010)
	0.0	429		Belgium	DiversiFerm (pers. comm.)
	0.0	582		Belgium	FASFC (pers. comm.)
Butter	0.0	64		Belgium	De Reu et al. (2004)
	0.0	518		Belgium	DiversiFerm (pers. comm.)
	0.0	192		Belgium	FASFC (pers. comm.)
Cream	0.0	132		Belgium	FASFC (pers. comm.)
Verocytotoxin-producing *Escherichia coli* (VTEC)					
Cheese	5.6	71	IMS, VIDAS O157 assay and PCR	Belgium	De Reu et al. (2002)
	0.0	20	IMS, VIDAS O157 assay and PCR	Belgium	De Reu et al. (2004)
	0.0	334	1.5% VTEC	Germany	Hahn et al. (1999a)
	4.0	25	Enrichment; 1 *stx2*-positive strain	Italy	Volponi et al. (2012)
	13.1	1039	PCR	France	Vernozy-Rozand, Montet, Berardin, Bavai, and Beutin (2005)
	5.7	1502	PCR	Switzerland	Zweifel et al. (2010)
	0.0	739	IMS	Scotland	Coia, Johnston, Steers, and Hanson (2001)
	8.9	180	- Vero cell assay	France	Fach et al. (2001)
	30.6		- PCR-ELISA		
	4.8	83	Isolation	Spain	Caro and García-Armesto (2007)
	30.4	112	- PCR-ELISA	Italy	Auvray, Lecureuil, Dilasser, Taché, and Derzelle (2009)
	27.7		- RT-PCR		
	2.7		- Colony hybridisation		
	4.5	143	- PCR *vtx1* gene	Italy	Civera et al. (2007)
	3.8		- PCR *vtx2* gene		
	0.8		- PCR *eae* gene		
	2.1		- PCR *ehxA* gene		
	0.0		- Isolation		
	0.0	1313	Isolation of *E. coli* O157; also butter	Italy	Conedera et al. (2004)
	4.9	- 796	- PCR	Switzerland	Stephan et al. (2008)
	41.0	- 39	- Non-O157 VTEC strains		
	0.0	70	IMS	Portugal	Almeida et al. (2007)
	29.8	400	- PCR *vtx* gene	France	Madic et al. (2011)
	37.3		- PCR *eae* gene		
	55.3		- At least one of O26, O103, O111, O145 and O157 genetic markers		
	6.5		- Combinations of above		
	0.0	25	Isolation of *E. coli* O157	Scotland	Williams and Withers (2010)
	10.0	10	Also butter	Germany	Messelhäusser et al. (2008)
	0.8	1042	PCR	Belgium	FASFC (pers. comm.)
Butter	0.0	64	IMS, VIDAS O157 assay and PCR	Belgium	De Reu et al. (2004)
	0.0	366	PCR	Belgium	FASFC (pers. comm.)
Cream	0.0	131	PCR	Belgium	FASFC (pers. comm.)
Listeria monocytogenes					
Cheese	0.0	55		Sweden	Rosengren et al. (2010)
	0.8	122		Norway	Jakobsen, Heggebø, Sunde, and Skjervheim (2011)
	2.8	71		Belgium	De Reu et al. (2002)
	0.0	20		Belgium	De Reu et al. (2004)
	2.4	334		Germany	Hahn et al. (1999a)
	0.0	17		Ireland	Coveney et al. (1994)
	11.4	70	1.4% > 2.3 log cfu g^{-1}; 10.0% < 2 log cfu g^{-1}	Portugal	Almeida et al. (2007)
	19.0	42		Italy	Rantsiou, Alessandria, Urso, Dolci, and Cocolin (2008)
	0.0	252		Portugal	Kongo, Malcata, Ho, and Wiedmann (2006)

Table 1 (*continued*)

Dairy product made from raw milk	Frequency of occurrence (%)	Number of samples	Comments	Country	References
	0.0	51		Spain	Arrese and Arroyo-Izaga (2012)
	4.0	25		Scotland	Williams and Withers (2010)
	41.9	31		Sweden	Loncarevic et al. (1995)
	0.0	230		Austria	Schoder et al. (2011)
	12.2	474	0.6% > 2 log cfu g^{-1}	Belgium	DiversiFerm (pers. comm.)
	6.0	901		Belgium	FASFC (pers. comm.)
Butter	18.7	64		Belgium	De Reu et al. (2004)
	29.9	519	0.2% > 2 log cfu g^{-1}	Belgium	DiversiFerm (pers. comm.)
	12.4	259		Belgium	De Reu and Herman (2004); De Reu, Herman, De Boosere, and De Ville (2006, 2007); De Reu, Herman, and De Ville (2008)
	3.6	361		Belgium	FASFC (pers. comm.)
Cream	5.0	20		Belgium	De Reu and Herman (2004)
	8.3	60		Croatia	Frece, Markov, Čvek, Kolarec, and Delaš (2010)
	4.2	48		England & Wales	Greenwood et al. (1991)
	0.7	134		Belgium	FASFC (pers. comm.)
Campylobacter					
Cheese	0.0	66		Ireland	Whyte et al. (2004)
	0.0	10		Germany	Messelhäusser et al. (2008)
	0.0	123		Belgium	FASFC (pers. comm.)
Staphylococcus aureus					
Cheese	69.0	55	Coagulase-positive staphylococci; 10.9% > 5 log cfu g^{-1}; 0% enterotoxins	Sweden	Rosengren et al. (2010)
	67.5	122	Average of cheese stages	Norway	Jakobsen et al. (2011)
	19.7	71	>3 log cfu g^{-1}; 7.1% (14) Enterotoxins	Belgium	De Reu et al. (2002)
	5.0	20	0% Enterotoxins	Belgium	De Reu et al. (2004)
	13.1	245	>4 log cfu g^{-1}	Germany	Hahn, Walte, Coenen, and Teufel (1999b)
	100.0	33	42.4% Enterotoxins	Italy	Cremonesi et al. (2007)
	80.4	46	Average of cheese stages; 100% enterotoxins	Italy	Poli et al. (2007)
	36.0	25	7 of 18 Examined strains from 2 cheeses able to produce enterotoxin C	Scotland	Williams and Withers (2010)
	8.3	737	>5 log cfu g^{-1}	Belgium	FASFC (pers. comm.)
Butter	1.6	64	0% Enterotoxins	Belgium	De Reu et al. (2004)
	20.3	281		Belgium	FASFC (pers. comm.)
Bacillus cereus					
Cheese	28.0	25	100% Enterotoxins	Scotland	Williams and Withers (2010)
	0.0	3		Belgium	FASFC (pers. comm.)
Mycobacterium avium subsp. *paratuberculosis*					
Cheese	4.2	143	PCR; no viable cells	Switzerland	Stephan et al. (2007)
	20.0	25	PCR	Scotland	Williams and Withers (2010)
Coxiella burnetii					
Cheese	57.0	68		France	Eldin et al. (2013)
Butter	0.0	Not given		France	Eldin et al. (2013)
Cream	50.0	2		France	Eldin et al. (2013)

[a] Abbreviations are: IMS, immunomagnetic separation; PCR, polymerase chain reaction; PCR-ELISA, polymerase chain reaction enzyme-linked immunosorbent assay.

Campylobacter, VTEC and the tick-borne encephalitis virus (TBEV) were in the framework of the present study allocated a score 3; *L. monocytogenes*, *Brucella*, *M. bovis* and pathogenic species of *Streptococcus* have to grow to cause illness and have score 2; and *S. aureus* and *B. cereus* have to grow to numbers of several log units to be able to produce sufficient toxins to cause illness and therefore they have a score of 1. For MAP and *C. burnetii* the foodborne and zoonotic potential is not known.

The consumption of dairy products made from raw milk has already caused several human cases and outbreaks. In Table 2, a non-exhaustive list is shown of reported human cases and outbreaks in Europe, the United States and Canada related to the consumption of dairy products made from raw milk found in scientific literature or reported by official organisations. Only outbreaks due to the consumption of raw milk cheeses were found and one outbreak was ascribed to the consumption of raw milk cream linked to infection with *E. coli* O157:H7 (CDSC, 1998a). Outbreaks due to the consumption of raw milk butter or buttermilk were not found. From a report from EFSA (EFSA & ECDC, 2014), it seems that in 2012 no outbreaks were reported in the EU due to the

Table 2
Reported human cases and outbreaks in Europe, the United States and Canada due to the consumption of dairy products made from raw milk.

Pathogenic agent	Dairy product made from raw milk	Country	Year	Cases	References
Salmonella enteric Muenster	Cheddar cheese from unpasteurised milk	Canada	1982	Not given	D'Aoust, Warburton, and Sewell (1985); van Cauteren et al. (2009)
Salmonella Typhimurium PT10	Cheddar cheese from unpasteurised milk	Canada	1984	>1700 confirmed cases	D'Aoust et al. (1985)
Salmonella	Farm raw milk cheese	Finland	1985	35 cases	Huchot, Bohnert, Cerf, Farrokh, and Lahellec (1993)
Salmonella Typhimurium	Raw milk vacherin mont d'or cheese	Switzerland	1985	215 cases	Anonymous (1986)
Salmonella Dublin	Soft stilton cheese from unpasteurised milk	England and Wales	1989	42 cases	Maguire et al. (1992)
Salmonella Paratyphi B	Raw goat milk cheese	France	1990	277 cases	Grimont and Bouvet (1991)
Salmonella Paratyphi B	Raw goat milk cheese	France	1993	273 cases, 1 dead	Desenclos et al. (1996)
Salmonella Berta	Farm soft cheese from unpasteurised milk	Canada	1994	35 confirmed cases	Ellis et al. (1998)
Salmonella Dublin	Raw cow milk mont d'or cheese	France and Switzerland	1995	25 cases, 12 hospitalised, 5 dead	Vaillant et al. (1996)
Salmonella Dublin	Raw cow milk mont d'or cheese	France	1996	14 cases, 1 dead	Infuso, Vaillant, and Desenclos (1997)
Salmonella Typhimurium PT12 atypical	Raw milk morbier cheese	France	1997	113 cases	De Valk et al. (2000)
Salmonella Typhimurium var Copenhagen phage type DT104 (outbreak 1) and non-var Copenhagen phage type DT 104b (outbreak 2)	Unpasteurised Mexican-style cheese	United States	1997	31 confirmed cases (outbreak 1); 79 cases (outbreak 2)	Cody et al. (1999)
Salmonella Typhimurium DT104	Unpasteurised Mexican-style cheese	United States	1997	54 confirmed cases	Villar et al. (1999)
Salmonella Newport	Raw milk cheese	United States	2001	27 cases, 12 hospitalised	CDC (2014)
Salmonella Enteritidis phage type 8	Raw milk cantal cheese	France	2001	215 cases	Haeghebaert et al. (2003)
Salmonella Typhimurium	Unpasteurised queso-fresco cheese	United States	2003	50 cases, 7 hospitalised	CDC (2014)
Salmonella Typhimurium	Unpasteurised queso-fresco cheese	United States	2004	12 cases, 1 hospitalised and 1 dead	CDC (2014)
Salmonella	Unpasteurised queso-fresco cheese	United States	2005	2 cases	CDC (2014)
Salmonella Typhimurium	Unpasteurised queso-fresco cheese	United States	2006	20 cases, 2 hospitalised	CDC (2014)
Salmonella enterica Newport	Unpasteurised Mexican-style aged cheese	United States	2006–2007	85 cases (but no significant association)	CDC (2008)
Salmonella Typhimurium	Raw milk cheese and raw milk	United States	2007	29 cases	CDC (2007)
Salmonella enteric Muenster	Unpasteurised goat cheese	France	2008	25 laboratory-confirmed cases, 4 hospitalised	van Cauteren et al. (2009)
Escherichia coli O119:B14 (*vtx2*)	Farm fresh cheese from raw cow and goat milk	France	1992–1993	4 cases, 4 HUS, 1 dead	Casenave et al. (1993)
E. coli O157 (PT28, *vtx2*)	Farm raw milk cheese	Scotland	1994	22 cases, 1 HUS	Ammon (1997)
E. coli O103	Farm fresh cheese from raw goat milk	France	1994	4 cases, 4 HUS	Decludt (1995)
E. coli O110:H-	Raw milk cheese	Germany	1996	3 cases, 0 HUS	Bockemühl and Karch (1996)
E. coli O157:H7	Fresh cheddar cheese curds	United States	1998	63 cases, 55 laboratory-confirmed, 24 hospitalised	CDC (2000)
E. coli O157:H7	Unpasteurised cream	England	1998	7 cases	CDSC (1998a)
E. coli O157 (PT2, *vtx2*)	Cheese from unpasteurised milk	England	1998	10 cases, 1 HUS case	CDSC (1998b)
E. coli O157	Unpasteurised farm cheese	Scotland	1998	4 cases	Strachan et al. (2006)
E. coli O157 (PT21, PT28)	Homemade raw goat milk cheese	Scotland	1999	27 cases, 1 HUS	Curnow (1999)
E. coli O157:H7	Unpasteurised gouda hard cheese	Canada	2002–2003	13 cases, 2 HUS	Honish et al. (2005)
E. coli O157:H7	Unpasteurised queso-fresco cheese	United States	2004	3 cases, 2 hospitalised	CDC (2014)
E. coli O157:H7	Raw milk cheese	Canada	2004	3 cases	MAPAQ (2004)
E. coli O157 (*vtx2*, *eae*)	Farm fresh unpasteurised goat cheese	France	2004	3 cases, 2 HUS	Espié et al. (2006)
E. coli O26, O80 (*vtx2*, *eae*)	Raw milk brie	France	2005	6 HUS	INVS (2007)
E. coli O157:H7	Raw milk cheese	Canada	2008–2009	16 cases	Gaulin et al. (2012)
E. coli O157:H7	Aged raw milk gouda cheese	United States	2010	38 cases, 15 hospitalised	McCollum et al. (2012)

Table 2 (*continued*)

Pathogenic agent	Dairy product made from raw milk	Country	Year	Cases	References
E. coli O157:H7, *E. coli* O157:NM(H-)	Unpasteurised cheeses	United States	2010	15 cases	CDC (2014)
E. coli O157:H7 and *Listeria monocytogenes*	Unpasteurised gouda cheese	United States	2010	38 cases, 15 hospitalised, 1 HUS	CDC (2014)
Listeria	Vacherin mont d'or cheese from unpasteurised milk	Switzerland	1983–1987	122 cases, 33 dead	Bille (1989)
Listeria meningitis	Anari raw goat milk soft cheese	England	1988	1 case	Azadian, Finnerty, and Pearson (1989)
Listeria monocytogenes Serovar 4b	Raw milk brie de meauw cheese	France	1995	36 cases, 4 dead, 7 foetal/ neonatal cases	Vaillant, Maillot, Charley, and Stainer (1998)
Listeria monocytogenes Serovar 4b	Raw milk livarot, pont-l'évêque cheese	France	1997	14 cases	Jacquet, Saint-Clement, Brouille, Catimel, and Rocourt (1998)
Listeria monocytogenes	Fresh Mexican-style raw milk cheese	United States	2000–2001	13 cases, 11 pregnant women (5 stillbirths, 3 premature deliveries, 3 infected newborns)	CDC (2001); MacDonald et al. (2005)
Listeria monocytogenes	Unpasteurised queso-fresco cheese	United States	2003	12 cases, 12 hospitalised, 1 dead	CDC (2014)
Listeria monocytogenes	Unpasteurised queso-fresco cheese	United States	2005	12 cases, 12 hospitalised, 0 dead	CDC (2014)
Brucella melitensis	Home-made fresh cottage cheese from unpasteurised milk	Spain	1996	81 cases	Castell Monsalve, Rullán, and CallizoNiet-Sandoval Alcolea (1996)
Brucella	Homemade unpasteurised cheese	United States	2001	4 cases, 0 dead	CDC (2014)
Brucella melitensis serovar 3	Unpasteurised raw goat milk cheese	Spain	2002	11 brucellosis cases	Méndez Martínez et al. (2003)
Brucella	Unpasteurised queso-fresco cheese	United States	2005	2 cases, 2 hospitalised, 0 dead	CDC (2014)
Brucella	Unpasteurised goat cheese	United States	2006	5 cases, 3 hospitalised, 0 dead	CDC (2014)
Brucella	Unpasteurised queso-fresco cheese	United States	2007	3 cases, 1 hospitalised, 0 dead	CDC (2014)
Brucella abortus	Raw milk cheese	France	2012	1 case (child)	Bronner, Hénaux, Fortané, Hendrikx, and Calavas (2014)
Campylobacter jejuni	Homemade unpasteurised cheese	United States	2000	18 cases, 0 hospitalised, 0 dead	CDC (2014)
Campylobacter jejuni	Unpasteurised cheese	United States	2003	18 cases, 0 hospitalised, 0 dead	CDC (2014)
Campylobacter jejuni	Homemade unpasteurised cheese	United States	2006	58 cases, 2 hospitalised, 0 dead	CDC (2014)
Campylobacter jejuni	Fresh raw milk cheese	United States	2007	68 cases	CDC (2009)
Campylobacter jejuni	Unpasteurised queso-fresco cheese	United States	2009	10 cases, 0 hospitalised, 0 dead	CDC (2014)
Staphylococcus aureus enterotoxins A and D	Farm raw sheep milk cheese	France	1983	20 cases	De Buyser, Janin, and Dilasser (1985)
Staphylococcus aureus enterotoxins A	Raw sheep milk cheese	Scotland	1984	27 cases	Bone, Bogie, and Morgan-Jone (1989)
Staphylococcus aureus	Stilton cheese from unpasteurised milk	England	1988	155 cases	Maguire et al. (1991)
Staphylococcal enterotoxin type E	Soft cheese from unpasteurised milk	France	2009	6 outbreaks, 23 cases	Ostyn et al. (2010)
Streptococcus equi, *Streptococcus zooepidemicus* (group C)	Mexican-style soft raw milk cheese (queso fresco)	United States	1983	16 cases, 5 hospitalised, 3 dead	Altekruse et al. (1998); CDC (1983)
Tick-borne encephalitis virus	Cheese from raw cow and goat milk	Austria	2008	6 cases	Holzmann et al. (2009)

consumption of dairy products made from raw milk and in 2013 one outbreak was reported due to VTEC O157 contamination of unpasteurised cheese (EFSA & ECDC, 2015).

The majority of the outbreaks (22 out of 64) due to the consumption of raw milk cheeses was caused by *Salmonella*, followed by VTEC. Consumption of contaminated soft and semi-soft cheeses is often implicated in outbreaks with VTEC, especially when they are made of unpasteurised cow or goat milk. VTEC O157:H7 is linked to the majority of the VTEC outbreaks, but also other serotypes have been implicated (Farrokh et al., 2013). *C. jejuni* (in the United States), *L. monocytogenes* and *Brucella* spp. were relatively often linked to raw milk cheese outbreaks, respectively 5, 8 and 7 out of 64 outbreaks. Dairy products made from raw milk can be a transmission route of *Brucella* spp. (EFSA & ECDC, 2014). In Mediterranean countries not officially free from brucellosis, it is assumed that the consumption of raw sheep and goat milk as well as cheese made from raw sheep and goat milk is the main source of contamination (FASFC, WIV, & CODA, 2011). Magwedere et al. (2011) have shown that raw goat milk, home-made goat cheese and coffee served with raw goat milk, as well as contact with goats can be a source of human cases of brucellosis. Enterotoxin-producing *S. aureus*, *Streptococcus* spp. and the TBEV were also linked to the consumption of raw milk cheeses. Three of the four outbreaks of *S. aureus* occurred more than 20 years ago, and two were caused by cheese made from raw sheep milk. Concerning *Streptococcus*, one outbreak occurred in the United States due to Mexican-style soft raw milk cheese in 1983. In 1997–2008, 64 cases of tick-borne encephalitis in patients that consumed unpasteurised milk and cheese made from sheep milk were reported in the Czech Republic (Křı́ž, Beneš, & Daniel, 2009).

4. Growth and survival of pathogenic microorganisms during production and storage/ripening of dairy products made from raw milk

The circumstances of production and storage of dairy products made from raw milk determine the behaviour (i.e., growth, survival or inactivation) of the microorganisms that are potentially present in the raw milk. The pathogens can grow, survive or be inactivated. Some of these important influencing factors are summarised as follows for raw milk cheeses. The growth of the fermenting bacteria reduces the growth possibilities of the pathogens by, on the one hand, competition and, on the other hand, a decline of the pH. The effect of starter cultures producing bacteriocins and the addition of potassium or sodium nitrate is especially aimed at inhibiting the growth of butyric acid bacteria. The outgrowth of *L. monocytogenes* could also be influenced due to the presence of bacteriocins (Dal Bello et al., 2012) while the outgrowth of *B. cereus* may be ascribed to potassium or sodium nitrate inhibiting spore germination (Avila, Gómez-Torres, Hernández, & Garde, 2014). The coagulation of the milk followed by sineresis of the curd, concentrates the pathogens in the curd. Some herbs used in the cheeses may have a bacteriostatic effect (Leuschner & Ielsch, 2003).

Salting creates conditions that are not optimal for survival or growth due to the decline of the water activity. Depending on the time, temperature, pH, water activity and NaCl concentration, dry matter content and the competing microbiota, growth or inactivation of the pathogens present in the milk will occur during ripening (Farrokh et al., 2013). Plastic coating used on certain cheeses prevents them from drying out and prevents contamination with pathogens and fungi from the environment. The coating may contain antifungal components such as natamycin. Vacuum packaging and paraffin are physical barriers and the vacuum packaging will inhibit the development of fungi and strict aerobic microorganisms. The presence of internal and external microbiota during ripening provides competition with the pathogens. During the ripening period, the physical and chemical characteristics of the cheese often change which can provide a better survival and even enable growth. During ripening a post-contamination can occur. Especially soft and semi-soft cheeses as well as cheeses with a washed crust such as red smear cheeses, are more exposed to surface contamination (Farrokh et al., 2013). Microorganisms will behave differently on the surface or in the crust due to the different conditions such as the pH.

The results documented in specific studies on the survival, growth and inactivation of pathogens in dairy products made from raw milk are summarised in Table 3. Information was only available for cheeses and butter. Concerning cheese, a distinction was made between hard, semi-hard and soft cheeses based on the classification made in the publications. When this classification was not clear, 'non specified' cheeses are mentioned.

It can be concluded from Table 3 that during the production of hard cheeses, some bacteria can survive, such as *Salmonella*, *L. monocytogenes*, *S. aureus* and MAP, albeit without subsequent growth. The number of *E. coli* can increase during the cheese production, which is due to a combination of a concentration effect during the formation of the curd as well as due to real growth of the pathogen (Farrokh et al., 2013). In hard cheeses several pathogens can be inactivated during storage. *Salmonella*, *E. coli*, *L. monocytogenes* and MAP may decrease in numbers, but can still be detected after long ripening periods. During the production of semi-hard cheeses, some bacteria can grow, such as *Salmonella*, *E. coli* and *S. aureus*. *L. monocytogenes* and MAP that survive the production process. During the ripening and storage of semi-hard cheeses, most bacteria will decrease in numbers, but *Salmonella*, *E. coli* and *S. aureus* can still be detected. *L. monocytogenes* and MAP can survive the ripening and storage. During the production of soft cheeses, *E. coli*, *L. monocytogenes* and *Brucella* spp. can grow. During the ripening and storage, *E. coli* and *Brucella* spp. can survive, but *L. monocytogenes* can possibly grow in and on soft cheeses, depending on the ripening stage and the circumstances. The growth of *L. monocytogenes* in butter does not occur or is limited (De Reu & Herman, 2004).

5. Identification of main microbiological hazards in dairy products made from raw milk

The information on the possible presence of human pathogenic microorganisms in raw milk, frequencies of occurrence of human pathogenic microorganisms in dairy products made from raw milk in Europe, outbreaks resulting from consumption of dairy products made from raw milk in Europe, the United States and Canada and the worst case scenario of the behaviour in dairy products made from raw milk is summarised in Table 4.

The main microbiological hazards linked to raw milk cheese are *L. monocytogenes*, human pathogenic VTEC, *Salmonella*, enterotoxin-producing *S. aureus* and *Campylobacter*. These pathogens can be present in raw milk and as there is no heat treatment before cheese production, they will not be inactivated. They have all caused a certain number of outbreaks linked to cheese and *Salmonella*, *L. monocytogenes*, *S. aureus* and VTEC have been detected in cheeses. *Salmonella*, *Campylobacter* and VTEC can cause disease in low numbers (often a few cells) and for *Salmonella* and VTEC there are growth possibilities during production and storage (survival for VTEC during storage). *L. monocytogenes* and *S. aureus* have to grow to cause disease, which is possible as can be seen from Table 4.

Concerning butter, cream and buttermilk, there is less information available in the scientific literature. For butter made from raw milk, the main microbiological hazards are *L. monocytogenes*, VTEC and *S. aureus* because these pathogens have been detected in butter. However, the risk of infection after consumption of raw milk butter is estimated to be relatively lower in comparison with certain cheeses, especially due to the limited growth possibilities of *L. monocytogenes*. For cream made from raw milk, the main microbiological hazards are estimated to be *L. monocytogenes*, *S. aureus* and VTEC because *L. monocytogenes* and *S. aureus* have been detected in cream and VTEC was linked to a cream outbreak. With regard to buttermilk made from raw milk, there is no information available in the scientific literature and the microbiological hazards related to the consumption of this product cannot be identified.

There are some additional risks linked to the consumption of dairy products made from raw milk, especially when they are produced on farms where animals are frequently infected with certain pathogens. This is the case for *Brucella* spp. Cattle can be

Table 3
Behaviour of human pathogenic microorganisms in different types of cheese made from raw milk during production and storage/ripening.

Production	Storage and/or ripening	References
Hard cheese		
Inoculation of 4–6 log cfu mL^{-1} of *Campylobacter jejuni*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella* Typhimurium, *Staphylococcus aureus*, *Yersinia enterocolitica* in milk; 1 d after production: only low numbers of *S. aureus*	One week after storage at 11–13 °C for 90 d: no detection of any of inoculated pathogens	Bachmann and Spahr (1995)
Inoculation of 4–5 log cfu mL^{-1} of *Mycobacterium avium* subsp. *paratuberculosis* (MAP) in cow milk	Steady and slow decrease during ripening at 12 °C for 10 d, 22 °C for 60 d or 12 °C for 50 d; viable cells detected at day 120	Spahr and Schafroth (2001)
One of thirty-five cows shedding 2.3 log cfu mL^{-1} of *Salmonella* Muenster in milk; 11 of 181 vats of curd positive; 2 of 11 vats of cheese positive	One of two vats positive after storage at 5 °C for 125 d	Wood, Collins-Thompson, Irvine, and Muhr (1984)
Inoculation of 2 log cfu mL^{-1} of *E. coli* K12 in milk; increase during production	Decrease of 1.5–2 log during storage at 4 °C for 120 d	Amornkul and Henning (2007)
Inoculation of 1–5 log cfu mL^{-1} of *E. coli* O157:H7 in milk; increase during production	Storage at 7 °C for 1 wk; decrease of less than 1 log cfu g^{-1} at day 60; decrease of less than 2 log cfu g^{-1} at day 120	Schlesser et al. (2006)
Inoculation of 1.3 log cfu mL^{-1} of *E. coli* O157:H7 in milk; 1.3 log cfu mL^{-1} in milk before coagulation, 1.6 log cfu g^{-1} in curd after cutting; 1.3 log cfu mL^{-1} in whey at draining; 2.4 log cfu g^{-1} in curd before salting	Storage at 9 °C; 2.2 log cfu mL^{-1} in cheese on day 1; decrease to 1.4 log cfu g^{-1} on day 60; below 0.7 log cfu g^{-1} after 108 d; Detection after more than 270 d	D'Amico, Druart, and Donnelly (2010)
Inoculation of 1.4 log cfu mL^{-1} of *E. coli* O157:H7 in milk; 1.4 log cfu mL^{-1} in milk before coagulation, 1.8 log cfu g^{-1} in curd after cutting; 0.5 log cfu mL^{-1} in whey removed; 0.7 log cfu mL^{-1} in whey plus wash water; 2.6 log cfu g^{-1} in curd before salting; 3.0 log cfu g^{-1} in cheese before brining	Storage at 14 °C for 5 wk, then at 9 °C; 2.2 log cfu mL^{-1} in cheese on day 1; decrease to 0.7 log cfu g^{-1} on day 60; below 0.7 log cfu g^{-1} after 94 d; detection after more than 270 d	D'Amico et al. (2010)
Natural contamination of *L. monocytogenes* in cheese	Never >1.3 log cfu g^{-1}; no detection after 5 months	Dalmasso and Jordan (2014)
Semi-hard cheese		
Inoculation of 4–6 log cfu mL^{-1} of *C. jejuni*, *E. coli*, *L. monocytogenes*, *S.* Typhimurium, *S. aureus*, *Y. enterocolitica* in milk	After storage at 11–13 °C for 90 d: only *L. monocytogenes* detected	Bachmann and Spahr (1995)
Inoculation of 4–5 log cfu mL^{-1} of MAP in cow milk	Steady and slow decrease during ripening at 14–15 °C for 120 d; viable cells detected at day 120	Spahr and Schafroth (2001)
Inoculation of 1 and 3 log cfu mL^{-1} of *E. coli* (5 strains including 3 verocytotoxin-producing *Escherichia coli* (VTEC))	Increase of 3.5 log cfu g^{-1} at day 1 (concentration effect and growth); slow and continuous decrease during ripening; generic *E. coli* Survived at higher counts; 6 cheeses with low inoculum: >1 log cfu g^{-1} at end of ripening; after enrichment: VTEC detection in almost all cheeses	Peng et al. (2013)
Inoculation of 2.4 log cfu mL^{-1} *S. aureus* in milk; 3.3 log cfu mL^{-1} in gel of early coagulation; 2.3 log cfu mL^{-1} in whey. 4.2 log cfu g^{-1} in curd at pressing	3.8 log cfu g^{-1} in cheese at day 7; 0 cfu g^{-1} in cheese at week 10	Jørgensen et al. (2005)
Inoculation of 4 log cfu g^{-1} of *L. monocytogenes* in sheep milk	Decrease after 6 wk; log reduction at 4 °C: 2.10 at day 91, 3.19 at day 101, presence at day 111, absent at day 114; log reduction at 12 °C: 1.74 at day 77, 2.90 at day 91, presence at day 98, absent at day 104; log reduction at 22 °C: 1.76 at day 54, 2.45 at day 67, 4.02 at day 70, presence at day 74, absent at day 77	Valero et al. (2014)
Soft cheese		
Inoculation of 4 log cfu mL^{-1} of *E. coli* O157:H7 and *L. monocytogenes*; growth of both pathogens during production	Storage at 2 °C for 75 d; *E. coli* O157:H7: highest count at day 10, decrease after 10 d, count at day 75 higher than inoculum; *L. monocytogenes*: survival, count at day 75 higher than inoculum	Ramsaran, Chen, Brunke, Hill, and Griffiths (1998)
Inoculation of 4 log cfu mL^{-1} of *E. coli* O157:H7 and *L. monocytogenes*; growth of both pathogens during production	Storage at 2 °C for 65 d; *E. coli* O157:H7: highest count after 24 h, decrease after 24 h, count at day 65 higher than inoculum; *L. monocytogenes*: survival, count at day 65 higher than inoculum	Ramsaran et al. (1998)
Inoculation of 3 log cfu mL^{-1} of VTEC; increase of 1 −2 log cfu g^{-1} during production; stabilisation during salting/drying	Storage at 4 °C; decrease during early stages of ripening	Montet et al. (2009)
Inoculation of 3.6 log cfu mL^{-1} of *Brucella abortus* in milk; 4.2 log cfu g^{-1} in curd; 4.3 log cfu g^{-1} in curd out of mould	Storage at 12 °C; 3.0 log cfu g^{-1} in cheese at day 5, 1.5 log cfu g^{-1} in cheese at day 8, 1.3 log cfu g^{-1} in cheese at day 12, 1.1 log cfu g^{-1} in cheese at day 15, 0.4 log cfu g^{-1} in cheese at day 18, 0 cfu g^{-1} in cheese at day 22	Plommet et al. (1988)
Inoculation of −0.7 and 0.3 log cfu cm^{-2} of *L. monocytogenes*	Storage at 4 °C; increase after day 28; increase to 2.96 log cfu g^{-1} at day 60 (low inoculum); increase to 4.55 log cfu g^{-1} at day 60 (high inoculum)	D'Amico et al. (2008)
Natural contamination of 3.8 log cfu mL^{-1} of *L. monocytogenes* in sheep milk	2.3–2.8 log cfu g^{-1} 7 d after storage at 4 °C for 7 d	Schoder, Winter, Kareem, Baumgartner, and Wagner (2003)
Mozzarella		
Inoculation of 5 log cfu mL^{-1} of *E. coli* O157:H7 in cow milk; curd stretching at 80 °C for 5 min: loss of viability; curd stretching at 70 °C for 5 min: 1 log reduction	Storage at 4 °C for 7 d; no detection	Spano et al. (2003)
Inoculation of 7.1–8.7 log cfu g^{-1} of VTEC O157 and O26 of curd; 4D reduction during heating curd		Trevisani, Mancusi, and Valero (2014)

(*continued on next page*)

Table 3 (*continued*)

Production	Storage and/or ripening	References
Non specified cheese		
Inoculation of *E. coli* O157:H7, O26:H11, O103:H2 and O145:H28 in cow, goat or sheep milk; during first 24 h of production: growth of 2–3 log cfu g^{-1}, no growth when acid coagulation	Decrease during 6 months of ripening; detectable at end of storage/ripening	Miszczycha et al. (2013)
Inoculation of *E. coli* O157:H7 and O26:H11 in cow milk; during first 24 h of production: growth from 2 to 4 log cfu g^{-1}	Stable around 4 log cfu g^{-1} during ripening and storage	Miszczycha et al. (2014)
Inoculation of 1.52 log cfu mL^{-1} of *E. coli* O157:H7 in milk	Storage a 6 °C; increase to 3.4 log cfu g^{-1} at day 1; decrease during ripening to <0 cfu g^{-1} in rind at day 21; decrease during ripening to <1 log cfu g^{-1} in core at day 21; detection of viable cells at day 90	Maher, Jordan, Upton, and Coffey (2001)
Inoculation of 3.56 log cfu g^{-1} dry weight of *L. monocytogenes* in cow milk; no growth during production	Storage at 13 °C for 14 d and at 8 °C for 14 d; increase of 2 log cfu g^{-1} dry weight during first 4 d of ripening; survival/decrease until end of ripening	Schvartzman et al. (2011)
Inoculation of 6 log cfu mL^{-1} of *E. coli*, *Listeria innocua* and *S. aureus* in milk; during production; increase of *E. coli*, survival of *L. innocua* and *S. aureus*	Storage at 8 °C for 56 d; *E. coli* highest count at day 7, decrease after day 7; *Listeria innocua* and *Staphylococcus aureus* no growth	Masoud et al. (2012)
Average counts of *S. aureus*: 1.26 log cfu mL^{-1} in cow/goat milk, 2.80 log cfu mL^{-1} in curd	Average counts of *S. aureus*: 3.50 log cfu g^{-1} in cheese (5–6 h), 3.13 log cfu mL^{-1} in cheese (24 h), 1.04 log cfu g^{-1} in cheese (30 d)	Jakobsen et al. (2011)
Inoculation of 9.7 log cfu g^{-1} of *Brucella melitensis* in goat milk; decrease during production; 6.3 log cfu mL^{-1} in whey at curd cutting; 6 log cfu mL^{-1} at draining	3.0 log cfu mL^{-1} during storage at 4 °C for 13–30 d; 4 log cfu mL^{-1} during storage at 24 °C for 6–15 d; no detection during storage at 24 °C for days 16–30	Méndez-González et al. (2011)
Butter		
Inoculation of *L. monocytogenes* and *L. innocua* in cream	No significant growth during storage at 4, 10 or 20 °C for 4 wk	De Reu and Herman (2004)
Natural contamination of −0.6 to 1.2 log cfu g^{-1} of *L. monocytogenes*	One log reduction during storage at 4 or 10 °C for 4 or 5 wk	De Reu and Herman (2004)

infected with *Brucella abortus* and sheep can be infected with *Brucella melitensis* in certain areas of Southern Europe. The same holds for *M. bovis* in regions where this pathogen is endemic, for example among cattle. Goats can be parasitised by the tick *Ixodes ricinus* that often carry the TBEV. The infection of goats is asymptomatic and the TBEV can enter the bloodstream through the tick followed by an excretion in the milk during the viraemic phase. In risk areas in Eastern Europe the TBEV can be endemic and therefore this is also an important microbiological hazard linked to dairy products made from raw milk.

For some microorganisms, the foodborne potential is not known or limited documentation is available. Cattle, goats and sheep are the main reservoirs of *C. burnetii* (Rahimi, Doosti, Ameri, Kabiri, & Sharifian, 2008). In general, people get infected by inhalation of contaminated dust and aerosols mainly formed during birth of animals, via manure or via contact with infected animals (Sci Com, 2010a, 2010b). Infection via the food chain occurs less frequently (Berri et al., 2005). Infectious *C. burnetii* can persist for long periods in milk and milk products. From scientific literature, it appears that dairy products made from unpasteurised milk may contain viable *C. burnetii*. Concerning MAP, the information in the scientific literature is limited and up to now, there is uncertainty whether this bacterium is zoonotic or to be considered as a human foodborne pathogen. Nevertheless, MAP and *C. burnetii* could be considered as

Table 4
Summary of information on microbiological hazards.

Organism	Possibly present in raw milk	Detected in dairy products made from raw milk (minimum – maximum frequency of occurrence in %) in Europe	Reported human cases and outbreaks in Europe, the US and Canada due to cheese consumption	Worst case behaviour in raw milk cheese		Score according to EFSA (2013)
				Production	Storage/ripening	
Listeria monocytogenes	Yes	0.0–41.9 (cheese, butter, cream)	8	Growth survival[b]	Growth survival[b]	2
Escherichia coli (human pathogenic)	Yes	0.0–55.3 (cheese)	18[a]	Growth	Survival	3
Staphylococcus aureus	Yes	0.0–100.0 (cheese, butter)	4	Growth	Growth	1
Salmonella	Yes	0.0–4.3 (cheese)	22	Growth	Growth	3
Campylobacter	Yes	0.0 (cheese)	5	No survival	No survival	3
Brucella	Yes	–[c]	7	Growth	Survival	3
Bacillus cereus	Yes	0.0–28.0 (cheese)	0	–	–	1
Mycobacterium bovis	Yes	–	0	–	–	3
Tick-borne encephalitis virus	Yes	–	1	–	–	3
Coxiella burnetii	Yes	0.0–57.0 (cheese, cream)	0	–	–	–[d]
Streptococcus	Yes	–	1	–	–	3[e]
Mycobacterium avium subsp. *paratuberculosis*	Yes	0.0–20.0 (cheese)	0	Survival	Survival	–[f]

[a] One due to cream consumption.
[b] In butter.
[c] A dash (–) indicates no information was available unless otherwise indicated.
[d] Foodborne potential not known.
[e] Pathogenic species not frequent.
[f] Zoonotic potential not known.

a potential microbiological hazard present in dairy products made from raw milk.

6. Discussion

The contamination levels of several pathogens such as *L. monocytogenes* and *S. aureus* usually encountered in raw milk are mostly lower than the level they have to reach to cause disease. It is assumed (based on the authors' expert opinion) that numbers of *L. monocytogenes* in raw cow milk are usually lower or at the level of ca. 1 log cfu mL^{-1}. In the case of a subclinical mastitis of the milk producing animal, high initial numbers of *L. monocytogenes* or *S. aureus* could be encountered in the raw milk (Pintado et al., 2009; Sahebekhtiari et al., 2011). Although this is rare and such milk is diluted in the normal industrial milk supply, it may occur, e.g., in a short supply chain. For low initial numbers of these pathogens that have to grow to produce disease, the growth possibilities during cheese production and storage will influence the risk of infection. When present in the raw milk, the growth of most pathogens is restricted by storage at refrigerator temperatures although, depending on the storage time and temperature, some pathogens such as *L. monocytogenes* could develop.

From the scientific literature, it seems that prevalences or concentrations of certain pathogens such as VTEC, *L. monocytogenes*, *S. aureus* and *C. burnetii* are mostly lower in dairy products made from pasteurised or heat treated milk than in dairy products made from raw milk (Civera et al., 2007; Eldin et al., 2013; Fach, Perelle, Dilasser, & Grout, 2001; Greenwood, Roberts, & Burden, 1991; Loncarevic, Danielsson-Tham, & Tham, 1995; Rosengren, Fabricius, Guss, Sylvén, & Lindqvist, 2010). Concerning outbreaks, it seems that cheese outbreaks are more linked to cheese made from unpasteurised milk than from cheese made from pasteurised milk (Altekruse, Timbo, Mowbray, Bean, & Potter, 1998; De Buyser, Dufour, Maire, & Lafarge, 2001; Gould, Mungai, & Behravesh, 2014). Moreover, the study of Gould et al. (2014) showed that raw milk cheese outbreaks were mostly related to contamination of the raw product or the ingredients by pathogens from animals or the environment, whereas pasteurised cheese outbreaks were more related to health and hygiene of the workers in contact with the cheese.

Regarding the behaviour of the pathogens during production and storage of cheese, there are differences depending on the use of raw milk or pasteurised milk. For example, *L. monocytogenes* showed in an inoculation experiment growth during the cheese production process when made from pasteurised milk whereas no growth was observed when made from raw milk, most probably due to the presence of background flora. However, during cheese ripening, growth of this pathogen occurred in raw milk cheese, but inactivation occurred in pasteurised cheese due to the physicochemical conditions of the cheeses (Schvartzman et al., 2011). Another study found no difference in the growth potential of *L. monocytogenes* inoculated on the surface of cheeses made from raw or pasteurised milk during storage (D'Amico, Druart, & Donnelly, 2008). In addition, the natural microbiota can influence the behaviour of pathogens in cheese. Delcenserie et al. (2014) found that cheese made from raw and pasteurised milk had different microbiota in the crust of the cheeses. Overall, pasteurisation ensures the inactivation of vegetative pathogenic microorganisms, which increases the safety of products made thereof in comparison with dairy products made from raw milk. However, it should be noted that dairy products made from pasteurised milk could be susceptible to post-contamination. Therefore, application of a good Hazard Analysis and Critical Control Points (HACCP) system during production is essential.

To limit the exposure to pathogens due to consumption of dairy products made from raw milk several control measures can be taken from farm to fork. At farm level, the pathogenic microorganisms that contaminate the raw milk can come from the milk-producing animal or from the environment. Mastitis or udder infection is the most common disease in cattle (Halasa, Huijps, Osteras, & Hogeveen, 2007). The intramammary infection is mostly caused by bacteria that penetrate the udder through the teat canal. In the holistic approach of prevention and control of mastitis, it is of utmost importance to keep the infection pressure in the stable as low as possible by means of good hygiene management and optimal comfort of the cows to obtain a good udder health and optimal milk quality (Barkema et al., 1998; Elbers et al., 1998; van Gastelen, Westerlaan, Houwers, & van Eerdenburg, 2011; Schukken, Grommers, Vandegeer, Erb, & Brand, 1990). However, contamination of the milk during milking cannot completely be avoided, not even with elaborate cleaning and disinfection (Magnusson, Christiansson, Svensson, & Kolstrup, 2006). Between the milking and the processing of dairy products, time should be restricted and temperatures kept as low as possible to prevent the pathogens that are possibly present from growing. During milk processing, a quick fermentation with efficient starter cultures should be applied to restrict the growth of the pathogens. After the production of cheese, a restriction of the shelf life and adherence to the cold chain from retail to consumer is important to ensure the safety of such products. The control of the procedures of cleaning and disinfection of the material that is used during the production process is also important from the milking to the sales of the products. Finally, both producers and consumers, in particular persons belonging to the YOPI group, should be aware of the risks pertaining to dairy products made from raw milk.

There are some limitations linked to the analysis of the information collected in this work. The frequencies of occurrence of pathogenic microorganisms in dairy products made from raw milk originate from ad hoc convenience sampling and the modalities conditions of the sampling plan (number of samples taken, method of analysis and corresponding limit of detection) as well as the method of analysis and detection limit may vary among these surveys and consequently it was not always easy to compare the outcome of these publications. Also, it is not known if the detected pathogens are able to cause disease. In particular, in the case of the detection of potential pathogenic *E. coli* serotypes, it is not known if all positive results actually refer to *E. coli* strains that carry virulence genes. Concerning the outbreaks due to the consumption of dairy products made from raw milk, only reported outbreaks were included. There can be underreporting due to, e.g., a long incubation period. Regarding the behaviour of the pathogens during the production process and the storage or ripening period of dairy products made from raw milk, it is evident that there is a variety of cheeses with their proper production process, intrinsic physicochemical characteristics, indigenous microbiota and actual storage conditions, which will impact on the growth potential of the pathogens.

7. Conclusion

Overall, the available information on some pathogens or dairy products made from raw milk is limited, but if everything is taken into consideration the microbiological hazards and dairy products made from raw milk of main concern are linked to raw milk cheeses and *L. monocytogenes*, pathogenic VTEC, enterotoxin-producing *S. aureus*, *Salmonella* and *C. jejuni/coli*. Next, *L. monocytogenes*, VTEC and *S. aureus* have been identified as microbiological hazards in raw milk butter and cream, albeit to a lesser extent because of a reduced growth potential of these pathogens in the latter products compared with cheese. In endemic areas, dairy products made from raw milk may also be contaminated with *Brucella* spp., *M. bovis* or the tick-borne encephalitis virus and need particular attention in monitoring and surveillance. Finally, *C. burnetii* and MAP are identified as potential hazards. For *C. burnetii* the role of food (dairy products made from raw milk) seems to be limited and for MAP no sufficient knowledge is available.

Due to the possible exposure of the consumer to the above mentioned pathogenic microorganisms in dairy products made from raw milk, appropriate risk communication on the consumption of these products in particular to a vulnerable population, is recommended.

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References

Almeida, G., Figueiredo, A., Rôla, M., Barros, R. M., Gibbs, P., Hogg, T., et al. (2007). Microbiological characterization of randomly selected Portuguese raw milk cheeses with reference to food safety. *Journal of Food Protection, 70*, 1710–1716.
Altekruse, S. F., Timbo, B. B., Mowbray, J. C., Bean, N. H., & Potter, M. E. (1998). Cheese-associated outbreaks of human illness in the United States, 1973 to 1992: sanitary manufacturing practices protect consumers. *Journal of Food Protection, 61*, 1405–1407.
Ammon, A. (1997). Surveillance of enterohaemorrhagic *E. coli* (EHEC) infections and haemolytic uraemic syndrome (HUS) in Europe. *Eurosurveillance, 2*, 91–95.
Amornkul, Y., & Henning, D. R. (2007). Utilization of microfiltration or lactoperoxidase system or both for manufacture of Cheddar cheese from raw milk. *Journal of Dairy Science, 90*, 4988–5000.
Anonymous. (1986). Epidémie de salmonellose due à un formage à pâte molle. *Bulletin de l'Office Fédéral de la Santé Publique, 8*, 48–49.
Arrese, E., & Arroyo-Izaga, M. (2012). Prevalence of *Listeria monocytogenes* in Idiazabal cheese. *Nutrición Hospitalaria, 27*, 2139–2141.
Auvray, F., Lecureuil, C., Dilasser, F., Taché, J., & Derzelle, S. (2009). Development of a real-time PCR assay with an internal amplification control for the screening of Shiga toxin-producing *Escherichia coli* in food. *Letters in Applied Microbiology, 48*, 554–559.
Avila, M., Gómez-Torres, N., Hernández, M., & Garde, S. (2014). Inhibitory activity of reuterin, nisin, lysozyme and nitrate against vegetative cells and spores of dairy-related *Clostridium* species. *International Journal of Food Microbiology, 172*, 70–75.
Azadian, B. S., Finnerty, G. T., & Pearson, A. D. (1989). Cheese-borne *Listeria meningitis* in immunocompetent patient. *Lancet, 333*, 322–323.
Bachmann, H. P., & Spahr, U. (1995). The fate of potentially pathogenic bacteria in Swiss hard and semihard cheeses made from raw milk. *Journal of Dairy Science, 78*, 476–483.
Barkema, H. W., Schukken, Y. H., Lam, T. J. G. M., Beiboer, M. L., Benedictus, G., & Brand, A. (1998). Management practices associated with low, medium, and high somatic cell counts in bulk milk. *Journal of Dairy Science, 81*, 1917–1927.
Berri, M., Rousset, E., Hechard, C., Champion, J. L., Dufour, P., Russo, P., et al. (2005). Progression of Q fever and *Coxiella burnetii* shedding in milk after an outbreak of enzootic abortion in a goat herd. *Veterinary Record, 156*, 548–549.
Bille, J. (1989). Anatomy of a foodborne listeriosis outbreak. In *Proceedings of symposium on foodborne listeriosis, 7 September 1988, Wiesbaden, FRG* (pp. 29–36). Hamburg, Germany: Behr's Verlag.
Bockemühl, J., & Karch, H. (1996). Zur aktuellen Bedeutung der enterohämorrhagischen. *Escherichia coli* (EHEC) in Deutschland (1994–1995). *Bundesgesundheitsblatt, 39*, 290–296.
Bone, F. J., Bogie, D., & Morgan-Jone, S. C. (1989). Staphylococcal food poisoning from sheep milk cheese. *Epidemiology and Infection, 103*, 449–458.
Bronner, A., Hénaux, V., Fortané, N., Hendrikx, P., & Calavas, D. (2014). Why do farmers and veterinarians not report all bovine abortions, as requested by the clinical brucellosis surveillance system in France? *BMC Veterinary Research, 10*, 93.
Caro, I., & García-Armesto, M. R. (2007). Occurrence of Shiga toxin-producing *Escherichia coli* in a Spanish raw ewe's milk cheese. *International Journal of Food Microbiology, 116*, 410–413.
Casenave, C., Desenclos, J. C., Maillot, E., Benoit, S., Deschenes, G., Nivet, H., et al. (1993). Elosions de syndrome hémolytique et urémique dans une commune rurale du Cher. *Bulletin Epidémiologique Hebdomadaire, 48*, 222–224.
Castell Monsalve, J., Rullán, J. V., Peiró Callizo, E. F., & Niet-Sandoval Alcolea, A. (1996). Epidemic outbreak of 81 cases of brucellosis following the consumption of fresh cheese without pasteurization. *Revista Española de Salud Pública, 70*, 303–311.
van Cauteren, D., Jourdan-da Silva, N., Weill, F. X., King, L., Brisabois, A., Delmas, G., et al. (2009). Outbreak of *Salmonellaenterica* serotype Muenster infections associated with goat's cheese, France, March 2008. *Eurosurveillance, 14*. Article 8.
CDC. (1983). Group C streptococcal infections associated with eating homemade cheese – New Mexico. *Morbidity and Mortality Weekly Report, 32*(510), 515–516.
CDC. (2000). Outbreak of *Escherichia coli* O157:H7 infection associated with eating fresh cheese curds – Wisconsin, June 1998. *Morbidity and Mortality Weekly Report, 49*, 911–913.
CDC. (2001). Outbreak of listeriosis associated with homemade Mexican-style cheese – North Carolina, October 2000–January 2001. *Morbidity and Mortality Weekly Report, 50*, 560–562.
CDC. (2007). *Salmonella* Typhimurium infection associated with raw milk and cheese consumption – Pennsylvania, 2007. *Morbidity and Mortality Weekly Report, 56*, 1161–1164.
CDC. (2008). Outbreak of multidrug-resistant *Salmonella enterica* serotype Newport infections associated with consumption of unpasteurized Mexican-style aged cheese – Illinois, March 2006–April 2007. *Morbidity and Mortality Weekly Report, 57*, 432–435.
CDC. (2009). *Campylobacter jejuni* infection associated with unpasteurized milk and cheese – Kansas, 2007. *Morbidity and Mortality Weekly Report, 57*, 1377–1379.
CDC. (2014). Foodborne Outbreak Online Database (FOOD). Available online http://wwwn.cdc.gov/foodborneoutbreaks/. Last accessed 07.07.14.
CDSC. (1998a). Cases of *Escherichia coli* O157 infection associated with unpasteurised cream in England. *Eurosurveillance, 2*. Article 3.
CDSC. (1998b). *Escherichia coli* O157 in Somerset. Communicable disease report. *CDR Weekly, 8*, 167.
Civera, T., Decastelli, L., Martorana, M., Dalmasso, A., Nucera, D., & Bottero, M. T. (2007). Survey on the presence of enterovirulent *Escherichia coli*, including *E. coli* O157, in cheese manufactured in the Italian Alpine Region. *Italian Journal of Food Science, 19*, 229–238.
Claeys, W. L., Cardoen, S., Daube, G., De Block, J., Dewettinck, K., Dierick, K., et al. (2013). Raw or heated cow milk consumption: review of risks and benefits. *Food Control, 31*, 251–262.
Claeys, W. L., Verraes, C., Cardoen, S., De Block, J., Huyghebaert, A., Raes, K., et al. (2014). Consumption of raw or heated milk from different species: an evaluation of the nutritional and potential health benefits. *Food Control, 42*, 188–201.
Cody, S. H., Abbott, S. L., Marfin, A. A., Schulz, B., Wagner, P., Robbins, K., et al. (1999). Two outbreaks of multidrug-resistant *Salmonella* serotype Typhimurium DT104 infections linked to raw-milk cheese in Northern California. *Journal of the American Medical Association, 281*, 1805–1810.
Coia, J. E., Johnston, Y., Steers, N. J., & Hanson, M. F. (2001). A survey of the prevalence of *Escherichia coli* O157 in raw meats, raw cow's milk and raw-milk cheeses in south-east Scotland. *International Journal of Food Microbiology, 66*, 63–69.
Conedera, G., Dalbit, P., Martini, M., Galiero, G., Gramaglia, M., Goffredo, E., et al. (2004). Verocytotoxin-producing *Escherichia coli* O157 in minced beef and dairy products in Italy. *International Journal of Food Microbiology, 96*, 67–73.
Coveney, H. M., Fitzgerald, G. F., & Daly, C. (1994). A study of the microbiological status of Irish farmhouse cheeses with emphasis on selected pathogenic and spoilage micro-organisms. *Journal of Applied Bacteriology, 77*, 621–630.
Cremonesi, P., Perez, G., Pisoni, G., Moroni, P., Morandi, S., Luzzana, M., et al. (2007). Detection of enterotoxigenic *Staphylococcus aureus* isolates in raw milk cheese. *Letters in Applied Microbiology, 45*, 586–591.
Curnow, J. (1999). *Escherichia coli* O157 outbreak in Scotland linked to unpasteurized goat's milk. *Eurosurveillance, 3*. Article 1387.
Dal Bello, B., Cocolin, L., Zeppa, G., Field, D., Cotter, P. D., & Hill, C. (2012). Technological characterization of bacteriocin producing *Lactococcus lactis* strains employed to control *Listeria monocytogenes* in cottage cheese. *International Journal of Food Microbiology, 153*, 58–65.
Dalmasso, M., & Jordan, K. (2014). Absence of growth of *Listeria monocytogenes* in naturally contaminated Cheddar cheese. *Journal of Dairy Research, 81*, 46–53.
D'Amico, D. J., Druart, M. J., & Donnelly, C. W. (2008). 60-Day aging requirement does not ensure safety of surface-mold-ripened soft cheeses manufactured from raw or pasteurized milk when *Listeria monocytogenes* is introduced as a postprocessing contaminant. *Journal of Food Protection, 71*, 1563–1571.
D'Amico, D. J., Druart, M. J., & Donnelly, C. W. (2010). Behavior of *Escherichia coli* O157:H7 during the manufacture and aging of Gouda and stirred-curd Cheddar cheeses manufactured from raw milk. *Journal of Food Protection, 73*, 2217–2224.
D'Aoust, J. Y., Warburton, D. W., & Sewell, A. M. (1985). *Salmonella* Typhimurium phage-type 10 from Cheddar cheese in a major Canadian foodborne outbreak. *Journal of Food Protection, 48*, 1062–1066.
Da Silva, F. M. T., Hald, T., Liebana, E., Allende, A., Hugas, M., Nguyen-The, C., et al. (2015). Risk ranking of pathogens in ready-to-eat unprocessed foods of non-animal origin (FoNAO) in the EU: initial evaluation using outbreak data (2007–2011). *International Journal of Food Microbiology, 195*, 9–19.
De Buyser, M.-L., Dufour, B., Maire, M., & Lafarge, V. (2001). Implication of milk and milk products in food-borne diseases in France and in different industrialized countries. *International Journal of Food Microbiology, 67*, 1–17.
De Buyser, M.-L., Janin, F., & Dilasser, F. (1985). Contamination of ewe cheese with *Staphylococcus aureus*: study of an outbreak of food poisoning. *Zentralblatt für Bakteriologie, Mikrobiologie und Hygiene, 14*, 677.
Decludt, B. (1995). *Cas groupés de syndromes hémolytiques et urémiques dans le département de l'Ardèche en 1994*. Saint-Maurice, France: Institut de Veille Sanitaire.

De Reu, K., Debeuckelaere, W., Botteldoorn, N., De Block, J., & Herman, L. (2002). Hygienic parameters, toxins and pathogen occurrence in raw milk cheeses. *Journal of Food Safety, 22*, 183–196.

De Reu, K., Grijspeerdt, K., & Herman, L. (2004). A Belgian survey of hygiene indicator bacteria and pathogenic bacteria in raw milk and direct marketing of raw milk farm products. *Journal of Food Safety, 24*, 17–36.

De Reu, K., & Herman, L. (2004). *Rapport 2003–2004 'Aanwezigheid en overleving van* Listeria monocytogenes *in rauwmelkse hoeveboter'*. Source: ILVO-T&V.

De Reu, K., Herman, L., De Boosere, I., & De Ville, W. (2006). *Rapport 2006 'Aanwezigheid en aantallen van* Listeria monocytogenes *in Belgische hoeveboter'. Rapport* Listeria *in hoeveboter*. Source: ILVO-T&V.

De Reu, K., Herman, L., De Boosere, I., & De Ville, W. (2007). *Rapport 2007 'Aanwezigheid en aantallen van* Listeria monocytogenes *in Belgische hoeveboter'.Rapport* Listeria *in hoeveboter*. Source: ILVO-T&V.

De Reu, K., Herman, L., & De Ville, W. (2008). *Rapport 2008 'Aanwezigheid en aantallen van* Listeria monocytogenes *in Belgische hoeveboter'. Rapport* Listeria *in hoeveboter*. Source: ILVO-T&V.

De Valk, H., Delarocque-Astagneau, E., Colomb, G., Ple, S., Godard, E., Vaillant, V., et al. (2000). A community-wide outbreak of *Salmonella enterica* serotype Typhimurium infection associated with eating a raw milk soft cheese in France. *Epidemiology and Infection, 124*, 1–7.

Delcenserie, V., Taminiau, B., Delhalle, L., Nezer, C., Doyen, P., Crevecoeur, S., et al. (2014). Microbiota characterization of a Belgian protected designation of origin cheese, Herve cheese, using metagenomic analysis. *Journal of Dairy Science, 97*, 1–11.

Desenclos, J.-C., Bouvet, P., Benz-Lemoine, E., Grimont, F., Desqueyroux, H., Rebière, I., et al. (1996). Large outbreak of *Salmonella enterica* serotype Paratyphi B infection caused by a goats' milk cheese, France, 1993: a case finding and epidemiological study. *British Medical Journal, 312*, 91–94.

EFSA. (2013a). Scientific opinion on the risk posed by pathogens in food of non-animal origin. Part 1 (outbreak data analysis and risk ranking of food/pathogen combinations). *EFSA Journal, 11*, 3025.

EFSA. (2013b). Analysis of the baseline survey on the prevalence of *Listeria monocytogenes* in certain ready-to-eat foods in the EU, 2010–2011 part A: *Listeria monocytogenes* prevalence estimates. *EFSA Journal, 11*, 3241.

EFSA. (2015). Scientific opinion on the public health risks related to the consumption of raw drinking milk. *EFSA Journal, 13*, 3940.

EFSA, & ECDC. (2014). The European summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2012. *EFSA Journal, 12*, 3547.

EFSA, & ECDC. (2015). The European summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2013. *EFSA Journal, 12*, 3547.

Elbers, A. R. W., Miltenburg, J. D., De Lange, D., Crauwels, A. P. P., Barkema, H. W., & Schukken, Y. H. (1998). Risk factors for clinical mastitis in a random sample of dairy herds from the southern part of the Netherlands. *Journal of Dairy Science, 81*, 420–426.

Eldin, C., Angelakis, E., Renvoisé, A., & Raoult, D. (2013). *Coxiella burnetii* DNA, but not viable bacteria, in dairy products in France. *American Journal of Tropical Medicine and Hygiene, 88*, 765–769.

Ellis, A., Preston, M., Borczyk, A., Miller, B., Stone, P., Hatton, B., et al. (1998). A community outbreak of *Salmonella berta* associated with a soft cheese product. *Epidemiology and Infection, 120*, 29–35.

Espié, E., Vaillant, V., Mariani-Kurkdjian, P., Grimont, F., Martin-Schaller, R., de Valk, H., et al. (2006). *Escherichia coli* O157 outbreak associated with fresh unpasteurized goats' cheese. *Epidemiology and Infection, 134*, 143–146.

Fach, P., Perelle, S., Dilasser, F., & Grout, J. (2001). Comparison between a PCR-ELISA test and the vero cell assay for detecting Shiga toxin-producing *Escherichia coli* in dairy products and characterization of virulence traits of the isolated strains. *Journal of Applied Microbiology, 90*, 809–818.

Farrokh, C., Jordan, K., Auvray, F., Glass, K., Oppegaard, H., Raynaud, S., et al. (2013). Review of Shiga-toxin-producing *Escherichia coli* (STEC) and their significance in dairy production. *International Journal of Food Microbiology, 162*, 190–212.

FASFC, WIV, & CODA. (2011). Working group on foodborne infections and intoxications. Available online http://www.coda-cerva.be/images/pdf/trends%20and%20sources%202010-2011.pdf. Last accessed 13.10.14.

Frece, J., Markov, K., Čvek, D., Kolarec, K., & Delaš, F. (2010). Comparison of conventional and molecular methods for the routine confirmation of *Listeria monocytogenes* in milk products produced domestically in Croatia. *Journal of Dairy Research, 77*, 112–116.

van Gastelen, S., Westerlaan, B., Houwers, D. J., & van Eerdenburg, F. J. C. M. (2011). A study on cow comfort and risk for lameness and mastitis in relation to different types of bedding materials. *Journal of Dairy Science, 94*, 4878–4888.

Gaulin, C., Levac, E., Ramsay, D., Dion, R., Ismaïl, J., Gingras, S., et al. (2012). *Escherichia coli* O157:H7 outbreak linked to raw milk cheese in Quebec, Canada: use of exact probability calculation and case-case study approaches to foodborne outbreak Investigation. *Journal of Food Protection, 75*, 812–818.

Gould, L. H., Mungai, E., & Behravesh, C. B. (2014). Outbreaks attributed to cheese: differences between outbreaks caused by unpasteurized and pasteurized dairy products, United States, 1998–2011. *Foodborne Pathogens and Disease, 11*, 545–551.

Greenwood, M. H., Roberts, D., & Burden, P. (1991). The occurrence of *Listeria* species in milk and dairy products: a national survey in England and Wales. *International Journal of Food Microbiology, 12*, 197–206.

Grimont, P. A. D., & Bouvet, P. (1991). Les salmonelles et les shigelles en 1990 en France. *Bulletin Epidémiologique Hebdomadaire, 15*, 102.

Haeghebaert, S., Sulem, P., Deroudille, L., Vanneroy-Adenot, E., Bagnis, O., Bouvet, P., et al. (2003). Two outbreaks of *Salmonella* Enteritidis phage type 8 linked to the consumption of Cantal cheese made with raw milk, France, 2001. *Eurosurveillance, 8*. Article 1.

Hahn, G., Walte, H. G., Coenen, C., & Teufel, P. (1999a). Direktvermarktung von Produkten aus Rohmilch: Befunde und Risikoerörterung. *Kieler Milchwirtschaftliche Forschungsberichte, 51*, 333–342.

Hahn, G., Walte, H. G., Coenen, C., & Teufel, P. (1999b). Direktvermarktung von Rohmilch: Befunde und Risikoerörterung. *Kieler Milchwirtschaftliche Forschungsberichte, 51*, 105–115.

Halasa, T., Huijps, K., Osteras, O., & Hogeveen, H. (2007). Economic effects of bovine mastitis and mastitis management: a review. *Veterinary Quarterly, 29*, 18–31.

Holzmann, H., Aberle, S. W., Stiasny, K., Werner, P., Mischak, A., Zainer, B., et al. (2009). Tick-borne encephalitis from eating goat cheese in a mountain region of Austria. *Emerging Infectious Diseases, 15*, 1671–1673.

Honish, L., Predy, G., Hislop, N., Chui, L., Kowalewska-Grochowska, K., Trottier, L., et al. (2005). An outbreak of *E. coli* O157:H7 hemorrhagic colitis associated with unpasteurized Gouda cheese. *Revue Canadienne de Santé Publique, 96*, 182–184.

Huchot, B., Bohnert, M., Cerf, O., Farrokh, C., & Lahellec, C. (1993). Does cheese made of raw milk represent a public health problem? A review of international epidemiological data. *International Dairy Federation, 48*. F-doc 223 supplement.

Infuso, A., Vaillant, V., & Desenclos, J. C. (1997). *Epidémie de salmonellose à* Salmonella enterica *sérotype Dublin, France, November–December 1996*. Saint-Maurice, France: Institut de Veille Sanitaire.

INVS. (2007). Epidémie d'infections à *E. coli* producteurs de Shiga-toxines non O157 liée à la consommation de Camembert au lait cru, nord-ouest de la France, octobre–décembre 2005. Available online http://www.invs.sante.fr/publications/2008/epidemie_e_coli_camembert/rapport_epidemie_stec.pdf. Last accessed 07.07.14.

Jacquet, C., Saint-Clement, C., Brouille, F., Catimel, B., & Rocourt, J. (1998). La listeriose humaine en France en 1997, données du Centre National de Référence des *Listeria*. *Bulletin Epidémiologique Hebdomadaire, 33*, 142–143.

Jakobsen, R. A., Heggebø, R., Sunde, E. B., & Skjervheim, M. (2011). *Staphylococcus aureus* and *Listeria monocytogenes* in Norwegian raw milk cheese production. *Food Microbiology, 28*, 492–496.

Jørgensen, H. J., Mørk, T., & Rørvik, L. M. (2005). The occurrence of *Staphylococcus aureus* on a farm with small-scale production of raw milk cheese. *Journal of Dairy Science, 88*, 3810–3817.

Kongo, J. M., Malcata, F. X., Ho, A. J., & Wiedmann, M. (2006). Detection and characterization of *Listeria monocytogenes* in São Jorge (Portugal) cheese production. *Journal of Dairy Science, 89*, 4456–4461.

Kříž, B., Beneš, C., & Daniel, M. (2009). Alimentary transmission of tick-borne encephalitis in the Czech Republic (1997–2008). *Epidemiologie, Mikrobiologie, Imunologie, 58*, 98–103.

Leuschner, R. G. K., & Ielsch, V. (2003). Antimicrobial effects of garlic, clove and red hot chilli on *Listeria monocytogenes* in broth model systems and soft cheese. *International Journal of Food Sciences and Nutrition, 54*, 127–133.

Loncarevic, S., Danielsson-Tham, M. L., & Tham, W. (1995). Occurrence of *Listeria monocytogenes* in soft and semi-soft cheeses in retail outlets in Sweden. *International Journal of Food Microbiology, 26*, 245–250.

MacDonald, P. D. M., Whitwam, R. E., Boggs, J. D., MacCormack, J. N., Anderson, K. L., Reardon, J. W., et al. (2005). Outbreak of listeriosis among Mexican immigrants as a result of consumption of illicitly produced Mexican-style cheese. *Clinical Infectious Diseases, 40*, 677–682.

Madic, J., Vingadassalon, N., Peytavin de Garam, C., Marault, M., Scheutz, F., Brugère, H., et al. (2011). Detection of Shiga toxin-product in *Escherichia coli* serotypes O26:H11, O103:H2, O111:H8, O145:H28, and O157:H7 in raw-milk cheeses by using multiplex real-time PCR. *Applied and Environmental Microbiology, 77*, 2035–2041.

Magnusson, M., Christiansson, A., Svensson, B., & Kolstrup, C. (2006). Effect of different premilking manual teat-cleaning methods on bacterial spores in milk. *Journal of Dairy Science, 89*, 3866–3875.

Maguire, H. C. F., Boyle, M., Lewis, M. J., Pankhurst, J., Wieneke, A. A., Jacob, M., et al. (1991). A large outbreak of food poisoning of unknown aetiology associated with Stilton cheese. *Epidemiology and Infection, 109*, 497–505.

Maguire, H., Cowden, J., Jacob, M., Rowe, B., Roberts, D., Bruce, J., et al. (1992). An outbreak of *Salmonella dublin* infection in England and Wales associated with a soft unpasteurized cow's milk cheese. *Epidemiology and Infection, 109*, 389–396.

Magwedere, K., Bishi, A., Tjipura-Zaire, G., Eberle, G., Hemberger, Y., Hoffman, L. C., et al. (2011). Brucellae through the food chain: the role of sheep, goats and springbok (*Antidorcus marsupialis*) as sources of human infections in Namibia. *Journal of the South African Veterinary Association, 82*, 205–212.

Maher, M. M., Jordan, K. N., Upton, M. E., & Coffey, A. (2001). Growth and survival of *E. coli* O157:H7 during the manufacture and ripening of a smear-ripened cheese produced from raw milk. *Journal of Applied Microbiology, 90*, 201–207.

MAPAQ. (2004). Mise en garde – Onze personnes malades à la suite de la consommation de fromages au lait cru fabriqués à la ferme. *Press Release*, 14 July 2004.

Masoud, W., Vogensen, F. K., Lillevang, S., Al-Soud, W. A., Sørensen, S. J., & Jakobsen, M. (2012). The fate of indigenous microbiota, starter cultures, *Escherichia coli*, *Listeria innocua* and *Staphylococcus aureus* in Danish raw milk and cheeses determined by pyrosequencing and quantitative real time (qRT)-PCR. *International Journal of Food Microbiology, 153*, 192–202.

McCollum, J. T., Williams, N. J., Beam, S. W., Cosgrove, S., Ettestad, P. J., Ghosh, T. S., et al. (2012). Multistate outbreak of *Escherichia coli* O157:H7 infections associated with in-store sampling of an aged raw-milk Gouda cheese, 2010. *Journal of Food Protection, 75*, 1759–1765.

Méndez-González, K. Y., Hernández-Castro, R., Carrillo-Casas, E. M., Monroy, J. F., López-Merino, A., & Suárez-Güemes, F. (2011). *Brucella melitensis* survival during manufacture of ripened goat cheese at two temperatures. *Foodborne Pathogens and Disease, 8*, 1257–1261.

Méndez Martínez, C., Páez Jiménez, A., Cortés Blanco, M., Salmoral Chamizo, E., Mohedano Mohedano, E., Plata, C., et al. (2003). Brucellosis outbreak due to unpasteurized raw goat cheese in Andalucia (Spain), January–March 2002. *Eurosurveillance, 8*, 164–168.

Messelhäusser, U., Beck, H., Gallien, P., Schalch, B., & Busch, U. (2008). Presence of Shiga toxin-producing *Escherichia coli* and thermophilic *Campylobacter* spp. in cattle, food and water sources on Alpine pastures in Bavaria. *Archiv für Lebensmittelhygiene, 59*, 103–106.

Miszczycha, S. D., Perrin, F., Ganet, S., Jamet, E., Tenenhaus-Aziza, F., Montel, M.-C., et al. (2013). Behavior of different Shiga toxin-producing *Escherichia coli* serotypes in various experimentally contaminated raw-milk cheeses. *Applied and Environmental Microbiology, 79*, 150–158.

Miszczycha, S. D., Thévenot, J., Denis, S., Callon, C., Livrelli, V., Alric, M., et al. (2014). Survival of *Escherichia coli* O26:H11 exceeds that of *Escherichia coli* O157:H7 as assessed by simulated human digestion of contaminated raw milk cheeses. *International Journal of Food Microbiology, 172*, 40–48.

Montet, M. P., Jamet, E., Ganet, S., Dizin, M., Miszczycha, S., Dunière, L., et al. (2009). Growth and survival of acid-resistant and non-acid-resistant Shiga-toxin-producing *Escherichia coli* strains during the manufacture and ripening of Camembert cheese. *International Journal of Microbiology, 2009*. Article 653481.

Ostyn, A., De Buyser, M.-L., Guillier, F., Groult, J., Félix, B., Salah, S., et al. (2010). First evidence of a food poisoning outbreak due to staphylococcal enterotoxin type E., France, 2009. *Eurosurveillance, 15*. Article 3.

Peng, S., Hoffmann, W., Bockelmann, W., Hummerjohann, J., Stephan, R., & Hammer, P. (2013). Fate of Shiga toxin-producing and generic *Escherichia coli* during production and ripening of semihard raw milk cheese. *Journal of Dairy Science, 96*, 815–823.

Pintado, C. M., Grant, K. A., Halford-Maw, R., Hampton, M. D., Ferreira, M. A., & McLauchlin, J. (2009). Association between a case study of asymptomatic ovine listerial mastitis and the contamination of soft cheese and cheese processing environment with *Listeria monocytogenes* in Portugal. *Foodborne Pathogens and Disease, 6*, 569–575.

Plommet, M., Fensterbank, R., Vassal, L., Auclair, J., Mocquot, G., Vachot, J. C., et al. (1988). Survival of *Brucella abortus* in ripened soft cheese made from naturally infected cow's milk. *Lait, 68*, 115–120.

Poli, A., Guglielmini, E., Sembeni, S., Spiazzi, M., Dellaglio, F., Rossi, F., et al. (2007). Detection of *Staphylococcus aureus* and enterotoxin genotype diversity in Monte Veronese, a protected designation of origin Italian cheese. *Letters in Applied Microbiology, 45*, 529–534.

Rahimi, E., Doosti, A., Ameri, M., Kabiri, E., & Sharifian, B. (2008). Detection of *Coxiella burnetii* by nested PCR in bulk milk samples from dairy bovine, ovine, and caprine herds in Iran. *Zoonoses and Public Health, 57*, 38–41.

Ramsaran, H., Chen, J., Brunke, B., Hill, A., & Griffiths, M. W. (1998). Survival of bioluminescent *Listeria monocytogenes* and *Escherichia coli* O157:H7 in soft cheeses. *Journal of Dairy Science, 81*, 1810–1817.

Rantsiou, K., Alessandria, V., Urso, R., Dolci, P., & Cocolin, L. (2008). Detection, quantification and vitality of *Listeria monocytogenes* in food as determined by quantitative PCR. *International Journal of Food Microbiology, 121*, 99–105.

Rosengren, Å., Fabricius, A., Guss, B., Sylvén, S., & Lindqvist, R. (2010). Occurrence of foodborne pathogens and characterization of *Staphylococcus aureus* in cheese produced on farm-dairies. *International Journal of Food Microbiology, 144*, 263–269.

Sahebekhtiari, N., Nochi, Z., Eslampour, M. A., Dabiri, H., Bolfion, M., Taherikalani, M., et al. (2011). Characterization of *Staphylococcus aureus* strains isolated from raw milk of bovine subclinical mastitis in Tehran and Mashhad. *Acta Microbiologica et Immunologica Hungarica, 58*, 113–121.

Schlesser, J. E., Gerdes, R., Ravishankar, S., Madsen, K., Mowbray, J., & Teo, A. Y. (2006). Survival of a five-strain cocktail of *Escherichia coli* O157:H7 during the 60-day aging period of Cheddar cheese made from unpasteurized milk. *Journal of Food Protection, 69*, 990–998.

Schoder, D., Melzner, D., Schmalwieser, A., Zangana, A., Winter, P., & Wagner, M. (2011). Important vectors for *Listeria monocytogenes* transmission at farm dairies manufacturing fresh sheep and goat cheese from raw milk. *Journal of Food Protection, 74*, 919–924.

Schoder, D., Winter, P., Kareem, A., Baumgartner, W., & Wagner, M. (2003). A case of sporadic ovine mastitis caused by *Listeria monocytogenes* and its effect on contamination of raw milk and raw-milk cheeses produced in the on-farm dairy. *Journal of Dairy Research, 70*, 395–401.

Schukken, Y. H., Grommers, F. J., Vandegeer, D., Erb, H. N., & Brand, A. (1990). Risk-factors for clinical mastitis in herds with a low bulk milk somatic-cell count. 1. Data and risk-factors for all cases. *Journal of Dairy Science, 73*, 3463–3471.

Schvartzman, M. S., Maffre, A., Tenenhaus-Aziza, F., Sanaa, M., Butler, F., & Jordan, K. (2011). Modelling the fate of *Listeria monocytogenes* during manufacture and ripening of smeared cheese made with pasteurised or raw milk. *International Journal of Food Microbiology, 145*, S31–S38.

Sci Com. (2010a). *Advice 24-2010 of 18 June 2010 of the Scientific Committee of the FASFC on the evaluation of a program for surveillance, prevention and control of* Coxiella burnetii *in small ruminants (dossier Sci Com 2010/11)*. Available online http://www.favv-afsca.fgov.be/wetenschappelijkcomite/adviezen/_documents/ADVIES24-2010_NL_DOSSIER2010-11.pdf. Last accessed 13.10.14.

Sci Com. (2010b). *Advice 25-2010 of 18 June 2010 of the Scientific Committee of the FASFC on the surveillance, prevention and control of* Coxiella burnetii *in cattle (dossier Sci Com 2010/12)*. Available online http://www.favv-afsca.fgov.be/wetenschappelijkcomite/adviezen/_documents/ADVIES25-2010_NL_DOSSIER2010-12.pdf. Last accessed 13.10.14.

Sci Com. (2011). *Advice 15-2011 of 14 October 2011 of the Scientific Committee of the FASFC on the risk–benefit evaluation of raw cow milk consumption and the effect of heat treatment on these risks and benefits*. Available online http://www.favv-afsca.fgov.be/wetenschappelijkcomite/adviezen/_documents/ADVIES15-2011_NL_DOSSIER2010-25.pdf. Last accessed 13.10.14.

Sci Com. (2013). *Advice 11-2013 of 22 March 2013 of the Scientific Committee of the FASFC on the evaluation of the risks and benefits of the consumption of raw milk from animal species other than cows*. Available online http://www.favv-afsca.fgov.be/wetenschappelijkcomite/adviezen/_documents/ADVIES11-2013_NL_DossierSciCom2012-12.pdf. Last accessed 13.10.14.

Sci Com. (2015). *Advice 02-2015 of 27 February 2015 of the Scientific Committee of the FASFC on the evaluation of the microbiological risks of the consumption of dairy products based on raw milk*. Available online http://www.favv-afsca.fgov.be/wetenschappelijkcomite/adviezen/_documents/ADVIES02-2015_NL_DOSSIER_2014-06.pdf. Last accessed 31.03.15.

Spahr, U., & Schafroth, K. (2001). Fate of *Mycobacterium avium* subsp. *paratuberculosis* in Swiss hard and semihard cheese manufactured from raw milk. *Applied and Environmental Microbiology, 67*(9), 4199–4205.

Spano, G., Goffredo, E., Beneduce, L., Tarantino, D., Dupuy, A., & Massa, S. (2003). Fate of *Escherichia coli* O157:H7 during the manufacture of Mozzarella cheese. *Letters in Applied Microbiology, 36*, 73–76.

Stephan, R., Schumacher, S., Corti, S., Krause, G., Danuser, J., & Beutin, L. (2008). Prevalence and characteristics of Shiga toxin-producing *Escherichia coli* in Swiss raw milk cheeses collected at producer level. *Journal of Dairy Science, 91*, 2561–2565.

Stephan, R., Schumaher, S., Tasara, T., & Grant, I. R. (2007). Prevalence of *Mycobacterium avium* subspecies *paratuberculosis* in Swiss raw milk cheeses collected at the retail level. *Journal of Dairy Science, 90*, 3590–3595.

Strachan, N. J. C., Dunn, G. M., Mary, E., Locking, M. E., Reis, T. M. S., & Ogden, I. D. (2006). *Escherichia coli* O157: burger bug or environmental pathogen? *International Journal of Food Microbiology, 112*, 129–137.

Trevisani, M., Mancusi, R., & Valero, A. (2014). Thermal inactivation kinetics of Shiga toxin-producing *Escherichia coli* in buffalo Mozzarella curd. *Journal of Dairy Science, 97*, 642–650.

Vaillant, V., Haeghebaert, S., Desenclos, J. C., Bouvet, P., Grimont, F., Grimont, P. A., et al. (1996). Outbreak of *Salmonella dublin* infection in France, November–December 1995. *Eurosurveillance, 1*. Article 1.

Vaillant, V., Maillot, E., Charley, C., & Stainer, F. (1998). *Epidémie de listeriose, France, avril-aout 1995*. Saint-Maurice, France: Institut de Veille Sanitaire.

Valero, A., Hernandez, M., De Cesare, A., Manfreda, G., González-García, P., & Rodríguez-Lázaro, D. (2014). Survival kinetics of *Listeria monocytogenes* on raw sheep milk cured cheese under different storage temperatures. *International Journal of Food Microbiology, 184*, 39–44.

Vernozy-Rozand, C., Montet, M. P., Berardin, M., Bavai, C., & Beutin, L. (2005). Isolation and characterization of Shiga toxin-producing *Escherichia coli* strains from raw milk cheeses in France. *Letters in Applied Microbiology, 41*, 235–241.

Verraes, C., Claeys, W., Cardoen, S., Daube, G., De Zutter, L., Imberechts, H., et al. (2014). A review of the microbiological hazards of raw milk from animal species other than cows. *International Dairy Journal, 39*, 121–130.

Villar, R. G., Macek, M. D., Simons, S., Hayes, P. S., Goldoft, M. J., Lewis, S. H., et al. (1999). Investigation of the multidrug-resistant *Salmonella* serotype Typhimurium DT104 infections linked to raw-milk cheese in Washington state. *Journal of the American Medical Association, 281*, 1811–1816.

Volponi, G., Rooks, D. J., Smith, D. L., Picozzi, C., Allison, H. E., Vigentini, I., et al. (2012). Short communication: characterization of Shiga toxin 2-carrying bacteriophages induced from Shiga-toxigenic *Escherichia coli* isolated from Italian dairy products. *Journal of Dairy Science, 95*, 6949–6956.

Whyte, P., McGill, K., Cowley, D., Madden, R. H., Moran, L., Scates, P., et al. (2004). Occurrence of *Campylobacter* in retail food in Ireland. *International Journal of Food Microbiology, 95*, 111–118.

Williams, A. G., & Withers, S. E. (2010). Microbiological characterisation of artisanal farmhouse cheeses manufactured in Scotland. *International Journal of Dairy Technology, 63*, 356–369.

Wood, D. S., Collins-Thompson, D. L., Irvine, D. M., & Muhr, A. N. (1984). Source and persistence of *Salmonella* Muenster in naturally contaminated Cheddar cheese. *Journal of Food Protection, 47*, 20–22.

Zweifel, C., Giezendanner, N., Corti, S., Krause, G., Beutin, L., Danuser, J., et al. (2010). Characteristics of Shiga toxin-producing *Escherichia coli* isolated from Swiss raw milk cheese within a 3-year monitoring program. *Journal of Food Protection, 73*, 88–91.