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Review

A review of the microbiological hazards of raw milk from animal species other than cows

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A B S T R A C T

This review concentrates on information concerning the microbiological hazards that can be present in raw milk from animal species other than cows. Total bacterial counts of raw milk are described for several animal species, indicating the quality of the milk, then frequencies of occurrence of several human pathogenic microorganisms are considered and, finally, human cases of illness and outbreaks due to the consumption of raw milk from non-bovine species are covered. Only raw milk from goats and camels has so far been reported to be associated with outbreaks. Raw milk from horse and donkey may have a higher microbiological quality than raw milk from other animal species, although human pathogenic strains of *Streptococcus* are considered as a microbiological hazard for such milk. For raw milk from other animal species, the main microbiological hazards seem to be human pathogenic *Escherichia coli*, *Campylobacter* spp., tick-borne encephalitis virus and *Brucella* spp.

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1. Introduction

In recent years, there has been a growing interest in local food production and consumption, and consumers are looking for foodstuffs that have undergone the least processing. As a result, there is an increased tendency to consume raw milk. Cow milk is the most frequently consumed type of milk; however, other types of raw milk are also consumed such as that from goats, sheep, horses, donkeys, camels, llamas, buffaloes, yaks and even reindeer. The consumption of raw milk holds a risk for the consumer, due to the possible presence of human pathogenic microorganisms in the raw milk (Claeys et al., 2013; FASFC, 2011, 2013).

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Pathogens possibly present in raw milk may originate from animals (even from those that are clinically healthy) or a contamination from the environment during the collection or storage of the milk. A distinction can be made between an endogenous infection, in which the milk is contaminated by direct transfer from the blood stream (systemic infection) or from an udder infection, and a cross-contamination, in which the milk is contaminated by faeces, the skin or the environment (external contamination during or after milking).

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 animals other than cows were described in a review by Claeys et al. (2014). In the present review, a collation is made of data found concerning the microbiological hazards of raw milk from animal species other than cows, in particular goats, sheep, horses, donkeys, camels, llamas, buffaloes, yaks and reindeer. Only zoonotic microorganisms and those originating from the environment have been taken into consideration. Microorganisms originating from humans, e.g., *Shigella* spp. and noroviruses have not been taken into account.

2. Total bacterial counts of raw milk

The microbiological quality of raw milk can be determined using various parameters, such as the number of *Enterobacteriaceae*, the number of coagulase-positive *Staphylococcus aureus* and the total bacterial count. The total bacterial counts presented in Table 1 are derived from studies published in scientific literature. The data must be interpreted with caution, since the counts have been determined in different ways using different methods.

D'Amico and Donnelly (2010) showed that there is no significant difference in the total plate count results of raw milk from goats, sheep and cows. The total plate count results of goat and sheep milk varies according to the month in which the animal is milked, the number of milking sessions making up the milk mix, the milking system used and the size of the herd (Alexopoulos et al., 2011; Gonzalo et al., 2006; Gonzalo, Carriedo, García-Jimeno, Pérez-Bilbao, & De La Fuente, 2010; Zweifel, Muehlherr, Ring, & Stephan, 2005). According to the scientific literature, raw horse milk has a lower total plate count and thus a higher microbiological quality than raw cow milk (Doreau & Martin-Rosset, 2002). One could consider as a possible explanation the difference in concentration of natural antimicrobial components such as lactoferrrin, lysozyme, immunoglobulins and lactoperoxidase. The activity or content of most antimicrobial systems or components in milk varies strongly between animal species. The content of lactoferrin in horse milk, the content of lysozyme in horse and donkey milk and the iron binding capacity of lactoferrin in horse milk are higher than in milk from other animal species (Claeys et al., 2014). However, the antimicrobial components/systems in raw milk have primarily a protective role at mucosal surfaces of the digestive tract in humans and animals. The activity to suppress in raw milk the growth of bacteria and to function as milk preservatives is generally considered as very limited and not of practical relevance. No reference was found documenting an effect of the antimicrobial components on microbial growth in raw milk from horses and donkeys.

In a review by Salimei and Fantuz (2012), it was found that the total plate count of horse milk is on average 4.6 log cfu mL^{-1}. Total plate counts are highest at the start of the lactation, and gradually decrease over the lactation period (Dankow, Wójtowski, Pikul, Niżnikowski, & Cais-Sokolińska, 2006). From Table 1, it can be seen that the counts of raw horse milk never exceeded 5 log cfu mL^{-1}, whereas this level was exceeded in the case of raw goat or sheep milk. This lower total plate count was ascribed to the good health status, intrinsic characteristics of the milk and the excellent natural anatomical position of the udder (Salimei & Fantuz, 2012). It is probable that the smaller size of the udder limits exposure of the teats to bacterial contamination (Doreau & Martin-Rosset, 2002). The review of Salimei and Fantuz (2012) however mentioned that the total plate count of donkey milk varies from 2.40 to 5.87 log cfu mL^{-1}, but is similar to that of horse milk. Neither lactation stage nor season had a significant influence on total plate count results (Ivanković et al., 2009). Regarding the other animal species, little information was available on total bacterial counts (see Table 1).

3. Frequencies of occurrence of human pathogenic microorganisms in raw milk

No systematic data were available on the prevalence of human pathogenic microorganisms in raw milk from species other than cows. However, studies of the frequencies of occurrence of pathogens in raw milk that have been published in the international scientific literature provide an indication of the prevalences. A search was made for all publications describing detection frequencies of human pathogenic microorganisms in raw milk from animal species other than cows. Publications with detection frequencies of zero percent were not included. It should be noted that these frequencies can vary according to the sampling and methodological approach. Variation can also be explained by geographical differences, the season in which the samples were taken, the size of the farm, the density of the animal population, regional differences in the keeping and taking care of animals, etc. Table 2 gives an overview of the collected publications.

Salmonella spp. have only been detected in raw milk from sheep and camels, and not in raw milk from goats, horses, donkeys or buffaloes. The frequency of occurrence in raw sheep milk was low, and ranged from 0 to 5%. For raw camel milk, the frequency of occurrence was about 10%. The review of Salimei and Fantuz (2012) confirmed that no reports were available detecting *Salmonella* spp. in raw milk from horse species.

Campylobacter spp. have only been reported in raw milk from sheep, and not in raw milk from goats, horses or buffaloes. However, the possible presence of *Campylobacter jejuni* in raw goat milk is apparent from an outbreak due to raw goat milk consumption (see Section 4 and Table 3).

Several studies have shown the possible presence of human pathogenic verocytotoxin-producing *Escherichia coli* (VTEC) in raw milk from goats, sheep, buffaloes and yaks, but not in raw horse milk.

The frequencies of occurrence of *E. coli* O157:H7 in raw milk from goats and sheep was about 1%, but for VTEC, this can be up to 16.3% for goat milk and 12.7% for sheep milk (Muehlherr, Zweifel, Corti, Blanco, & Stephan, 2003). The same was true for raw buffalo and yak milk, as can be seen from Table 2. The studies in Table 2 do not always mention whether the detected strains contained virulence genes. Human pathogenic VTEC contain genes for the production of verotoxins and a combination of genes coding for virulence factors that permit attachment to the intestines, as well as other adhesion factors and their regulators. However, this is only an indication of pathogenicity, and does not provide absolute certainty. Because of the differences in the methods described in the literature on detected VTEC, these data have to be interpreted with caution. Limited validated methods exist that can be used to isolate the non-O157-serotypes of *E. coli*, and because of this, the prevalence of such serotypes in raw milk is difficult to estimate (Vernozy-Rozand & Roze, 2003).

The frequency of *Listeria monocytogenes* in raw goat milk was found to be less than 8% and below 4% in raw sheep milk. This

Table 1
Total bacterial counts of raw milk from a variety of lactating mammals that is used for human consumption.

Average total bacterial count (log cfu mL^{-1})	Number of samples	Comments	Country	References
Cow				
4.05	137,973	Total bacterial count; Bactoscan (fluoro-opto-elektronic determination)	Belgium	MCC Vlaanderen (personal communication, 2011)
4.31	91,215	Total bacterial count; Bactoscan (fluoro-opto-elektronic determination)	Belgium	Comité du Lait (personal communication, 2011)
Goat				
4.63	2098	Bactoscan (fluoro-opto-elektronic determination)	Belgium	MCC-Vlaanderen & Comité du Lait (personal communication, 2009-2012)
4.40	100	Aerobic plate count; according to reference procedures specified in the Dairy Products (Hygiene) Regulations 1995	United Kingdom	Little & de Louvois, 1999
4.70	60	Standard plate count; according to IDF Standard 100B:1991	Italy	Foschino, Invernizzi, Barucco, & Stradiotto, 2002
7.56	not given	Total bacteria; extensively farmed goats; according to standard procedures on plate count agar, incubation 30 °C-72 h	Greece	Morgan et al., 2003
7.60	not given	Total bacteria; extensively farmed goats; according to standard procedures on plate count agar, incubation 30 °C-72 h	Portugal	Morgan et al., 2003
5.03	not given	Total bacteria; extensively farmed goats; according to standard procedures on plate count agar, incubation 30 °C-72 h	France	Morgan et al., 2003
4.69	344	Standard plate count; pour plate method with plate count agar	Switzerland	Muehlherr et al., 2003; Zweifel et al., 2005
4.40	not given	Total plate count; nutrient agar, incubation 37 °C-48 h	United States	Park & Humphrey, 1986
4.59	not given	Standard plate count; day 150–180 of lactation; nutrient agar, incubation 34 °C-48 h	United States	Park, 1991
3.98	not given	Standard plate count; procedure according to Houghtby, Martin, & Koenig, 1992	United States	Zeng & Escobar, 1995
2.96	not given	Standard plate count; according to American Public Health Association procedure	United States	Zeng & Escobar, 1996
2.20	25	Standard plate count; according to AOAC method 986.33, Petrifilm aerobic count	United States	D'Amico & Donnelly, 2010
5.69	30	Conventional culture of total plate count	Indonesia	Taufik et al., 2011
Sheep				
4.56	26	Aerobic plate count; according to reference procedures specified in the Dairy Products (Hygiene) Regulations 1995	United Kingdom	Little & de Louvois, 1999
4.79	63	Standard plate count; pour plate method with plate count agar	Switzerland	Muehlherr et al., 2003; Zweifel et al., 2005
5,13	9353	Bulk tank total bacterial count; 315 flocks; Bactoscan 8000	Spain	Gonzalo et al., 2006
5.05	68,781	Total plate count; Bactoscan 8000	Spain	Gonzalo, Carriedo, García-Jimeno, Pérez-Bilbao, & De La Fuente, 2010
5.48	155	Total plate count; plate count agar	Greece	Alexopoulos et al., 2011
1,90	15	Standard plate count; according to AOAC method 986.33, Petrifilm aerobic count	United States	D'Amico & Donnelly, 2010
Horse				
4.15	260	Total aerobic plate count; chilled and frozen samples; according to reference method ISO 4833	Belgium	ILVO (personal communication, 2005–2012)
4.66	150	Total microbial count; day 1–5 of lactation; Bactoscan 8000S	Poland	Dankow et al., 2006
4.57	150	Total microbial count; day 15–150 of lactation; Bactoscan 8000S	Poland	Dankow et al., 2006
Donkey				
4.59	28	Total aerobic plate count; chilled and frozen samples; according to reference method ISO 4833	Belgium	ILVO (personal communication, 2007–2012)
3.58	not given	Total bacterial count; milk samples from 14 donkeys; according to the ISO 21187:2004 norm, flow cytometric method, Bactoscan FC	Croatia	Ivanković et al., 2009
1.70	101	Half-udder milk samples; plate count agar, inclusion method, incubation 48 h	Italy	Pilla, Daprà, Zecconi, & Piccinini, 2010
Camel				
5.28	4	Total aerobic plate count; according to reference method ISO 4833	Belgium	ILVO (personal communication, 2010)
Buffalo				
5.65	42	Total aerobic mesophilic cell count	Romania	Coroian, Corioan, Vodnar, & Trif, 2010
5.59	112	Total aerobic mesophilic cell count; according to Chinese standard method GB/T4782.2-2003, in pour-plates of plate count agar, incubation 37 °C-2 d	China	Han et al., 2007

pathogen has also been detected in buffalo milk with frequencies up to 25%, but not in raw horse milk. The review of Salimei and Fantuz (2012) confirmed that no reports were available detecting *L. monocytogenes* in raw milk from horse species.

St. aureus has previously been reported in raw milk from goats, sheep, horses, donkeys, camels and buffaloes. However, these studies have not always indicated whether the strains are enterotoxigenic. When they did, this is shown in Table 2. Scherrer, Corti,

Table 2
Frequencies of occurrence of human pathogenic microorganisms in raw milk from animal species other than cows.

Animal species	Frequency of occurrence (%)	Number of samples	Comments	Country	References
Salmonella spp.					
Sheep	5	240		Greece	Fotou et al., 2011
Camel	9.52	21	Milk from camels with clinical mastitis	Iraq	Al-Tofaily & Al rodhan, 2011
Campylobacter spp.					
Sheep	2.22	90	Farm tank milk	United Kingdom	FSA, 1999
Human pathogenic *E. coli*					
Goat	0.70	286	*E. coli* O157; farm tank milk; 1 of the 2 isolates *vt*-positive	United Kingdom	FSA, 1999
	1.7	60	*E. coli* O157:H7	Italy	Foschino et al., 2002
	16.3	344	*vt*-positive; farm tank milk	Switzerland	Muehlherr et al., 2003
	13.7	73	PCR-positive (*vt*, *eae*, *ehxA*) for *E. coli* O157; 6.8% *vt*-positive; 1.4% *E. coli* O157:H7	Spain	Rey et al., 2006
	0.65	460	*E. coli* O157; 0.43% PCR-positive and *E. coli* O157:H7 (*vt1* and/or *vt2*, *eae*, *ehxA*)	Greece	Solomakos et al., 2009
	0.75	49	*E. coli* O157:H7	United States	D'Amico, Groves, & Donnelly, 2008
Sheep	1	100	*E. coli* O157:H7, *vt1*- and *vt2*-positive	Greece	Dontorou et al., 2003
	12.7	344	*vt*-positive; farm tank milk	Switzerland	Muehlherr et al., 2003
	10.1	287	PCR-positive (*vt*, *eae*, *ehxA*) for *E. coli* O157; 1.4% *vt*-positive; 0% *E. coli* O157:H7	Spain	Rey et al., 2006
	0.84	595	*E. coli* O157; 0.50% PCR-positive and *E. coli* O157:H7 (*vt1* and/or *vt2*, *eae*, *ehxA*)	Greece	Solomakos et al., 2009
Buffalo	0.6	160	*E. coli* O26	Italy	Lorusso et al., 2009
	1.4	213	*E. coli* O157:H7; farm tank milk	Turkey	Seker & Yardimci, 2008
Yak	22.2	87	Virulence genes for VTEC or EPEC	India	Bandyopadhyay et al., 2012
Listeria monocytogenes					
Goat	0.8	480		United Kingdom	Greenwood, Roberts, & Burden, 1991
	0.4	480	*L.* spp. other than *L. monocytogenes*	United Kingdom	Greenwood et al., 1991
	2.56	1.445	Farm tank milk	Spain	Gaya, Saralegui, Medina, & Nunez, 1996
	2.10	286	Farm tank milk	United Kingdom	FSA, 1999
	3.8	150	Farm tank milk	United States	Abou-Eleinin, Ryser, & Donnelly, 2000
	7.8	450	*L.* spp.; farm tank milk	United States	Abou-Eleinin et al., 2000
Sheep	1.8	56		United Kingdom	Greenwood et al., 1991
	3.33	90	Farm tank milk	United Kingdom	FSA, 1999
Buffalo	25	8	Farm tank milk	United Kingdom	FSA, 1999
	6.25	64	26.23% *L.* spp.	India	Barbuddhe, Chaudhari, & Malik, 2002
Staphylococcus aureus					
Goat	49.1	1350	*St.* spp.; 17.3% *St. aureus* (from 694 isolates)	Greece	Kalogridou-Vassiliadou, 1991
	10	94		United Kingdom	FSA, 1998
	9.44	286	Farm tank milk	United Kingdom	FSA, 1999
	15	100		United Kingdom	Little & de Louvois, 1999
	43	60	23% enterotoxinogenic	Italy	Foschino et al., 2002
	90	60	Coagulase-positive *St.*, of which 0% enterotoxinogenic	Italy	Foschino et al., 2002
	31.7	344	Farm tank milk	Switzerland	Muehlherr et al., 2003
	96.2	213	57.3% enterotoxin-producing isolates	Norway	Jørgensen, Mørk, Høgåsen, & Rørvik, 2005
	38.2	406	Non-haemolytic spp. (mastitis agent)	United States	White & Hinckley, 1999
	11.0	117	(Mastitis agent)	United States	White & Hinckley, 1999
	48	25		United States	D'Amico & Donnelly, 2010
	<1	896	4 Kids	Australia	Ryan & Greenwood, 1990
	13.3	896	Coagulase-negative *St.*	Australia	Ryan & Greenwood, 1990
	37.70	not given	Coagulase-positive *St.*	Indonesia	Taufik et al., 2011
	76.7	not given	Coagulase-positive *St.*; mixed milk	Indonesia	Taufik et al., 2011
Sheep	21	17		United Kingdom	FSA, 1998
	56.67	90	Farm tank milk	United Kingdom	FSA, 1999
	35	26		United Kingdom	Little & de Louvois, 1999
	33.3	63	Farm tank milk	Switzerland	Muehlherr et al., 2003
	24	240		Greece	Fotou et al., 2011
	100	71	Average 3.94 log cfu mL^{-1}	Greece	Alexopoulos et al., 2011
	47	15		United States	D'Amico & Donnelly, 2010
Horse	13	23	Fresh and frozen milk	Netherlands	de Jager, 2009
Donkey	4.95	101	0% with genes for enterotoxin or toxic shock syndrome toxin	Italy	Pilla et al., 2010
	1.98	101	*S. equi*	Italy	Pilla et al., 2010
	0.99	101	*S. equisimilis*	Italy	Pilla et al., 2010
Camel	8.8	320	10.7% with gene for enterotoxin	Sudan	Shuiep et al., 2009
	28.57	21	Milk from camel with clinical mastitis	Iraq	Al-Tofaily & Al rodhan, 2011
	9.52	21	*S. agalactiae*; milk from camels with clinical mastitis	Iraq	Al-Tofaily & Al rodhan, 2011

Table 2 (*continued*)

Animal species	Frequency of occurrence (%)	Number of samples	Comments	Country	References
Buffalo	21.5	8	Farm tank milk	United Kingdom	FSA, 1999
	10.8	548	*St.* spp., all *St. aureus* at least one toxin produced	Brazil	Oliveira et al., 2011
	11.1	548	Coagulase-positive strains	Brazil	Oliveira et al., 2011
	83.3	548	Coagulase-negative strains	Brazil	Oliveira et al., 2011
	5.6	548	Coagulase-negative and-positive strains	Brazil	Oliveira et al., 2011
	76	112		China	Han et al., 2007
Bacillus cereus					
Goat	29.9	1350	*B.* spp.; 34.4% *B. coagulans* in 23.4% *B. licheniformis* (from 338 isolates)	Greece	Kalogridou-Vassiliadou, 1991
Sheep	29	240	*B.* spp.	Greece	Fotou et al., 2011
Streptococcus spp.					
Goat	1.9	1350		Greece	Kalogridou-Vassiliadou, 1991
	4	100	Haemolytic *Str.*	United Kingdom	Little & de Louvois, 1999
	4.1	43	(Mastitis agent)	United States	White & Hinckley, 1999
	0.6	896	4 Kids	Australia	Ryan & Greenwood, 1990
Sheep	23	26	Haemolytic *Str.*	United Kingdom	Little & de Louvois, 1999
	100	65	Average 4.95 log cfu mL^{-1}	Greece	Alexopoulos et al., 2011
Coxiella burnetii					
Goat	1.8	56	Farm tank milk	Iran	Rahimi et al., 2008
	4.5	110	Farm tank milk	Iran	Rahimi et al., 2011
Sheep	5.7	140	Farm tank milk	Iran	Rahimi et al., 2011
Camel	1.4	70	Farm tank milk	Iran	Rahimi et al., 2011
Helicobacter pylori					
Goat	25.6	160		Italy	Quaglia et al., 2008
	8.7	103		Iran	Rahimi & Kheirabadi, 2012
Sheep	60.3	51		Sardinia	Dore, Sepulveda, Osato, Realdi, & Graham, 1999
	60	63		Sardinia	Dore et al., 2001
	33	130		Italy	Quaglia et al., 2008
	12.2	90		Iran	Rahimi & Kheirabadi, 2012
Buffalo	23. 4	64		Iran	Rahimi & Kheirabadi, 2012
Camel	3.6	55		Iran	Rahimi & Kheirabadi, 2012
Mycobacterium avium subsp. *paratuberculosis*					
Goat	1.1	90	PCR-positive, not isolated; mixed milk	United Kingdom	Grant, O'Riordan, Ball, & Rowe, 2001
	23.0	344	Farm tank milk	Switzerland	Muehlherr et al., 2003
Sheep	23.8	63	Farm tank milk	Switzerland	Muehlherr et al., 2003
Buffalo	21.7	23	Non-tuberculous *M.*	Brazil	Jordão Junior et al., 2009
Tick-borne encephalitis virus					
Goat	20.7	29	Via RT-PCR	Risk area in Poland	Cisak et al., 2010
Sheep	22.2	27	Via RT-PCR	Risk area in Poland	Cisak et al., 2010

Muehlherr, Zweifel, and Stephan (2004) analysed 293 *St. aureus* isolates from 127 bulk-tank milk samples of goats and sheep and detected genes for enterotoxin production in 191 isolates. In raw donkey milk, enterotoxin-producing *St. aureus* were not reported.

No data regarding the frequency of occurrence of *Bacillus cereus* in raw milk from other species than cows were available.

Streptococcus spp. have been detected in raw milk from goats, sheep, donkeys and camels. However, the studies did not always mention whether the strains involved were able to produce toxins. When they did, this is included in Table 2. In raw milk from horses and donkeys, *Streptococcus equi* and *Streptococcus equisimilis* have both been detected (Pilla et al., 2010; Salimei & Fantuz, 2012). *Streptococcus agalactiae* (Abdurahman, Agab, Abbas, & Aström, 1995) and *Streptococcus equi zooepidemicus* (Younan et al., 2005) have been isolated from raw camel milk.

As shown in Table 2, the presence of *Coxiella burnetii* varied from 1.8 to 4.5% in raw goat milk, from 0 to 5.7% in raw sheep milk and, in raw camel milk, the frequency was 1.4%. In raw cow milk, the presence varied from 3.2 to 6.2% (Rahimi, Ameri, Karim, & Doosti, 2011; Rahimi, Doosti, Ameri, Kabiri, & Sharifian, 2008), which is slightly higher than in raw goat, sheep and camel milk. After an outbreak of Q-fever in goats in France in 2002, the occurrence of *C. burnetii* in goat milk samples was investigated in 2003. The bacterium was only found in milk from goats that had suffered miscarriages and only for about three months after giving birth. After that, the bacterium was no longer present in the milk, not even in the season after birth (Berri et al., 2005). As a result of an outbreak of Q-fever in goats and sheep in the Netherlands in 2007, the occurrence of *C. burnetii* in goat and sheep milk samples was examined in 2008. Using real-time PCR, 32.9 and 0% of the raw goat and sheep milk samples respectively were found to be positive (van den Brom et al., 2012).

Helicobacter pylori has been isolated from milk of goats, sheep, camels and buffaloes (Quaglia et al., 2008; Rahimi & Kheirabadi, 2012). The frequency of occurrence of *H. pylori* varied in literature reports from 8.7 to 25.6% for raw goat milk, 0–60.3% for raw sheep milk, 23.45% for raw buffalo milk and 6% for raw camel milk. In raw cow milk, it ranged from 14.1 to 50% (Quaglia et al., 2008; Rahimi & Kheirabadi, 2012), which is much higher than in raw milk from the other species. This could be due to the much larger number of samples of cows milk tested.

The frequency of occurrence of *Mycobacterium avium* subsp. *paratuberculosis* (MAP) was similar in raw goat and sheep milk, and ranged from 0 to 24%. MAP was also detected in raw buffalo milk (Jordão Junior, Lopes, David, Farache Filho, & Leite, 2009). In raw buffalo milk, *Mycobacterium bovis* has been detected (Jordão Junior et al., 2009).

In Poland, the tick-borne encephalitis virus (TBEV) was found to occur at a frequency slightly above 20% in raw milk from goats and sheep.

Regarding *Brucella* spp., no studies were performed to estimate prevalences in raw milk from animal species other than cows. However, in the European Union in 2012, Italy provided data about the presence of *Brucella* spp. in 'milk from other animal species or unspecified' and in raw sheep milk. The numbers of samples were

Table 3
Reported human cases and outbreaks of a variety of microbial infections and intoxications due to consumption of raw milk from animal species other than cows.

Pathogenic agent	Country	Year	Comments	References
Raw goat milk				
E. coli O157:H7	Czech Republic	1995	4 cases of Haemolytic Uraemia Syndrome (HUS) (children), 1 case of mild diarrhoea and 4 asymptomatic cases	Bielaszewska et al., 1997
	Canada	2001	5 children, of which 3 with bloody diarrhoea and 2 with HUS and hospitalised	McIntyre et al. 2002; Milk Facts, 2012
	United States	2008	2 cases of HUS (children aged 1 and 9 years) and 2 cases, of which 3 laboratory confirmed	Milk Facts, 2012; Real Raw Milk Facts, 2012
E. coli O157:H-	Austria	2001	1 case of bloody diarrhoea (child of 9 years)	Allerberger et al., 2001
E. coli sp.	United States	2009	1 case of HUS (child)	Wyoming Department of Health, 2008
E. coli O157:H7 and/or *Campylobacter jejuni*	United States	2010	30 cases, of which 2 cases of HUS and 47 asymptomatic cases, of which 11 cases laboratory confirmed: 6 *Campylobacter*, 2 *E. coli* O157, 3 *Campylobacter* and *E. coli* O157	Milk Facts, 2012; Real Raw Milk Facts, 2012
Campylobacter jejuni	United States	1983	4 cases	Harris et al., 1987
		1991	3 cases	Marler, 2007
		2005	11 cases, of which 3 hospitalised	Real Raw Milk Facts, 2012
		2012	18 cases	Real Raw Milk Facts, 2012
Campylobacter sp.	United States	2007	60 cases (also by raw cow milk)	Milk Facts, 2012
Brucella melitensis	Spain	2006	9 cases in 2 families of Moroccan immigrants	Ramos et al., 2008
Brucella sp.	United States	2006	5 cases, of which 3 hospitalised	Real Raw Milk Facts, 2012
	Namibia		1 family and 1 case by consumption of raw goat milk, raw goat cheese and coffee with raw milk	Magwedere et al., 2011
Coxiella burnetii	France	1992	9 cases (psychiatric facility)	Fishbein & Raoult, 1992
Enterotoxins of haemolytic *Staphylococcus aureus*	United States	1942	3 cases of vomiting and purging, of which 2 died (children aged 3 and 4 years); due to 1 goat with mastitis	Weed et al., 1943
Enterotoxin D of *Staphylococcus aureus*	Switzerland	2008	3 cases (children)	Giezendanner et al., 2009
Tick-borne encephalitis virus	Slovakia	1951	660 cases, of which 261 with encephalitis and 271 hospitalised	Balogh et al., 2010; Kríz et al., 2009
		1993	7 cases (family) of tick-borne encephalitis and hospitalised	Kohl, Kozuch, Elecková, Labuda, & Zaludko, 1996
	not given	not given	2 cases of tick-borne encephalitis (elderly couple)	Sixl, Stünzner, Withalm, & Köck, 1989
	Poland	1995	15 cases with neurological symptoms and hospitalized, 33 cases with flu-like symptoms and 15 asymptomatic cases	Matuszczyk, Tarnowska, Zabicka, & Gut, 1997
	Estonia	2005	15 cases with flu-like symptoms, 4 cases of vomiting and 8 cases with neurological symptoms and hospitalized	Kerbo, Donchenko, Kutsar, & Vasilenko, 2005
	Hungary	2007	154 people exposed, 31 cases of which 25 cases of tick-borne encephalitis	Balogh et al., 2010
Toxoplasma gondii	Great Britain	1988	1 case with mononucleosis-like clinical picture (13 years of age) and 1 case with flu-like illness (15 years of age)	Skinner, Timperley, Wightman, Chatterton, & Ho-Yen, 1990
	United States	1973	1 case of toxoplasmosis (infant)	Riemann, Meyer, Theis, Kelso, & Behymer, 1975
	United States	1978	1 case of retinochoroiditis and 9 asymptomatic cases	Sacks, Roberto, & Brooks, 1982
Raw camel milk				
Brucella abortus	not given	not given	1 case with endocarditis and disseminated intravascular coagulation	Almér, 1985
Brucella abortus and *melitensis*	Saudi-Arabia	2007/8	2 cases (male and female)	Kalimuddin et al., 2010
Brucella sp.	Saudi-Arabia	2011	1 case with manifestation of brucellosis in soft tissue of chest wall	Al-Ayed, Bin-Hussain, Al Hajjar, & Al Nassar, 2011
Brucella melitensis	Israel	2011	15 cases with acute brucellosis	Shimol et al., 2012

not given (EFSA, 2014). *Brucella abortus* has previously been detected in raw buffalo milk (Capparelli et al., 2009) and raw reindeer milk (Forbes & Tessaro, 1993).

No data regarding the frequency of occurrence of *Toxoplasma gondii* in raw milk was available in the literature. However, the high seroprevalence (67%) of this parasite in camels in Sudan suggests this parasite may be important for the health of nomads who consume raw camel milk (Elamin, Elias, Daugschies, & Rommel, 1992).

Data regarding the frequency of *Yersinia enterocolitica* in raw milk from species other than cows are scarce. This pathogen was detected in raw buffalo milk (Toora, Bala, Tiwari, & Singh, 1989).

4. Reported human cases and outbreaks due to the consumption of raw milk

As raw cow milk is more widely produced and more frequently consumed than raw milk from other animal species, more human cases and outbreaks are linked to the consumption of raw cow milk than to the consumption of raw milk from other animal species.

A search was made to make a list that contains reports of cases and outbreaks arising from the consumption of raw milk of all animal species other than cows. It seems that up to now only raw goat milk and raw camel milk (see Table 3) were associated with outbreaks, as there were no reports of outbreaks for other species. A factor contributing to this could be the fact that raw goat and raw camel milk are consumed to a greater extent than raw milk from other animal species apart from cows. The list shown in Table 3 has to be considered as non-exhaustive, because not every case or outbreak is reported, and not every case or outbreak has been epidemiologically linked with the source of infection. For this reason, the true level of incidence was underestimated. The list includes cases and outbreaks reported in the scientific literature as well as from other data sources (Marler, 2007; Milk Facts, 2012; Real Raw Milk Facts, 2012; Wyoming Department of Health, 2008).

Cases of *E. coli* O157 and *C. jejuni* infections in humans are frequently reported as being linked to the consumption of raw goat milk (see Table 3).

Brucella spp. in raw goat and camel milk has caused a number of human cases (see Table 3). Studies have shown that the main source of human brucellosis turns out to be the consumption of unpasteurised milk (often from camel) (Mousa, Elhag, Khogali, & Marafie, 1988; Shaalan et al., 2002) or contact with goats, sheep and camels (Mousa et al., 1988). Several publications showed that the main source of infection for *Brucella* in both children (al-Eissa et al., 1990; Benjamin & Annobil, 1992) and adults (Lulu et al., 1988) in Saudi Arabia and Kuwait was raw milk.

An outbreak of Q-fever in a psychiatric institution was described by Fishbein and Raoult (1992), where it was possible that *C. burnetii* was transferred to the ill persons via the raw goat milk or the raw milk products. However, airborne transmission could not be ruled out for this infection, as this is normally the case for the transfer of *Cox. burnetii* from animals to humans.

Table 3 also describes two outbreaks linked to enterotoxins from *St. aureus* in raw goat milk (Giezendanner, Meyer, Gort, Müller, & Zweifel, 2009; Weed, Micheal, & Harger, 1943). Both outbreaks were caused by a goat with mastitis.

The TBEV has caused one major outbreak and several cases due to the consumption of raw goat milk. In the Czech Republic, in the period 1997–2008, 64 cases of tick-borne encephalitis were reported due to the consumption of unpasteurized goat and cow milk, and unpasteurised sheep milk cheeses. Of all these cases, 56% was due to consumption of raw goat milk (Kríz, Benes, & Daniel, 2009).

Finally, *T. gondii* infections due to the consumption of raw goat milk have been described, and are shown in Table 3.

5. Discussion

According to the scientific literature, raw horse milk has a relatively low total plate count and thus a relatively high microbiological quality. Many pathogens that were detected in raw milk from several animal species were not reported to be detected in raw horse or donkey milk, except for some species of *Streptococcus*. This pathogen was also detected in raw milk from goats, sheep and camels. Therefore, it is concluded that the most probable main microbiological hazards in raw horse and donkey milk would be human pathogenic strains of *Streptococcus*, as for the milk from the remaining animals, other pathogens are relatively more important.

The main microbiological hazards that seem to be associated with raw milk from the other animal species are human pathogenic *E. coli* and *Campylobacter* spp. Human pathogenic *E. coli* were detected in raw milk from goats, sheep, buffaloes and yaks, and caused several outbreaks linked to the consumption of raw goat milk. The relative high number of VTEC outbreaks can be explained by the low infective dose. *Campylobacter* spp. were detected in raw sheep milk and also caused several outbreaks linked to the consumption of raw goat milk. The infective dose of *Campylobacter* spp. can be as low as 500 cells, but this varies according to several factors (Lampel, Al-Khaldi, & Cahill, 2012). Also, human pathogenic *E. coli* and *Campylobacter* spp. are considered as the main microbiological hazards of raw cow milk, together with *Salmonella* spp. (Claeys et al., 2013). Other important microbiological hazards are the TBEV and *Brucella* spp. The TBEV was found in relatively high frequencies of occurrence in raw goat and sheep milk, and caused several outbreaks (one of which was relatively large) that were all linked to the consumption of raw goat milk. The TBEV is especially an important microbiological hazard when the goats and sheep are exposed to ticks carrying this virus. After parasitisation by the tick, the TBEV enters the blood stream of the goat or sheep and the virus is excreted in the milk (Balogh et al., 2010). *Brucella* spp. also caused several outbreaks linked to the consumption of raw goat milk and raw camel milk. This pathogen is an important microbiological hazard for raw milk from animals that live in countries that are not free of brucellosis, e.g., in countries were raw camel milk is consumed.

Based on the available information, the other human pathogenic microorganisms that were described in Sections 3 and 4 would most probably be relatively less important microbiological hazards associated with raw milk. *Salmonella* spp. has been detected in raw sheep milk (Fotou et al., 2011) and raw camel milk (Al-Tofaily & Al rodhan, 2011), but no outbreaks were reported. However, this pathogen is one of the main microbiological hazards in raw cow milk (Claeys et al. 2013). *L. monocytogenes* has been detected in raw goat, sheep and buffaloe milk, but no outbreaks were reported. This can be explained by the relatively high infective dose and the fact that the growth in raw milk is limited due to competition with commensal flora, whereby the pathogen cannot reach sufficient numbers to cause human illnesses. High numbers of *L. monocytogenes* in milk can nevertheless occur when infected animals secrete this bacterium directly in their milk. Those animals can present distinctive clinical signs or can be asymptomatic shredders (Delhalle et al., 2012).

St. aureus has been found in raw milk from goats, sheep, horses and donkeys, but not much is known about the frequency of occurrence of enterotoxin-producing strains. However, Scherrer et al. (2004) detected enterotoxin genes in 65% of 293 *St. aureus* strains isolated from 293 raw goat and sheep samples. Outbreaks of *St. aureus* enteroxins are rare, because the bacteria must be present at high levels (e.g., $>10^5$ cfu mL^{-1}) before the produced enterotoxins can cause intoxications in humans. This is unlikely, given the fact that the raw milk spoils quickly before a sufficient number of this pathogenic microorganism can be reached (Lampel et al., 2012).

B. cereus has not been reported to be detected in raw goat and sheep milk. If present, this organism would not be able to multiply sufficiently in raw milk before the decay of the milk, to cause infections in humans. The number of organisms most often associated with human illness is 10^5 to 10^8 (Lampel et al., 2012). *Cox. burnetii* was present in raw goat, sheep and camel milk, and caused infections due to the consumption of raw goat milk, but this pathogen is mainly transferred to humans by inhalation and, to a limited extent, by consuming raw milk (Berri et al., 2005).

H. pylori and MAP have been detected in raw milk, but there is uncertainty about the zoonotic nature of both pathogens (Quaglia et al., 2008; Van Brandt, 2011). Only a few rare cases of toxoplasmosis have been reported in Great Britain and the United States, but it is not known if raw milk as transmisseion route is epidemiologically important (Tenter, Heckeroth, & Weiss, 2000). *M. bovis* and human pathogenic *Y. enterocolitica* were less frequently reported to be associated with raw milk.

6. Conclusions

The consumption of raw milk poses a risk to public health via its potential contamination with human pathogenic microorganisms. In this review, the microbiological quality of raw milk from animal species other than cows were assessed by collecting data of total bacterial counts for the different milk sources. The microbiological hazards of these milk sources were collated based on frequencies of occurrence of pathogenic microorganisms in raw milk and reported human cases and outbreaks linked to the consumption of raw milk from animal species other than cows.

To complete the information on the microbiological quality and hazards of raw milk from animals other than cows, additional research would be necessary to determine total bacterial counts and/or systematic prevalences of certain microbiological hazards. Also, more accurate detection methods should be developed for some microbiological species in order to more precisely determine quantities and/or prevalences of these hazards.

In conclusion, consumers should deal carefully with the consumption of all types of raw milk, and, to avoid the risk, should treat the milk (e.g., by heating) before consumption.

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