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Review Article

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A systematic literature review of milk consumption and associated bacterial zoonoses in East Africa

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Abstract

Consumption of unsafe animal-source foods is the major cause of foodborne disease outbreaks in low-income countries. Despite current knowledge of the threat posed by raw milk consumption to human health, people in many countries in East Africa still consume unboiled milk. This literature review explored the association between milk consumption and the occurrence of five milk-borne bacterial zoonoses: brucellosis, salmonellosis, campylobacteriosis, *Escherichia coli* infections, and tuberculosis. A search for literature published up to 1 October 2021 was conducted through the Web of Science, PubMed, and Scopus databases, using Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines. The selection process yielded 65 articles describing studies conducted in East Africa 2010–2021, which were carefully scrutinized. The most investigated pathogen was *Brucella* spp. (54.5%), followed by *E. coli* (18.2%), *Salmonella* spp. (12.1%), *Mycobacterium* spp. (6.1%), and *E. coli* O157: H7 (6.1%). The most common predisposing factors for potential milk-borne disease outbreaks were consumption of contaminated raw milk, inadequate cold storage along the milk value chain, poor milk handling practices, and lack of awareness of the health risks of consuming unpasteurized milk. Thus, a tailor-made training program is needed for all milk value chain actors to enhance the safety of milk sold in informal markets, and a One Health approach should be applied. Future studies should employ more advanced diagnostic techniques and countries in East Africa should invest in modern diagnostic tools and equipment, both in hospitals and in local rural settings where most cases occur.

Keywords: dairy, East Africa, raw milk, foodborne disease, risk factors, food safety

Introduction

Zoonoses are infectious diseases caused by pathogens that spread between humans and animals, with transmission through either direct or indirect contact. The main routes by which humans are infected include animal handling and husbandry, close habitation with livestock or animals, and consumption of contaminated animal products. Consuming undercooked animal-source foods such as meat, milk, and dairy products are a major risk factor for foodborne diseases. Additionally, consuming unboiled milk increases the risk of spread of multidrug-resistant pathogens to humans (Caudell et al. 2018), thus posing a public health concern. Unboiled milk is preferred by certain pastoral communities in East Africa and, this preference is positively linked to increased human infections (Nato et al. 2019, Makala et al. 2020). Raw milk consumption is reported to be the leading factor in transmission of foodborne pathogens through milk and milk products. For example, of 16 reported cases of human campylobacteriosis screened in the USA, 15 were found to have consumed raw milk (Oliver et al. 2009). This high incidence was local, however, as it occurred in one of the few federal states that permit sale of raw milk (Oliver et al. 2009). Otherwise, milk-borne diseases are rarely observed in high-income countries, due to hygienic milk production, pasteurization, low consumption of unprocessed milk, and hygienic food preparation (Nyokabi et al. 2021b).

The past decade has seen rapid development of dairy farming in East African countries. The top six milk-producing countries in Africa now include two from East Africa, namely Kenya, and Ethiopia, with annual milk production of 5 528 900 and 3 644 000 metric tonnes, respectively (FAO 2021). However, this increase in milk production has not been accompanied by changes in cultural behaviors and traditions relating to milk consumption (Prakashbabu et al. 2020), which remain strongly anchored in African communities. Milk is regarded as having important social, cultural, and economic value in many African countries, and its consumption is often governed by traditions and cultures (Ndambi et al. 2008). Some communities are still engaging in risky practices in terms of zoonotic diseases, such as drinking unboiled milk, assisting animal births with bare hands, and living near livestock (Amenu et al. 2019a). Milk processing rates are very low in East Africa, e.g. in Kenya only 15% of milk is processed and the remaining 85% is consumed raw, of which 40% is consumed by farmers and their families (Dolecheck and Bewley 2018).

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Scientific evidence has shown that pasteurization of raw milk kills pathogenic bacteria but does not affect its nutritional values (Macdonald et al. 2011). Pasteurization involves heating food to a specific temperature for a set period of time to inactivate non-spore-forming pathogenic bacteria, to destroy most heat-sensitive bacteria, and extend the shelf life of foods (LeJeune and Rajala-Schultz 2009). The most common method of pasteurization in developing countries is cooking or boiling in the household, which lacks standardization (Murchie 2016). It is thus difficult to effectively eliminate pathogenic bacteria from pasteurized foods, while in developed countries like the USA, high-temperature short-time pasteurization is the most commonly used method (Ahmed and Ramaswamy 2007).

Some factors associated with zoonosis outbreaks have been identified. For example, in Tanzania, assisting an aborting animal, proximity of cattle to residential neighborhoods, and religious beliefs have been found to be associated with brucellosis infection in humans (John et al. 2010). These contributing factors vary from country to country, but most are very common in East Africa. Moreover, several studies have demonstrated that knowledge of some zoonotic diseases is low among communities in low-income countries (Morse et al. 2012, Worsley-Tonks et al. 2022). Additionally, some zoonotic diseases are neglected or confused with febrile illnesses, most of which are confused with endemic malaria, hindering effective diagnosis and treatment, and also prevention (Chipwaza et al. 2014, Carugati et al. 2019). Q fever; an infectious disease caused by *Coxiella burnetii*, remains a neglected zoonosis in many developing countries and this has implications for its management and resurgence (Njeru et al. 2016). Although evidence suggests that Q fever prevalence is relatively low in some African countries, its endemicity requires good human awareness for appropriate control measures (Wardrop et al. 2016). Therefore, it is very important to raise awareness among communities and health service providers about the burden and management of zoonotic diseases (Zhang et al. 2016).

Studies conducted specifically in East Africa have shown a trend for brucellosis, tuberculosis, and Q fever outbreaks in pastoralist communities (Cavalerie et al. 2021). In knowledge, attitude, and practices (KAP) studies on dairy farmers regarding zoonotic diseases, a correlation has been found between farmers' behavior and an increase in zoonotic disease incidence (Amenu et al. 2019b, Prakashbabu et al. 2020, Nyokabi et al. 2021b). Several recommendations for control programs for major zoonotic diseases in East Africa have been formulated (Cavalerie et al. 2021), including enhancing national research agendas and promoting the One Health approach. Prevention of bacterial zoonoses is a key component of future agricultural policies that could be implemented to reduce the health and economic burden of these diseases on the local community members in East Africa. Therefore, this review focused on the relationship between milk consumption and occurrence of bacterial zoonoses in East Africa and particularly on risk factors associated with the occurrence of important milk-borne bacterial zoonoses [brucellosis, salmonellosis, campylobacteriosis, *Escherichia coli* infections, tuberculosis, and some neglected zoonoses (Q fever)] in humans consuming unsafe raw cow milk and other predisposing factors. The analysis addressed the following research question: "What are the most prevalent zoonoses, and what is the relationship between milk consumption and occurrence of these bacterial zoonoses in East African countries?"

Materials and methods

Study design

A systematic review was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Fig. 1).

Search strategy

An initial review of the literature was conducted through a search in databases such as Web of Science, PubMed, and Scopus for all relevant and recent articles published from 2010 to 2021 on milk quality and bacterial zoonoses (brucellosis, campylobacteriosis, *E. coli*, Q fever, salmonellosis, and tuberculosis) in seven East African countries (Burundi, Ethiopia, Kenya, Rwanda, South Sudan, Tanzania, and Uganda). Since the search strategies involved complex combinations, milk-related terms (e.g. cow milk, milk quality, and milk contamination), disease-specific names, and finally country, search strings were systematically constructed. Disease-specific search strings were formed using a combination of scientific disease name (e.g. tuberculosis), and agent name (e.g. *Mycobacterium*), combined using the Boolean operator, 'OR'. Additionally, the Boolean operator 'AND' was used to combine milk-related terms to zoonotic diseases and specific countries. The following search terms, combined with Boolean operators, were used to conduct the literature review: cow milk, milk product, milk consumption, milk contamination, milk quality, bacterial zoonosis, zoonos∗, tuberculosis, *Mycobacterium*, *Brucell*∗, *Salmonell*∗, *Campylobact*∗, *E. coli*, *E. coli*, and Country. When a relevant publication was identified, the reference list was examined to identify additional relevant publications. Search hits were exported to Endnote, combined into one library, and scanned for duplicates using methods described previously (Bramer et al. 2016). A manual check was performed to confirm the relevance of the final set of papers.

Selection of studies and data extraction

For this review, only papers published in English were considered. Apart from that, cross-sectional, longitudinal, and cohort studies were considered eligible. Articles involving milk consumption and prevalence of zoonotic infections in humans were considered eligible. Additionally, KAP studies were included to obtain relevant information on risk factors associated with zoonotic disease outbreaks in the study area, but meta-analysis papers were not included (Fig. 1). Papers with titles and/or abstracts that were not pertinent to the current research interest were excluded. The last search was made on 1 October 2021. All searches were conducted independently by two authors (J.P.M. and M.A.M.), and disagreements were resolved by consensus or by consultation with a third author (J.B.N.). The following data were extracted from the original articles: (1) country of publication; (2) year of publication; (3) zoonose occurrence; (4) type of study (cross-sectional, KAP); (5) source of pathogens/data; and (6) name of authors.

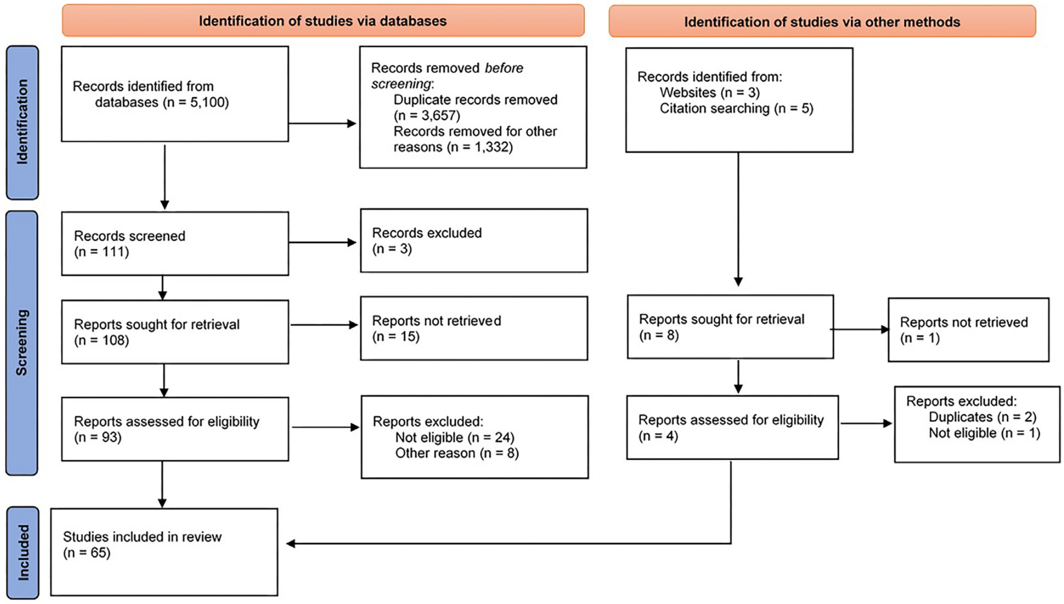

Figure 1. PRISMA flow diagram showing the number of papers retained in different stages of the literature search. The final selection of papers to be included in the review was done by considering both country and type of databases.

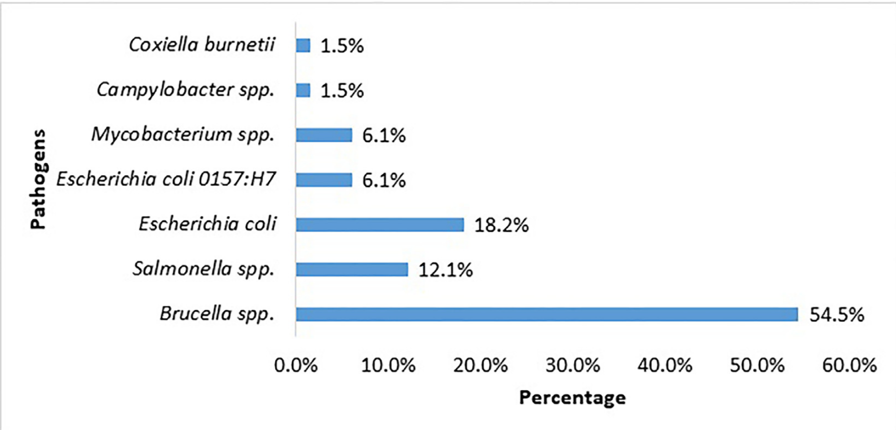

Figure 2. Distribution of different pathogens studied in published papers for countries in East Africa (2010–2021).

Results

A review of the selected papers revealed that the most investigated pathogen was *Brucella* spp. (54.5%), followed by *E. coli* (18.2%), *Salmonella* spp. (12.1%), *Mycobacterium* spp. (6.1%), and *E. coli* O157: H7 (6.1%) (Fig. 2). The least studied pathogens were *C. burnetii* and *Campylobacter* spp. (both 1.5%). Regardless of the country, brucellosis was the most studied disease in East Africa. Among the selected countries, Uganda and Tanzania had the highest number of publications on brucellosis [27.8% and 25.0% ($n = 36$), respectively], while Burundi had the lowest number (2.8%) (Table 1).

In terms of study type, cross-sectional studies were predominant (72.2%), while KAP studies only represented 11% of all studies included in the review. Only five case controls and one cohort study were considered eligible due to their target population and descriptive findings. Overall, studies on humans, raw milk, livestock-humans, and livestock represented 41.6%, 19.4%, 19.4%, and 16.7% of the total, respectively (Table 2).

Studies on both pathogenic and commensal *E. coli* were included in the dataset (Table 3). Out of 15 articles retrieved, 26.6% (4/15) described pathogenic *E. coli* O157: H7 serotype, while 66.6% (10/15) reported on other *E. coli* strains in general. Most of the studies on *E. coli* O157: H7 were carried out in Ethiopia (3/4), with only one in Tanzania. All these studies were cross-sectional (100%) in nature, and the majority of bacteria were isolated from raw cow milk (80%). Irrespective of the *E. coli* serotype studied, Ethiopia accounted for the majority (46.6%) of the papers retrieved, followed by Kenya (26.6%), Tanzania (13.3%), Rwanda (6.6%), and Uganda (6.6%), while no articles were found for Burundi and South Sudan.

In total, seven articles on *Salmonella* spp. were included in the dataset, all from four countries (Table 4). The majority of these studies were cross-sectional (85.7%), with only one longitudinal study (14.3%). Most were carried out in Ethiopia (42.8%), followed by Rwanda (28.6%), while only one

Table 1. Number of publications per pathogen and country.

Country	*Brucella* spp.	*Salm.* spp.	*E. coli*	*E. coli* 0157:H7	*Mycob.* spp.	*Camp.* spp.	*C. burnetii*	Total
Burundi	1	0	0	0	0	0	0	1
Ethiopia	5	4	4	3	1	0	0	17
Kenya	5	0	4	0	0	0	1	10
Rwanda	2	2	1	0	0	0	0	5
South. Sudan	4	0	0	0	1	0	0	5
Tanzania	9	1	2	1	0	1	0	14
Uganda	10	1	1	0	2	0	0	14
Total	36	8	12	4	4	1	1	66

Salm., Salmonella; *E. coli, Escherichia coli*; *Mycob., Mycobacterium*; *Camp., Campylobacter*.

article was retrieved for Tanzania (14.3%) and one for Uganda (14.3%).

Analysis of the dataset revealed that KAP studies accounted for 58.8% (10/17) and studies on risk factors 35.2% (6/17) (Table 5). Regardless of the type of zoonotic disease investigated, most studies were carried out in Kenya (35.2%), followed by Uganda (23.5%), while Ethiopia and Tanzania each accounted for 17.6%, and only one study was carried out in South Sudan (5.8%). No studies were retrieved for the remaining two East African countries considered (Burundi and Rwanda). Different laboratory techniques were used to isolate, identify, and characterize selected bacteria, ranging from standard microbiological methods to molecular diagnostic techniques (Table 6).

Discussion

In the selected dataset, brucellosis was the most frequently investigated of prevalent zoonotic diseases in East Africa. The analysis revealed some discrepancies between the diagnostic methods used, which suggests underestimation of the true prevalence rates of the zoonotic pathogens investigated and their relationship to the milk consumption patterns. It also revealed that consumption of unpasteurized milk, lack of knowledge about zoonotic diseases, and poor milk handling were associated with the occurrence of zoonotic bacterial infections. In low- and middle-income countries, the burden of foodborne disease is disproportionately high and originates from many food sources (Havelaar et al. 2022), and their effects may be acute or chronic in nature. Evidence from various studies indicated a positive association between milk consumption and the risk of contracting bacterial zoonoses in Africa (Kazoora et al. 2016, Dadar et al. 2019, Nyokabi et al. 2021). Conventionally, raw milk is boiled before consumption (Fusco et al. 2020), but some African communities do not boil milk owing to traditional and cultural beliefs, including that "if you boil milk you will provoke udder inflammation in the cows that produced the milk" (Prakashbabu et al. 2020). While boiling milk greatly reduces the presence of most bacteria (Tremonte et al. 2014), it is possible for milk to be re-contaminated due to poor storage and handling practices. In fact, one study found no statistically significant difference between the levels of bacterial contamination in raw and boiled milk (Häsler et al. 2014). Locally processed milk and milk products could potentially pose a risk to consumers, possibly due to inadequate cooling chain, poor processing, and/or handling practices when serving customers. This risk was confirmed by findings in a study where human brucellosis seroprevalence was higher among people consuming locally processed milk products (OR 2.54, 95% CI 1.12–5.78) (Tumwine et al. 2015).

Brucellosis

Although both animals and humans are at high risk of contracting brucellosis, a comparative study of humans and livestock in Kenya revealed that the seroprevalence was two-fold higher in animals than in humans living in the same pastoral community (Osoro et al. 2015). Reported seroprevalence rates of *Brucella* spp. isolated from raw milk varied by country, with the highest rate recorded in Tanzania (Swai and Schoonman 2011) and the lowest in Uganda (Makita et al. 2010). Interestingly, similar findings on human brucellosis were reported in studies on pastoral communities in Tanzania (Asakura et al. 2018a) and on pregnant women living close to wildlife and livestock areas who suffered abortions in association with some predisposing factors to brucellosis (Assenga et al. 2015, Bodenham et al. 2020, Makala et al. 2020, Ntirandekura et al. 2020). Other studies have found that consuming unboiled raw milk (Nasinyama et al. 2014) and living in proximity to livestock (Asiimwe et al. 2015, Tumwine et al. 2015) are strongly associated with occurrence of human brucellosis. A study in Kenya concluded that consumption of unpasteurized milk, handling infected aborted materials without protection, and consuming raw meat and raw blood were potential routes of exposure to brucellosis and other zoonoses (Onono et al. 2019). Another study reported that 79.5% of nomadic pastoralists participate in risky practices for human brucellosis, e.g. drinking unboiled milk showed a positive correlation with *Brucella* spp. seroprevalence (68.2%) (Njenga et al. 2020). Majalija et al. (2018) found that 14% of respondents reported drinking raw milk, of which 46.4% were seropositive to *Brucella abortus*, compared with 1.2% seropositive among those who did not drink raw milk. They also found a significant association between consuming raw milk and seroprevalence of *B. abortus* (OR 2.162, 95% CI 0.021–1.379), while other risk factors did not show any significant correlation (Majalija et al. 2018). Other studies observed a similar pattern where seroprevalence of human brucellosis was positively associated with raw milk consumption (OR 406.15, 95% CI 47.67–3461.69) (Migisha et al. 2018) or consumption of unpasteurized milk ($P = .023$; OR 2.57; 95% CI 1.14–5.80) (Muloki et al. 2018).

Low education level coupled with lack of other sources of income were reported to leave the communities concerned with no choice but to engage in risky milk consumption practices (Njenga et al. 2020). Many studies showed that economic

Table 2. Studies on livestock and human brucellosis in East Africa (2010–2021).

Country	Prevalence rate	Type of study	Source of pathogens/data	Reference(s)
Burundi				
	14.7% (95% CI 9.4%–20.8%)	Cross-sectional	Dairy cattle	Musallam et al. (2019)
Ethiopia				
	2.4% (95% CI 1.4%–3.7%) in cattle 2.6% (95% CI 1.2%–5%) in humans	Cross-sectional	Ruminants and pastoralists	Edao et al. (2020)
	3.0% in cows and 2.4% in humans	Cross-sectional	Livestock and humans	Lakew et al. (2019)
	31.5% (95% CI 27.4%–36.0%)	Cross-sectional	Humans	Mehari et al. (2021)
	NA	KAP study	Farmers	Legesse et al. (2018)
	3.5% (95% CI 2.4%–4.5%)	Cross-sectional	Cattle	Megersa et al. (2011)
Kenya				
	15.4% (95% CI 12.0%–19.5%)	Cross-sectional	Humans	Kiambi et al. (2020)
	OR 7.7 (95% CI 1.5–40.1)	Case-control	Humans/unboiled milk	Muturi et al. (2018)
	NA	KAP Study	Livestock and humans	Njenga et al. (2020)
	NA	Cross-sectional and case-control	Raw milk	Onyango et al. (2021)
	16% in animals and 8% in humans	Cross-sectional	Livestock and humans	Osoro et al. (2015)
Rwanda				
	19.7% (95% CI 15.5%–24.4%)	Cross-sectional	Raw milk	Djangwani et al. (2021)
	25%	Cross-sectional	Humans	Rujeni and Mbanzamihigo (2014)
South Sudan				
	NA	Case-control	Humans	Lado et al. (2012)
	31% (95% CI 28.0%–34.2%) in cattle and 33.3% (23.9%–44.3%) in herders	Cross-sectional	Cattle and herders	Madut et al. (2018a)
	23.3% (97/416)	Cross-sectional	Humans	Madut et al. (2018b)
	27.2% (95% CI 23.9%–30.6%)	Cross-sectional	Humans	Madut et al. (2019)
Tanzania				
	44.4% (55/124, 95% CI 35.5%–53.5%)	Cross-sectional	Cattle	Asakura et al. (2018a)
	7.0% (28/673, 95% CI 5.7%–8.4%)	Cross-sectional	Cattle	Asakura et al. (2018b)
	0.6% (95% CI 0.1–2.1%) in humans and 6.8% (95%CI: 5.4%–8.5%) in cattle	Cross-sectional	Livestock, wildlife, and humans	Assenga et al. (2015)
	NA	Case-control	Livestock	Assenga et al. (2016)
	6.10%	Cross-sectional	Humans	Bodenham et al. (2020)
	10.9% (34/313)	Cross-sectional	Humans	Makala et al. (2020)
	NA	KAP study	Local community	Mburu et al. (2021)
	21% (95% CI 12.5%–32%) in women and 5% (95% CI 3.1%–8%) in ruminants	Cohort	Livestock and humans	Ntirandekura et al. (2020)
	56%	Cross-sectional	Raw cow milk	Swai and Schoonman (2011)
Uganda				
	NA	Case-control	Pastoralists	Asiimwe et al. (2015)
	26.5% (49/185)	Cross-sectional	Raw cow milk	Asiimwe et al. (2015)
	NA	KAP study	Pastoralists	Kansiime et al. (2014)
	7.5% ($n = 200$)	Cross-sectional	Humans	Majalija et al. (2018)
	12.6% (90% CI 6.8%–18.9%)	Risk assessment	Raw cow milk	Makita et al. (2011)
	14.9% (95% CI 10.6%–20.1%)	Cross-sectional	Humans	Migisha et al. (2018)
	18.70%	Cross-sectional	Humans	Muloki et al. (2018)
	5.8% (95% CI 3.3%–8.3%) in farmers and 9% (95% CI 13.3%, 4.7%) in milk consumers	Cross-sectional	Cattle farmers and consumers	Nasinyama et al. (2014)
	25.50%	Cross-sectional	Raw cow milk	Rock et al. (2016)
	17.0% ($n = 235$)	Cross-sectional	Humans	Tumwine et al. (2015)

NA, not available/applicable.

Table 3. Studies on *E. coli* spp., including *E. coli* O157: H7, in East Africa (2010–2021).

Country	Prevalence rate (%)	Type of study	Source of pathogens/data	Reference(s)
Ethiopia				
	5.2% (*E. coli* O157:H7)	Cross-sectional	Raw cow milk	Ababu et al. (2020)
	2.5% (*E. coli* O157:H7) 51.7% (*E. coli*)	Cross-sectional	Ready to consume milk	Amenu et al. (2019a)
	2.9% (*E. coli* O157:H7)	Cross-sectional	Raw cow milk	Disassa et al. (2017)
	33.9% (*E. coli*)	Cross-sectional	Raw cow milk	
	58% (*E. coli*)	Cross-sectional	Raw cow milk	Reta et al. (2016)
	29.6% (*E. coli*)	Cross-sectional	Raw and pasteurized cow milk	Garedew et al. (2012)
	NA (*E. coli*)	Cross-sectional	Raw cow milk	Berhe et al. (2020)
Kenya				
	66.7% (*E. coli*)	Cross-sectional	Unpasteurized milk	Brown et al. (2020)
	25% in cow milk and 32% in camel milk (*E. coli*)	Cross-sectional	Cow milk and camel milk	Nato et al. (2019)
	13.8% (*E. coli*)	Cross-sectional	Raw cow milk	Ngaywa et al. (2019)
	42.4% (*E. coli*)	Cross-sectional	Raw cow milk	Nyokabi et al. (2021a)
Rwanda				
	8.5% (*E. coli*) at farm level 62.5% (*E. coli*) at MCC level	Cross-sectional	Raw cow milk	Ndahetuye et al. (2020)
Tanzania				
	66% (*E. coli*)	Cross-sectional	Raw cow milk	Ngasala et al. (2015)
	10.1% (*E. coli* O157:H7)	Cross-sectional	Raw cow milk and milk products	Schoder et al. (2013)
Uganda				
	12% (*E. coli*)	Cross-sectional	Raw cow milk	Majalija et al. (2020)

NA, not available/applicable.

Table 4. Studies on *Salmonella* spp. in East Africa (2010–2021).

Country	Prevalence rate (%)	Type of study	Source of pathogens/data	Reference(s)
Ethiopia				
	6%	Cross-sectional	Raw milk	Ejo et al. (2016)
	6.3%	Longitudinal	Raw milk	Geresu et al. (2021)
	3.3%	Cross-sectional	Raw milk	Reta et al. (2016)
Rwanda				
	5.2%	Cross-sectional	Raw milk	Kamana et al. (2014)
	14%	Cross-sectional	Raw milk	Ndahetuye et al. (2020)
Tanzania				
	10.1%	Cross-sectional	Raw milk and milk products	Schoder et al. (2013)
Uganda				
	5%	Cross-sectional	Raw cow milk	Majalija et al. (2020)

insecurity and culture are positively associated with engagement in risky food practices (James et al. 2014, Kopetz et al. 2014, Cheng et al. 2016). Education is important to prevent the spread of disease in such communities, e.g. 33.3% seroprevalence to *B. abortus* was found among those with no formal education in Uganda (Majalija et al. 2018) and poor community knowledge of brucellosis was shown to be significantly associated with human brucellosis seroprevalence and risky practices such as drinking raw milk (17.6%, $P < .01$) and blood (35.3%, $P < .01$) (Asakura et al. 2018b). In some low-income settings, cultural beliefs are a constraint to education. For example, Maasai communities in Tanzania were found to rate education less highly than other communities in that country, and are thus more likely to employ more risky practices for human brucellosis infection, such as drinking raw milk ($P = .06$) or blood ($P < .01$) and helping calf delivery with bare hands ($P = .03$) than other tribes (Asakura et al. 2018a). Other studies suggested that community knowledge about the zoonotic nature of brucellosis is not positively associated with a decrease in use of risky practices by community members. Legesse et al. (2018) conducted a KAP study on human brucellosis and found that the majority (89.3%) of interviewed farmers had good knowledge of brucellosis but still consumed unpasteurized milk. Lack of knowledge about brucellosis among community members is a predisposing factor to human brucellosis (Mburu et al. 2021). It is possible that there may be perpetual transmission of brucellosis to humans from raw milk consumption in these communities, due to increased malpractices. These findings emphasize the need for awareness campaigns and training programs for smallholder dairy farmers in order to foster behavioral change and improve milk quality along the whole value chain.

Table 5. KAP studies and risk factors associated with milk-borne bacterial zoonoses identified in East Africa (2010–2021).

Country	Milk-borne diseases of interest/pathogen	Type of study	Target population	Reference(s)
Ethiopia				
	Brucellosis	KAP study	Farmers	Legesse et al. (2018)
	Salmonella spp.	Quantitative risk assessment	Raw milk	Weldeabezgi et al. (2020)
	Bovine tuberculosis	Cross-sectional	Cattle	Kemal et al. (2019)
Kenya				
	C. burnetii (Q fever)	KAP study	Residents	Ndeereh et al. (2016)
	Brucella spp.	KAP study	Nomadic pastoralists and non-pastoralists	Njenga et al. (2020)
	Zoonotic diseases	KAP study	Informal value chain actors	Nyokabi et al. (2018)
	N/A	KAP study	Farmers	Nyokabi et al. (2021b)
	Brucellosis	KAP study	Farmers	Onono et al. (2019)
	Brucellosis	Cross-sectional and case-control	Pastoral communities	Onyango et al. (2021)
South Sudan				
	Brucellosis	Case-control	Humans	Lado et al. (2012)
Tanzania				
	E. coli	Cross-sectional	Humans	Caudell et al. (2018)
	Brucellosis	KAP study	Local community	Mburu et al. (2021)
	Zoonoses	KAP study	Local community	Swai et al. (2010)
Uganda				
	Brucellosis	Case-control	Pastoralists	Asiimwe et al. (2015)
	Human brucellosis	KAP study	Local community	Majalija et al. (2018)
	Brucellosis	KAP study	Pastoralists	Kansiime et al. (2014)
	Human tuberculosis	Cross-sectional	Livestock and humans	Meisner et al. (2019)
	Mycobacterium spp.	KAP study	Cattle farmers	Kazoora et al. (2016)

Campylobacter spp.

Isolation and identification of *Campylobacter* spp. are difficult due to its long incubation period and special culture requirements, such as microaerobic conditions (Brandl et al. 2004), which makes it difficult to study. Only one study on *Campylobacter* spp., in raw milk from East Africa (Kashoma et al. 2016), was included in this review. That study found that 13% of the sampled raw milk contained different *Campylobacter* species. In contrast, studies in developed countries show that *Campylobacter* species are highly frequently isolated from raw milk and are associated with campylobacteriosis in humans. For example, Del Collo et al. (2017) detected *Campylobacter* spp. at 46% of bulk tank milk samples from US dairies, while a follow-up study of a milk-borne campylobacteriosis outbreak in Finland revealed persistent *C. jejuni* contamination of bulk tank milk for several months (Jaakkonen et al. 2020). Further, a retrospective cohort study conducted in England revealed a positive correlation between campylobacteriosis outbreaks in humans and consumption of unpasteurized milk (Kenyon et al. 2020). These findings suggest that raw milk is likely to be contaminated with pathogenic *Campylobacter* spp. and, if consumed, could pose a potential human health risk.

Escherichia coli

Escherichia coli is a gram-negative, rod-shaped, facultative anaerobic bacterium. Most *E. coli* strains are non-pathogenic and colonize the gastrointestinal tract of both animals and humans, but some strains have become very pathogenic through genetic evolution (Kaper et al. 2004). The most frequently isolated pathogenic *E. coli* is the enterohemorrhagic *E. coli* (EHEC) serotype O157: H7 (Shridhar et al. 2017). Since cattle are the natural reservoir of *E. coli* O157: H7 and between 1% and 50% of healthy cattle carry and shed *E. coli* O157: H7 in their feces (Cho et al. 2006), raw milk contamination can occur during milk handling. Some of the studies reviewed suggested that the presence of *E. coli* bacteria in raw and pasteurized milk is associated with poor and unhygienic milk handling practices, fecal contamination, higher environmental contamination, and poor storage conditions (Ngasala et al. 2015; Reta et al. 2016). Other studies reported that *E. coli* is frequently detected at milk collection center (MCC) level, possibly due to bacterial contamination by workers and equipment used in milk storage (Ndahetuye et al. 2020). The presence of *E. coli* O157: H7 bacteria in raw milk is a global public health concern. In Africa, the risk of *E. coli* O157: H7 outbreaks is highly associated with raw milk consumption. Moreover, a study in Tanzania found that consumption of raw milk was associated with an increased probability of carrying multidrug-resistant *E. coli* strains, which was most likely connected to scarcity of potable water and to the informal sales channels for raw milk that prevail in low-income countries operating outside national quality control standards and regulations (Caudell et al. 2018). In the USA, researchers have found a positive correlation between *E. coli* O157: H7 outbreaks and consumption of raw cow milk (Denny et al. 2008). Similar findings have been reported in Brazil (Cerva et al. 2014).

Salmonella spp.

In the set of papers reviewed, presence of *Salmonella* spp. in raw milk was significantly associated with poor hygiene practices at farm level (Ndahetuye et al. 2020) or poor milk handling practices by traders due to lack of adequate training (Schoder et al. 2013). Similarly, findings in Uganda suggest that the main sources of *Salmonella* spp. in raw milk can be grouped into poor hygiene, handling, and transporta-

Table 6. Diagnostic techniques used in isolating and identifying zoonotic pathogens.

Pathogens	Laboratory method	Number of references	Reference(s)
Brucella spp.	Milk ring test (*only*)	1	Swai and Schoonman (2011)
	Milk ring test and ELISA	1	Kamwine et al. (2017)
	ELISA (*only*)	9	Makita et al. (2010), Muloki et al. (2018), Muturi et al. (2018), Asakura et al. (2018a), Madut et al. (2019), Musallam et al. (2019), Djangwani et al. (2021), Osoro et al. (2015), and Rock et al. (2016)
	Rose Bengal (*only*)	1	Rujeni and Mbanzamihigo (2014)
	Rose Bengal and ELISA	5	Asakura et al. (2018b), Assenga et al. (2015), Edao et al. (2020), Madut et al. (2018a), and Makala et al. (2020)
	Rose Bengal and any other test (complement fixation, culture, agglutination, fluorescence polarization)	5	Megersa et al. (2011), Tumwine et al. (2015), Migisha et al. (2018), Makala et al. (2020), and Ntirandekura et al. (2020)
	Rose Bengal, agglutination, and ELISA	1	Madut et al. (2018b)
	Agglutination (*Only*)	2	Asiimwe et al. (2015) and Majalija et al. (2018)
	Agglutination and ELISA	1	Nasinyama et al. (2014)
	PCR (*only*)	1	Kiambi et al. (2020)
	Culture and PCR	1	Bodenham et al. (2020)
Campylobacter spp.	Multiplex PCR	1	Kashoma et al. (2016)
E. coli	Standard microbiological techniques (culture, biochemical tests, and microscopic examination)	12	Caudell et al. (2018), Amenu et al. (2019b), Ababu et al. (2020), Berhe et al. (2020), Brown et al. (2020), Garedew et al. (2012), Nato et al. (2019), Majalija et al. (2020), Ndahetuye et al. (2020), Nyokabi et al. (2021b), Reta et al. (2016), and Gwandu et al. (2018)
	Standard microbiological techniques confirmed by PCR and sequencing	1	Ngaywa et al. (2019)
	Viable counts (TBC, TCC)	2	Schoder et al. (2013) and Ngasala et al. (2015)
Salmonella spp.	Standard microbiological techniques (culture, biochemical tests, and microscopic examination)	6	Kamana et al. (2014), Ejo et al. (2016), Majalija et al. (2020), Ndahetuye et al. (2020), Geresu et al. (2021), and Reta et al. (2016)
	Viable counts (TBC, TCC)	1	Schoder et al. (2013)
Mycobacterium spp.	Ziehl–Neelsen (ZN) and fluorescence microscopy (FM)	1	Boyong et al. (2018)
	Tuberculosis skin test (TST)	1	Meisner et al. (2019)

ELISA, enzyme-linked immunosorbent assay; PCR, polymerase chain reaction; TBC, total bacteria count; and TCC, total coliform count.

tion practices (Majalija et al. 2020). However, Reta et al. (2016) observed a more complex contamination process that included all critical control points along the raw milk value chain, resulting in an increase in total bacterial counts from the start (12% on-farm) to the end (42.9% at the point of sale) of the value chain. Similarly, a study in Rwanda found that *Salmonella* spp. isolation rate was much lower (5.2%) at farm level than in milk shops (21.4%) (Kamana et al. 2014). In that study, the high isolation rate at milk shops was tentatively attributed to poor handling and unhygienic practices by the personnel (Kamana et al. 2014). However, contradictory findings were made by Ndahetuye et al. (2020), who recovered no *Salmonella* spp. in milk samples from MCC, whereas a significant proportion (14.0%) of milk samples from farms showed presence of *Salmonella* spp. This difference could have been due to the dilution effect resulting in undetectable levels of *Salmonella* spp. in milk samples from MCC (Ndahetuye et al. 2020). This is supported by the fact that MCCs have cold chain infrastructure that reduces growth of microorganisms and improves milk quality (Demirbaş et al. 2009, O'Connell et al. 2017), in contrast to direct sales from farms.

Tuberculosis

Tuberculosis (TB) is a leading zoonotic infectious cause of human death worldwide, which is transmitted to humans through consumption of raw, unpasteurized or contaminated milk, dairy products and other animal products (Kazoora et al. 2016). Two studies dealing with perceptions of the local communities and risk factors associated with the occurrence of TB in humans were included in this review (Kazoora et al. 2016, Meisner et al. 2019). The two studies revealed that local communities engage in predisposing risk practices such as consuming raw milk, consuming dairy products from raw milk, living in proximity with livestock among others (Kazoora et al. 2016, Meisner et al. 2019). It was also reported that the majority of study respondents have very low knowledge and poor practices regarding zoonotic aspect of TB (Meisner et al. 2019). It is important to note that despite the knowledge about TB, many people still consume raw milk as a necessity due to lack of time or resources to properly pasteurize milk before consumption (Kazoora et al. 2016). This poor practice is also associated with low education level and living in low-resource settings (Njenga et al. 2020).

Q fever

Q fever is an emerging zoonotic disease caused by an intracellular bacterium *C. burnetii* (Porter et al. 2011). *Coxiella burnetii* is transmitted to humans through direct contact, inhalation of contaminated aerosols, or by consuming contaminated animal products, mainly unboiled milk (Celina and Cerný 2022). Only one article investigating the knowledge, attitudes, and practices about Q fever and rickettsioses were included in this review (Ndeereh et al. 2016). The study revealed that the local communities have no knowledge about Q fever, while only 9.1% of health providers know about the disease (Ndeereh et al. 2016). This low knowledge among health providers could be justified by the fact that Q fever is poorly diagnosed in low and middle-income countries, and the disease is worldwide considered a neglected and re-emerging zoonotic disease (Ullah et al. 2022). It is currently known that ingestion of contaminated raw milk poses a low risk of contracting Q fever since the oral route is reported to be a less efficient way of transmission (Arricau-Bouvery and Rodolakis 2005). Despite this low probability of transmission, we recommend special attention to reducing exposure to raw milk for at risk people (young children, old people, pregnant women, patients with cardiac pathology, or immunosuppressed) and promoting consumption of pasteurized milk and its products to decrease the prevalence of Q fever.

Investigation methods

Scrutiny of the investigation methods used in the articles included in this review revealed that cross-sectional study was the most common method used. This method has scientific limitations when assessing temporal variations and the causal effect of independent variables on the response variable (Wang and Cheng 2020). However, the trends in the dataset revealed a common pattern of prevalence of the investigated diseases or pathogens in all selected countries, confirming the validity of the results. Laboratory diagnostic methods used in the papers included rapid tests, conventional microbiological techniques, and enzymatic techniques coupled with molecular diagnosis. However, the laboratory methods employed in many studies resulted in some data gaps. For example, Kamwine et al. (2017) found that the milk ring test for brucellosis identification had lower sensitivity (85%) and specificity (95.5%) than the indirect enzyme-linked immunosorbent assay (sensitivity 98.5%, specificity 99.5%). They concluded that the presence of *Brucella* spp. antibodies in milk could not be associated with a current infection in lactating cows, and recommended a field study to confirm the source of the antibodies in raw milk (Kamwine et al. 2017). Most ELISA methods do not report the current infection and sometimes detect some immunoglobulins (Ig) and not others (Osoro et al. 2015). Similarly, a study on patients presenting with febrile illnesses and seeking healthcare services in Kenya found that the febrile brucella plate agglutination test, which is commonly used in hospitals, had low diagnostic performance compared with real-time polymerase chain reaction, with estimated sensitivity of only 36.6% (95% CI 24.6%–50.1%) and specificity of 69.3% (95% CI 64.0%–74.3%) (Kiambi et al. 2020). Additionally, identification and differentiation of mycobacteria belonging to the *Mycobacterium tuberculosis* complex could have provided evidence of their zoonotic nature and their transmission in humans. These discrepancies in diagnostic methods result in underreporting of many zoonotic diseases in low-income countries, due to lack of adequate diagnostic capability (Ndeereh et al. 2016). Finally, access to improved diagnostic tools and equipment in low- and middle-income countries is very difficult due to insufficient funding allocated to disease diagnosis, lengthy procurement processes, to cite a few (Yadav et al. 2021).

Conclusions

Overall, this review revealed potential health risks to raw milk consumers in East Africa. There is sufficient evidence to show that milk-borne bacterial infections in East African countries are associated with consumption of contaminated raw milk, which is common practice in many East African counties. Inadequate cold chain conditions along the milk value chain, poor milking practices, and lack of awareness of the health risks of consuming unpasteurized milk further predispose milk consumers to the risk of contracting milk-borne diseases, as do lack of infrastructure, inadequate boiling, and recontamination of boiled milk due to poor storage conditions and handling practices. However, the findings should be interpreted with caution because most of the articles reviewed described cross-sectional studies that could not provide clear evidence on the persistent exposure of consumers to contaminated raw milk. Therefore, further studies involving isolation and identification of pathogenic bacteria in milk are needed to identify zoonotic risk factors associated with raw milk consumption.

Only papers published in English were included in the review, which may explain why there were few articles from Rwanda (a bilingual country) and Burundi (a French-speaking country). In addition, Rwanda and Burundi are smaller than other East African countries from which many publications were retrieved. However, the findings are still generalizable to those two countries. In fact, since similar findings were found for different countries at different times, the conclusions on associations between risk factors and the occurrence of zoonotic infections are likely to be valid. Considering the limitations in diagnostic methods used in some of the studies reviewed, it is obvious that the true prevalence rates of these zoonotic diseases might be higher than reported. Therefore, further livestock and human studies using advanced investigation methods are needed. Additionally, East African countries need to invest in modern diagnostic tools and equipment, in hospitals and especially in local rural settings. Greater access to these tools should be supported to improve surveillance and control programs for both humans and animals. Finally, a tailor-made training program for all milk value chain actors should be implemented to improve the safety of milk sold via informal channels and a One Health approach should be applied.

Conflict of interest

The authors declare that there are no commercial or financial relationships that could be construed as a potential conflict of interest.

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Author contributions

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Data availability

The authors declare that all data supporting the findings of this study are available within the article (Tables 1–6).

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