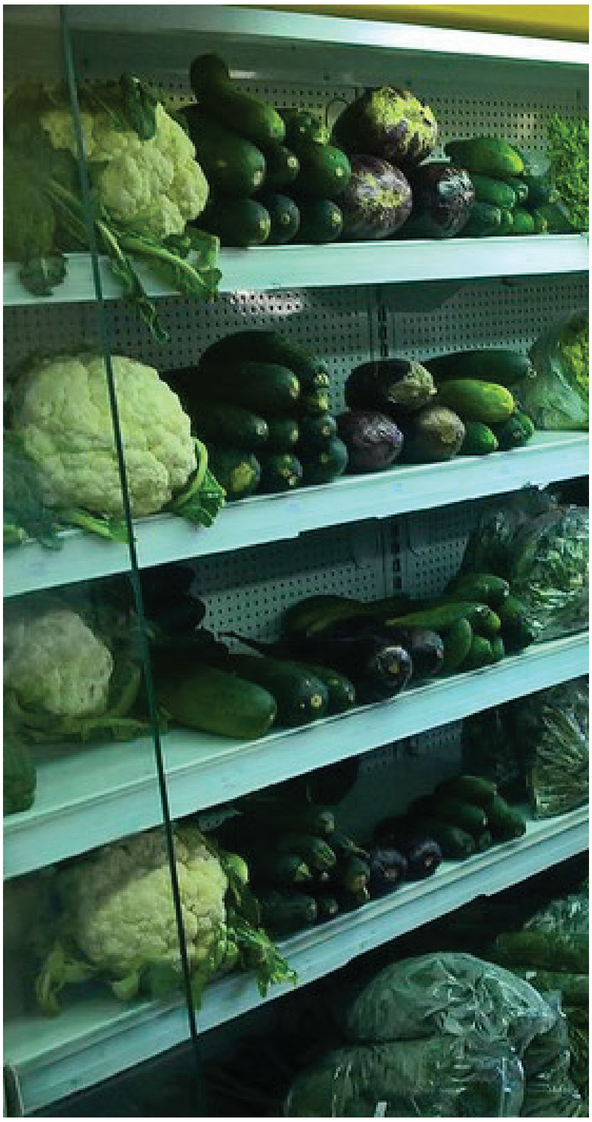

ILRI DISCUSSION PAPER

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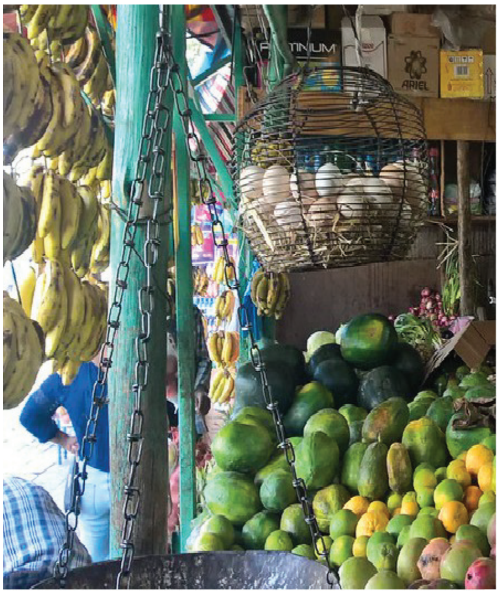
A rapid review of foodborne disease hazards in East Africa



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RESEARCH PROGRAM ON
Agriculture for Nutrition and Health

A rapid review of foodborne disease hazards in East Africa

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Abbreviations and acronyms

AfCFTA	Africa Continental Free Trade Area
ASF	Animal-source foods
DALYs	Disability-adjusted life years
EAC	East African Community
FBD	Foodborne diseases
GFSP	Global Food Safety Partnership
ILRI	International Livestock Research Institute
MRSA	Methicillin-resistant *S. aureus*
NTS	Non-typhoidal Salmonella
SSA	sub-Saharan Africa
STEC	Shiga toxin-producing *Escherichia coli*
WHO	World Health Organization

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Executive summary

Food is essential for life and livelihoods. Hazards in food can make it unsafe for human consumption, depending on their levels and how they are amplified or reduced on the farm to form pathway. A study to assess occurrence of food hazards in East Africa (EA) using a rapid literature review approach was designed. In addition to foods, studies reporting important foodborne diseases, in animals and humans, were considered. Searches were done in PubMed, CAB Direct, and Google Scholar databases. Data were extracted from 71 publications, which together yielded 228 records: animals (51), humans (65), food (97), and vegetables (15). A separate desk search was used to capture chemical hazards. Several hazards or hazard proxies were found in animal-source foods, and included *Staphylococcus* spp (16%), *E. coli* (18%), and *Campylobacter* spp (18%). In vegetables, *Salmonella* spp were the most commonly reported hazards (and accounted for about one third of the reported cases of vegetables contaminated with hazards or hazard proxies). Cholera, salmonellosis, botulism and anthrax were among the disease outbreaks observed in the review. A number of studies reported aflatoxins and heavy metal presence, some at levels beyond what regulatory bodies recommend.

Although this was a rapid review, implemented within a short time, it did allow for some important conclusions to be drawn: foodborne disease (FBD) hazards or hazard proxies are common in animals, food, and people in EA; bacterial hazards are more reported than viral, parasitic, or chemical hazards; *Salmonella* spp, toxigenic *E. coli*, *Campylobacter* spp and *Taenia solium* are important hazards. Consumption of raw milk, vegetables eaten without cooking as well as unhygienically handled cooked meat are important matrices for FBD transmission. Surveillance and reporting of FBD is weak and needs urgent strengthening.

1.0 Introduction

Food is essential for life and livelihoods and must be safe to support health and nutrition. For a long time, the health burden associated with foodborne diseases (FBD) was less known and often underestimated. In 2010, the Foodborne Disease Burden Epidemiology Reference Group (FERG) under the aegis of the World Health Organization (WHO) analysed a total of 31 FBD hazards and estimated that these caused 600 million illnesses and 420,000 deaths, resulting in a burden of 33 million disability-adjusted life years (DALYs) (WHO 2015). DALYs are a measure of disease burden in the population. They combine losses due to mortality and morbidity and are computed by summing the number of years of life lost (YLL) due to premature mortality and the years lived with disability (YLD) due to sickness. One DALY is equivalent to one year of healthy life that is lost. A second part of the FERG study assessed the health burden of four heavy metals which were found to cause an additional more than 1 million illnesses, over 56,000 deaths, and more than 9 million DALYs (Gibb et al. 2019). Combined (approximately, because the two parts of the study used different methodologies), the health burden of FBD is around 42 million DALYs per year, comparable to the health burden of tuberculosis or malaria. The figure is conservative and likely an under-estimate of the real burden of foodborne disease (Yen et al. 2018).

Foodborne diseases can have both acute and chronic forms. In the first part of the FERG study, the most frequent (91%) causes of foodborne illnesses were diarrhoeal disease agents (which were also responsible for 54% of the deaths) (Havelaar et al. 2015). The relationship between diarrhoea and malnutrition is bidirectional - diarrhoea leads to malnutrition and malnutrition makes worse the course of diarrhoea (Nel 2010). The malnutrition effect is through reduction in food intake, decreased nutrient absorption and metabolic insufficiencies (Martinez and Tomkins 1995). Children under five years bear a disproportionately high burden of FBD (40%) (Havelaar et al. 2015); because of their poorly developed immune systems, susceptibility to small pathogen doses, and their inability to judge food safety (Fung et al. 2018). Other vulnerable groups are the elderly, malnourished, pregnant and immunosuppressed (Grace 2015).

Africa is among the continents impacted most by FBDs (Havelaar et al. 2015). In monetary terms, the World Bank estimated the cost of unsafe food in the region to be USD16.7 billion, comprising productivity and treatment losses, but excluding costs that are not easy to quantify (Jaffee et al. 2019). Food safety is key to attaining several of the United Nations' Sustainable Development Goals (SDGs), including zero hunger, health and well-being, clean water and sanitation, and responsible production. Trade in safe products not only safeguards human health but also supports national and regional economies. The African Union, under the 2014 Malabo Declaration on Agriculture and Postharvest Losses, plans to triple the intra-African trade in agricultural commodities and services by the year 2025. Food safety will need to be considered to ensure progress. Trade under the Africa Continental Free Trade Area (AfCFTA) started in January 2021[1]. Food safety will be critical in sustaining the initiative.

Most East African Community (EAC) partner states are in the WHO subregion 'AFR E' (as per the WHO burden study). The region has one of the highest shares of the FBD burden, and a review of foodborne diseases and hazards present in locally consumed products was deemed necessary, to not only understand the current situation but also identify priorities, and support risk management. The study was undertaken as part of the project 'Situational Analysis of food safety control systems in East Africa Community member states' with findings intended to add to the ongoing food safety

1 https://www.un.org/africarenewal/magazine/january-2021/afcfta-africa-now-open-business

work and inform decision-making, especially in defining value chain areas that should be targeted for investments. The region has a strategy on Food and Nutrition Security (2018-2022) which covers food safety; partner states need evidence to support its implementation.

A food hazard is any agent that has the potential to cause ill health. Both biological and chemical hazards were considered in the review. Hazards are different from risks. Risk considers the probability of an agent to cause disease when one is exposed to it, and the magnitude of the resulting effects. It can be qualitative or quantitative depending on the assessment criteria used. It is possible for a hazard contamination level to be low yet its risk to human health is high, and vice versa. Some studies report presence of microbes which may or may not be pathogenic; for example, the presence of Enterobacteriaceae indicates faecal bacteria are present, some of which may be pathogenic (for example, hazards) and some commensals (for example, not hazards): we refer to these as hazard proxies.

2.0 Study design

2.1 Rapid review methodology

Because the review needed to be done within a short period, we chose a 'rapid review' approach, rather than a systematic literature review (SLR) which would have taken longer (Khangura et al. 2012). SLRs are not appropriate where evidence is urgently required and rapid reviews are an option to reducing the time constrain associated with SLRs (Kaltenthaler et al. 2016); as was the case in our study.

We additionally extracted information relevant to FBD in East Africa from FERG, which remains the most reliable source of information on health burden. A separate review was done to capture studies on aflatoxins and chemical hazards..

2.2 Description of the search process

We defined key words and combined them into appropriate syntaxes. We conducted searches in PubMed and Google Scholar (GS), except for Tanzania, where, CAB Direct was used in place of GS (for technical reasons as the system could not run at the time the search was applied for other countries). For GS, short syntaxes were developed and applied, and sorted by relevance. For each, we considered the first 100 hits. However, for Uganda, Rwanda, and Burundi, because of the limited time available, the GS search was restricted to syntaxes yielding the largest number of hits (top three). We identified and removed duplicates (after results from the different databases were combined). Titles were screened by one person and were judged as either acceptable or not acceptable. Abstracts linked to acceptable titles were screened by two reviewers, independently, after which the files with reviewer decisions were combined. The reviewers addressed the inconsistencies in their decisions and agreed on the ones to include or exclude from the review. A third reviewer assessed the excluded papers as well as papers where the reviewers had differed in their decisions and made a final decision on which to take to the next stage of review. Additional papers were then sought and added to the template of the respective country, after checking to be sure they had not been captured in the main review.

All full papers were reviewed and a decision on those to accept or reject was made. Quality assessment was subjective and was based on clarity of the study design, analyses of the data, and presentation of the results. Because of the limited time available to the research team, full paper review and quality assessment were done at the same time (meaning that an acceptable full paper was also of good quality and was recommended for data extraction). We focused on papers that were specific on hazard type and those that indicated the number of samples tested and those that were found positive. Studies that mentioned indicators of food quality as the only outcome (coliform counts, total bacteria) were excluded from the rapid review. We extracted data from a few abstracts (the ones found relevant but whose full papers were not available for review, but still gave the required information).

2.3 Inclusion and exclusion criteria

The included papers were those published between 2000 and 2020, presented in English, and were related to FBD and hazard or hazard proxy occurrence in the six East African countries (namely Burundi, Rwanda, Tanzania, Uganda, South Sudan and Kenya). We did not search for papers published in French, which might have excluded relevant papers (especially for research done in Rwanda and Burundi). We excluded studies that did not consider food hazards, experiments, focused on antimicrobial resistance, and studies outside of EAC. For microbial papers, we only considered records that specified the number of samples analysed and reported results (positive or negative).

2.4 Data extraction and presentation

Data were extracted from eligible publications and entered in a Microsoft Excel® template. At the start, two people extracted data from five of the publications, reviewed the entries in a meeting with a third reviewer, then proceeded to extract data for specific countries, individually. Virtual meetings, by the reviewers, were planned each week to discuss progress as well as review papers that the data extraction pair had found challenging to manage. The following data were extracted (where available): author and title, year data were collected, country, region within the country, type of study, sampling method used, what was studied (animals, humans, food), type of hazard (or proxy), name of the hazard (or proxy), number of samples analysed, number of samples that were positive, test used, and indications of disease burden.

Descriptive analyses, including frequency tables, graphs, etc. were used to summarize data by country, what was studied (humans, animals, food), and hazard type. A meta-analysis was not performed given that this was a rapid review, using an approach that did not strictly adhere to the documented SLR protocol.

3.0 Results

3.1 Number of reviewed publications

For the rapid review, we extracted data from 72 publications, most of which were from studies in Kenya and Tanzania (Table 1) (excludes the two papers from South Sudan which are presented in the results). In Burundi, none of the retrieved studies was found to be eligible for data extraction (and a Google search targeting studies mentioned in a previous project report did not return any results). However, several abstracts reported in French from PubMed suggested *Salmonella* spp had been detected in people and animals, and *Shigella* (one study in people). Twenty-six papers were added from other sources (from the reference session of included publications and from papers that the authors were aware of from past research on the topic).

Table 1. Number of papers considered at each stage of the rapid review process, June–August 2020

Country	Database	Number of titles screened	Number of duplicates	Number of abstracts screened	Number of abstracts accepted	Number of full papers where data were extracted
Tanzania	PubMed	292	10	98	28	22
	CAB Direct	59				
Kenya	PubMed	390	30	370	58	29
	Google Scholar	1,071 (from a total of 26,796 hits)				
Uganda	PubMed	184	19	182	26	15
	Google Scholar	300 (from a total of 20,530 hits)				
Rwanda	PubMed	19	9	139	26	6
	Google Scholar	300 (from a total of 8499 hits)				
Burundi	PubMed	5	2	58	14	0
	Google Scholar	300 (from a total of 4,587 hits)				

The 72 papers yielded a total of 228 records; most were from studies in Kenya (39%) and Tanzania (37%). While most human studies were from Kenya (46%; n=90), food studies were the most frequent in Tanzania (54%; n=85), Uganda (37%; n=38) and Rwanda (60%; n=15). Thirty-three percent (75/228) of the records were from studies with designs that were either not mentioned or were considered unclear. Ten of the records (4%) were on outbreak investigations. Faeces from humans and animals (39%), meat (16%), milk (16%), serum from animals and humans (9%) and vegetables (7%) (n=228) were among the samples analysed. Animals were sampled either at the farm or at the slaughterhouse level (before slaughter). They included cattle (37%) and pigs (49%).

The records were from studies involving animals (51/228), food (95/ 228), humans (65/228) and vegetables (15/228) samples. They reported on bacteria (72%), chemicals (2%), parasites (22%) and viruses (4%). *Escherichia coli* (25%; 42), *Campylobacter* spp (20%; 33), and *Salmonella* spp (18%; 30) were the most frequently reported bacteria (n=165). Three of the *E. coli* records were positive for E. coli O157 (Table 2) (one from milk, one from infant food, one from cattle faeces).

Table 2. Summary of pathogenic E. coli reports found in the review

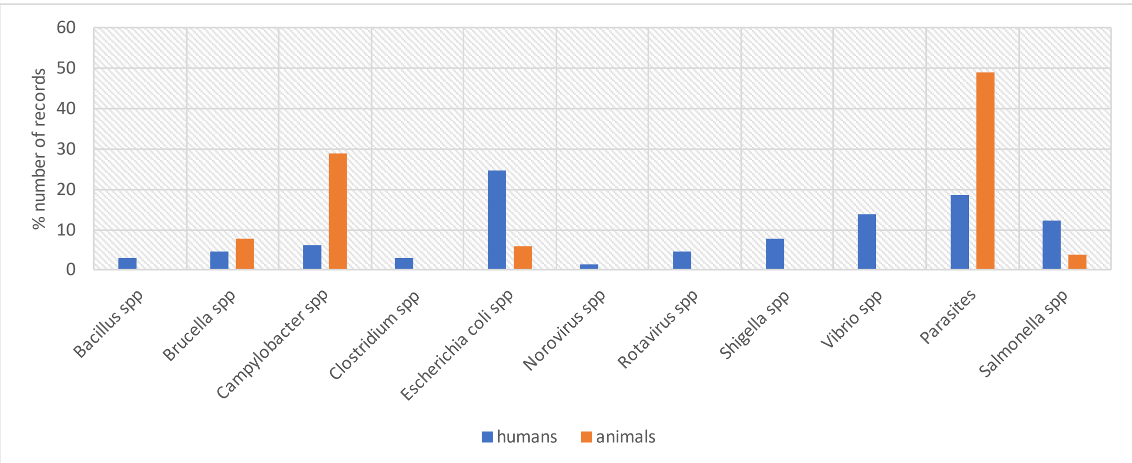
E. coli type	Country	Population sampled	Number sampled	Number positive	% positive	Reference
Shiga toxin-producing E. coli	Uganda	healthy cattle	159	45	28	Mulindwa et al. (2001)
Shiga toxin-producing E. coli	Kenya	food handlers working in a hotel	1,399	2	0.1	Oundo et al. (2008)
Enteropathogenic E. Coli	Kenya	Infants attending hospital	862	75	9	Saidi et al. (1997)
Enterotoxigenic E. coli	Kenya	Infants attending hospital	862	43	5	Saidi et al. (1997)
Shiga toxin-producing E. coli	Kenya	Infants attending hospital	862	1	0.1	Saidi et al. (1997)
E. coli O157	Tanzania	Dairy	109	10	9	Schoder et al. (2013)
E. coli O157	Kenya	Cattle	285	15	5	Kangethe et al. (2007)
E. coli O157	Kenya	Infant foods	127	21	17	Tsai et al. (2019)

Most of the Salmonella spp reports (15/ 27) did not specify the species or serotype (however, five isolates specified non-typhoid Salmonella, four *S. enteritidis*, one *S. gallinarum*, and one *S. typhi*). Chemicals (n=5) (reported in the rapid review part of the study) included antibiotic residues, all of which were reported in milk. Toxins of *Clostridium botulinum* were reported in an outbreak investigation study in Uganda. Adenovirus, sapovirus, rotavirus and norovirus were among the viruses reported in the review.

3.2 Foodborne pathogens found in animal and human studies

Campylobacter spp (16%), *E. coli* (16%), and parasites (31%) were the most frequently reported pathogens in the animal and human records (n=116),overall (Figure 1)[2].

Figure 1. Records of foodborne bacterial pathogens reported in humans and animal studies, rapid review, June–August 2020.



3.2.1 Evidence from animal studies

Nonga et al. (2009) examined faeces from 107 slaughter cattle in Tanzania and found six (5.6%) to be positive for *Campylobacter* spp (five were *C. jejuni* and one was *C. coli*). Kashoma et al. (2015) isolated *Campylobacter* spp in faeces of pigs (149/458; 32.5%) as well as in beef (68/214; 35.4%) and dairy (42/192; 19.6%) cattle. Mdegela et al. (2011)

2 Samples found to be negative on testing were *E. coli* (four), parasites (three), *Brucella spp*(one), and *Vibrio* (one).

examined 66 slaughter pigs and found 44 to also be positive for *Campylobacter* spp (most isolates, 74%, were *C. jejuni*). *Escherichia coli* was reported in 24% of human and 5% of animal samples. A study in peri-urban Nairobi involving cattle found *E. coli* O157:H7 in 15 of the 285 pooled faecal samples (5.2%) (Kangethe et al. 2007). A study in Uganda did not find any *E .coli* O157; the authors reported that 45 of the 159 cattle examined were positive for shiga toxin-producing *E. coli* (STEC) (Mulindwa et al. 2001).

In an abattoir survey in Tanzania, Luwumba et al. (2019) reported a brucellosis prevalence of 7.5% (14/190) in cattle and 1.5% (3/200) in goats, using the Rose Bengal test (4.7% of cattle were positive when tested using enzyme-linked immunosorbent assay (ELISA) and none of the goats tested positive). Non-typhoid *salmonella* was investigated in 237 layer farms in Uganda (Odoch et al. 2017); 78 (n=366 samples) were found to be positive (20% of the farms had a positive finding). The isolates were diverse, and included *S. newport* (30.8%), *S. hadar* (14.1%), *S. aberdeen (*12.8%), *S. heidelberg* (12.8%), and *S. bolton* (12. 8%). Out of the 997 pigs examined for mycobacterium in Uganda, 93 (or 9.3% of total) were positive by necropsy and 32 (or 3.1%) by culture (Muwonge et al. 2010).

Foodborne parasites constituted 49% (n=51) of animal records. In the study by Braae et al. (2014), in Mbeya District of Tanzania, pigs were sampled at baseline (n=822 pigs), during follow-up in six (n=812) and 14 months (n=998) after the study started. The number of pigs positive for *T. solium* cysticercosis, by Ag ELISA, was 127 (15%), 198 (24%), and 202 (20%) for the baseline, six-month, and eight-month periods, respectively. Previous *T. solium* cysticercosis studies in Kenya are summarized in Table 3.

Table 3. Occurrence of *Taenia solium* cysticercosis in pigs in Kenya, rapid literature review, June–July 2020

Point of sampling	Number of pigs examined	Number positive	% positive (or the crude prevalence)	Test method used	Authors
Farm	107	15	14	tongue examination	Githigia et al. (2005)
Farm	505	33	6.5	tongue examination	Mutua et al. (2007)
Farm	284	11	4	Ag ELISA	Kagira et al. (2010)
Slaughter	343	171	49.9	HP10 Ag ELISA	Thomas et al. (2016)
	343	19	5.5	tongue examination	
Farm	232	76	32.8	Ag ELISA	Eshitera et al. (2012)
	392	22	5.6	tongue examination	
Slaughter	700	61	11	Ag ELISA	Akoko et al. (2019)
Slaughter	276	12	4.3	Ag ELISA	Nguhiu et al. (2017)

Cryptosporidium spp, *Toxoplasma* spp, *Trichinella* spp and ascarids were additionally reported (Table 4).

Table 4: Parasite occurrence in animals, rapid literature review, June–July 2020

Country	Name of the parasite	Animal species	Number sampled	Number positive	% positive	Reference
Tanzania	Cryptosporidium parvum	Cattle	942		0.5	Kusiluka et al. (2005)
	Giardia lamblia		202		1.5	
Tanzania	Cryptosporidium hominis and C. xiaoi	Sheep Goats	56 9	5 2	9 2	Parsons et al. (2015)
Tanzania	Toxoplasma gondii	Goats	337	64	19.3	Swai and Kaaya (2013)
Tanzania	*Ascaris suum*	Pigs	70	31	44.3	Ngowi et al. (2004)
	Echinococcus granulosum			3	4.3	
	Taenia hydatigena			1	1.4	
Uganda	*Trichinella spp*	Pigs	1,125	78	6.9	Roesel et al. (2016)

3.2.2 Evidence from human studies

O'Reilly et al. (2012) reported non-typhoidal ***Salmonella*** spp (10%; 118/1,137), Campylobacter (5%; 57/1,137), and Shigella (4%; 42/1,137) in children hospitalized in western Kenya. In Nyagatare, eastern Rwanda, of the samples taken from women presenting with symptoms of brucellosis (n=198), 6.1% tested positive (Gafirita et al. 2017). In Ijara, Kenya, Kiambi et al. (2020) found 60 (15.4% of 386) patients with febrile symptoms to be positive for Brucella, using real-time PCR. In the study by Madut et al. (2019) in the Bahr el Ghazal region of South Sudan, slaughterhouse workers (n= 234) were screened for Brucella antibodies; 32.1% were sero-positive for brucellosis. Wainaina et al. (2020) analysed stool samples from 283 food handlers in Nairobi and found 43 (15.2%) to be positive for norovirus.

Foodborne parasites constituted 18% (n=65) of human records. In Kongwa District of Tanzania, Eom et al. (2011) analysed a total of 1,057 faecal samples, and confirmed two as *T. solium* and three as *T. saginata*. Analysis of stool samples (of food handlers) in Kisii, Kenya, found 41% (n=168); *Entamoeba histolytica* (12%), *A. lumbricoides* (13%), hookworms (7.7%), and *G. lamblia* (3.6%) (Nyarango et al. 2008). Sparganosis, a parasitic infection caused by larvae of tapeworms belonging to the *Spirometra genus* (Galán-Puchades, 2019), was reported in South Sudan by Eberhard et al. (2015).

A few foodborne outbreak investigation studies were reported including anthrax, botulism and cholera (Table 5).

Table 5. Disease outbreak reports, rapid literature review, June–July 2020

Country	Nature of the outbreak	Number of cases reported	Number of deaths	Implicated cause of the outbreak	Reference
Uganda	Gastrointestinal anthrax	61	0	Consumption of meat from a sick cow; 82% of the cases (n=50) and 12% of the controls (n=100) consumed meat from the implicated butchery	Nakanwagi et al. (2020)
Uganda	Foodborne botulism in a school	3	1	home-made oil-based condiment	Viray et al. (2015)
Rwanda	Salmonellosis	129	0	Food served at a church function	Nzabahimana et al. (2014)
Uganda	Cholera	61	0	97% (n=32) of the cases obtained their drinking water from a specific water-collection site; 62% (n=128) of the controls obtained water from the same water point (ORMH=4.8; 95% CI=2.4–107)	Pande et al. (2018)
Uganda	Cholera	183	2	94% of the cases (n=49) and 79% (n=201) of the controls drank water that was neither boiled nor treated (ORMH=4.8; 95% CI=1.3–18).	Kwesiga et al. (2018)
Uganda	Cholera	122	2	69% (42/61) of the cases and 33% (41/126) of the controls collected water from a point along Lake Albert (OR=6.7; 95% CI: 2.5 –17).	Oguttu et al. (2017)
Uganda	Cholera	222	3	The outbreak was thought to have been triggered by washing away of latrines by floods	Iramiot et al. (2019)

3.3 Foodborne hazards in animal-source foods

Several bacterial hazards were reported (summarized in Table 6; n=77). *Staphylococcus* spp (16%), *E. coli* (18%), and *Campylobacter* spp (18%) were the most frequently reported ones. Nonga et al. (2015) analysed 40 milk samples (11 boiled, 29 raw) and found 25 (62.5%) positive for *E. coli* (60% had total viable counts higher than recommended limits). Five of the positive samples were from milk that had been boiled. *Bacillus cereus* was confirmed in milk sampled in Dar es Salaam (Kivaria et al. 2006) while 50% (n=59) of milk samples collected and analysed by Swai and Schoonman (2011) in Tanga, were positive for *Brucella*. *Enterobacter aerogenes* and *Enterococcus foecalis* in milk was reported by Kivaria et al. (2006). None of the milk samples analysed by Kamana et al. (2014) and Schoder et al. (2013) were positive for pathogenic Listeria monocytogenes.

Antimicrobial residues were reported in 4.5% (n=67) of the milk samples analysed by Mdegela et al. (2009). In an earlier study, in Dar es Salaam, nine of the 128 (7%) samples analysed by Kivaria et al. (2006) were positive for drug residues.

Ngasala et al. (2015) did not find any positive samples out of the 35 milk samples they analysed. In Kenya, Shitandi and Sternesjö (2001) found 165 milk samples positive for penicillin residues (14.9%; n=1109); 118 samples exceeded the EU limits. Ekuttan et al. (2007) reported an antibiotic residue prevalence of 4% (11/259) in samples taken from dairy farms in Dagoretti, Nairobi, and 0.07% (1/136) in samples from neighbouring non-dairy households.

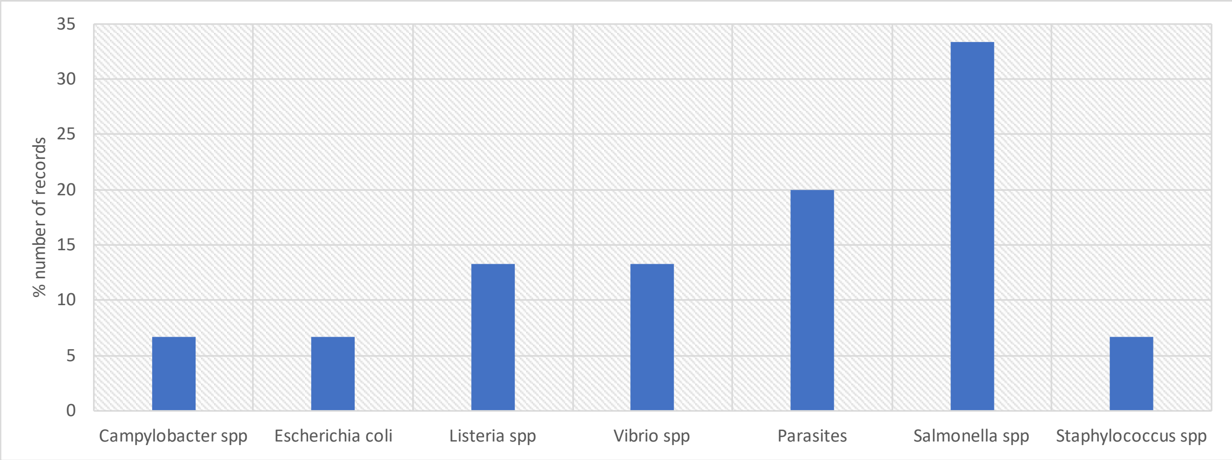
Table 6. Hazard contamination in milk and meat consumed in selected EAC countries, rapid review, June– July 2020

Hazard name	Food sampled	Number sampled	Number positive	% positive	Country	Reference
Staphylococcus spp	Raw milk	109	46	42.2	Tanzania	Schoder et al. (2013)
Listeria seeligeri	Raw milk	109	2	1.8		
Salmonella spp	Raw milk	109	1	0.9		
E. coli O157:H7	Raw milk	109	10	9		
Staphylococcus aureus	Milk	128	8	6.3	Tanzania	Kivaria et al. (2006)
Staphylococcus aureus	Milk along value chain	330	175	53	Rwanda	Kamana et al. (2014)
Staphylococcus aureus	Milk	603	85	14	Kenya	Omwenga et al. (2019)
Staphylococcus aureus	Raw milk	148	30	20.3	Uganda	Asiimwe et al. (2017)
	Sour milk	91	11	12.1		
Staphylococcus aureus	RTE goat meat	20	17	85	Uganda	Bagumire and Karumuna (2017)
	RTE beef	20	17	85		
	RTE chicken	20	17	75		
Salmonella spp	Beef	150	35	23.3	Rwanda	Niyonzima et al. (2018)
	Goat or mutton	48	6	12.5		
	Chicken	36	8	22		
	Pork	24	4	16		
Salmonella spp	Boiled beef	150	8	5.3	Rwanda	Niyonzima et al. (2017)
	Grilled goat	84	16	19		
	Fried pork	30	6	20		
	Grilled chicken	20	3	15		
	Grilled rabbit	16	2	11		
Campylobacter spp	Carcass – ham	107	1	0.9	Tanzania	Nonga et al. (2009)
	Carcass – neck	107	2	1.9		
	Carcass – pelvis	107	4	3.7		
	Carcass – thigh	107	3	2.8		
Campylobacter spp	Raw milk	284	38	13.4	Tanzania	Kashoma et al. (2016)
	Carcass – cattle	253	24	9.5		

3.4 Foodborne disease hazards in vegetables

The most frequently documented hazard was *Salmonella* (n=15; 33%) (Figure 2). In Morogoro, Tanzania, Hounmanou et al. (2016) reported *Vibrio cholerae* O1 in 21.7% (n=60) of Chinese cabbage samples. Ssemanda et al. (2018) investigated vegetables sampled from farms in Rwanda (n=99), and found them to be contaminated with *Listeria monocytogenes* (1%), *Campylobacter* spp (3%), *Salmonella* spp (5.1%), and pathogenic *E. coli* (6.1%). Ascaris eggs were reported in leafy vegetable samples analysed by Steinbaum et al. (2017) (3.5%; 5/143). Contamination of 'kachumbari' (a type of vegetable salad) with *Salmonella* was reported in the study by Imathiu (2018) (19%; 16/86). In a study involving 77 pork butcheries in Uganda, Heilmann et al. (2015) isolated *Salmonella enteritidis* in tomatoes (8%; n=77), cabbages (5%; n=77), and onions (1%; n=77). Nyarango et al. (2008) assessed vegetables in Kisii, Kenya, and found 65.5% (n=84) to be contaminated with intestinal parasites.

Figure 2. Occurrence of FBD hazards in vegetables consumed in selected East African countries, rapid review, June–July 2020.



4.0 Aflatoxins and chemical hazards

FERG has included several chemical hazards in the global estimate for burden of foodborne disease. These include aflatoxins, arsenic (Ar), lead (Pb), cadmium (Cd), methylmercury, peanut allergens and dioxins (Havelaar et al. 2015; Gibb et al. 2019). In East Africa the most commonly documented hazards are mycotoxins, heavy metals, pesticide residues and veterinary drug residues.

4.1 Aflatoxin and their health impacts

Aflatoxins are among the mycotoxins prevalent in the East African region. Most studies have been done in Kenya, probably because of the outbreak in 2004 (Azziz-Baumgartner et al., 2005; Lewis et al. 2005; Probst et al. 2007). The outbreak occurred during a time of severe hunger and was one of the most severe episodes of acute human aflatoxin poisoning in history (317 cases were reported; the case fatality rate was 39%). However, there has been numerous reports on aflatoxin occurrence in all the five EAC countries (Table 7) resulting in a relatively high donor investment in this area (GFSP 2019).

According to published studies, a substantial proportion of samples tested for aflatoxins exceed national standards: typically, by 10–50%. But country standards may be stricter than WHO standards. In practice, standards are rarely enforced. Although typically, most samples do not exceed standards by large amounts, in outbreak situations, maize may contain massive amounts of aflatoxins. One interesting study (Sirma et al. 2018) found that if standards were enforced in Kenya, and in the absence of other interventions to replace the staple food discarded, the population would have a maize shortage of 22% leading to millions of death from starvation unless maize could be sourced elsewhere; on the other hand, the strict enforcement of standards would save around 1,400 lives a year from averted liver cancer.

Fewer studies have assessed the impact of aflatoxins on human health, and those that have been conducted agree with the FERG data that aflatoxins are a minor cause of health burden (in comparison to other foodborne hazards). However, the association between aflatoxins and childhood stunting has not been fully elucidated: it may be explained by correlation or causation. If the relation is causal, the health impacts would be considerably higher.

4.1.1 Aflatoxin contamination in milk

A cross-sectional study of aflatoxin contamination of milk and dairy feeds in five counties in Kenya, representing different agro-ecological zones, was carried out. Consumption of AFB1-contaminated feeds by dairy animals can lead to release of AFM1 in milk. The dairy feed concentrates from farmers had AFB1 levels ranging from less than one part per billion (ppb) to 9,661 ppb and the positive samples ranged from 47.8 to 90.3%. The proportion of milk samples with AFM1 above the WHO/FAO standard of 50 parts per trillion (ppt) varied from 3.4% (Kwale) to 26.2% (Tharaka-Nithi); the highest concentration was 6,999 ppt (Senerwa et al. 2016).

A probabilistic survey was conducted of informal raw milk vendors in Nairobi. The cELISA test found the mean concentration of AFM1 was 128.7 parts per trillion (ppt) (median=49.9; 95% confidence interval=3.0–822.8) with a maximum of 1,675 ppt. Overall, 55% of samples exceeded the European Union (EU) maximum level of 50 ppt and 6% exceeded the recommended maximum level of the United States Food and Drug Administration of 500 ppt (Kirino et al. 2016). Another survey in peri-urban Nairobi reported contamination in 99% percent of the samples analysed. The mean aflatoxin level was 84 ng/kg; 64% of the samples exceeded the EU legal limit (Kagera et al. 2019). An earlier study reported a geometric mean of 62 ppt, in low income areas (n=135), and 36 ppt in high income areas (n=156) of Nairobi, and observed a significant seasonal variation in aflatoxin content (Lindahl et al. 2018).

Milk and dairy products sampled from Burundi had aflatoxin levels ranging from 5–261ng/kg (Udomkun et al. 2018). The average contamination in fresh milk and yoghurt was 89.25±25 ng/kg and 88.02±1.28 ng/kg, respectively. Fresh milk and yoghurt samples (total of 30%) exceeded the EU limit of, while 20% of the cheese samples were above 250ng/kg (Udomkun et al. 2018).

4.1.2 Aflatoxin contamination in staple foods

A summary of aflatoxin contamination in selected commodities is given in Table 7. In Tanzania, in a longitudinal study lasting more than two years, 6.4% of Bambara nut were found to exceed the regulatory standard immediately after harvest, but 62.5% to were over the standard after storage. Likewise, only 2% of harvested sunflower seeds were over standard, but the frequency increased to 61% after storage; groundnuts 19% were over the standard after harvest, and 82 % after storage (Seetha et al. 2017). High levels of aflatoxins in sunflower seeds, up to 662 ppb, have been reported in Tanzania (Mmongoyo et al. 2017). In northern Uganda, sampled groundnuts had a mean aflatoxin level of 2.4 ppb and over 70% of the samples exceeded the EU limit of 4 ppb (Echodu et al. 2019). The same study reported contamination in sorghum (11.8 ±1.8 µg/kg), millet (3.9 ± 1.1 µg/kg) and sesame (3.2 ± 2.1 µg/kg). In Burundi, all groundnuts from samples the markets were found to be contaminated with aflatoxin with an average concentration of 7 ppb (for the grain), 220.3 ppb (roasted) and 824 ppb (for the processed flour). (Udomkun et al. 2018). Grosshagauer et al. (2020) reported aflatoxin contamination in complementary foods in Rwanda. High levels were reported in nine of the 17 samples: 294 µg/kg and 229 µg/kg for total and aflatoxin B1 respectively.

4.1.3 Risk assessment studies

Results show that aflatoxin exposure from milk contributes relatively little to the incidence of liver cancer. One study found the annual incidence rates of cancer attributed to the consumption of AFM1 in milk in rural areas to be around 0.003 cases per 100,000 people per year (Sirma et al. 2019). Another study estimated the risk of AFM1 in urban areas to be 0.004 cases per 100,000 people per year (Ahlberg et al. 2018). A quantitative risk assessment on the risk of aflatoxin from maize consumed in Kenya estimated 1,346 cases of liver cancer from maize, 35 cases from millet and sorghum, and 5 cases from milk in Kenya in 2016 (Sirma et al. 2018).

Table 7: Occurrence of aflatoxin in staples in East African countries

Country	Region	Food product	Level of contamination (ppb)	Percentage of samples positive (%)	Regulatory limit (ppb)	Percentage above regulatory limit (%)	Reference
Kenya	Western	Maize	-	49	10	15	Mutiga et al. (2015)
	Makueni Siaya	Maize	62 53	100 100	10 10	97.5	Nabwire et al. (2019)
	Western	Peanuts	-	100	20	8	Mutegi et al. (2009)
	Eastern (2005) (2006) (2007)	Maize	13 26 2	-	20	41 51 16	Daniel et al. (2011)
	Makueni	Maize	<20	-	20	36	Mwihia et al. (2008)
	Makueni	Maize kernel 'Muthokoi' Maize meal	53 10 6	45 20 35	10	0 0 5	Kilonzo et al. (2014)
	Eastern	Maize	-	46–85	10	22–60	Mutiga et al. (2014)
Tanzania	Iringa, Kilimanjaro, Ruvuma, Tabora	Maize	24	18	10	12	Kimanya et al. (2008)
	Babati District	Maize	3	19	10	0	Nyangi et al. (2016)
	Central region (2012/2013)	Sorghum Maize Groundnuts	57.2	-	10	10 0 81.9	Seetha et al. (2017)
Uganda	Northern	Sorghum, maize, millet	15.7	-	4	82	Kitya et al. (2009)
Uganda	Northern	Sorghum, maize, millet	16 1.9 2.9	-	4	77 26 12	Echodu et al. (2019)
Burundi	Gitega and Cibitoke Provinces	Maize Sorghum Cassava	38 7 3.7	100	4	51	Udomkun et al. (2018)
Burundi		Sorghum, Millet Rice	0	0	4	o	Munimbazi and Bullerman (1996)

4.2 Pesticides, heavy metal residues, and other chemicals

Omwenga et al. (2021) reported organophosphates (OP) and carbamate contamination in vegetable samples collected from Nairobi (spinach, tomatoes, French beans and kales). OP pesticides were detected in 22% of the samples and profenofos, chlorpyrifos, acephate, methamidophos and omethoate were the most frequently detected pesticides. The EU limits were exceeded in 8–33% of the vegetable samples. Kunyanga et al. (2018) reported dimethoate, metalaxyl, bifenthrin, cyromazine, metribuzin and pyrimethamil in commonly consumed vegetables including kales, amaranth leaves, and tomatoes. Thiabendazole was detected in samples of mangoes, however, this is not considered hazardous since it is applied on the peels which are normally not consumed. In Tanzania, Kapeleka et al. (2020) analysed a total of 613 vegetable samples and found 47% to be contaminated with pesticide residues with 74.2% having levels that the exceeded maximum residue limits (MRLs). The main contaminants were organophosphorus, organochlorines, pyrethroids and carbamates.

Kunyanga et al. (2018) reported presence of lead in sampled fruits and vegetables in the range of 0.01 to above 0.06 mg/100g. Cadmium was also detected in all samples but at concentrations lower than 0.01mg/100g. Amaranth leaves, cabbage, scarlet eggplant and tomato samples were collected from five open-air markets in Bushenyi District, Uganda. Analysis of heavy metals was performed using atomic absorption spectrophotometer. Nickel, lead, chromium and cadmium were detected in decreasing order of concentration in all samples. Lead and nickel significantly exceeded the WHO limits in all the sample species (Kasozi et al. 2021). Mukantwali et al. (2014) studied heavy metal contamination in pineapple products produced by small and medium processors in Rwanda. Lead concentration in the pineapple syrup was 11 to 18 times higher than the permissible limit of 0.05 mg/kg. Levels of copper, zinc and cadmium in the jam were above the permissible levels and ranged from 0.63 to 2.47 (0.03) mg/kg for copper; 0.82 to 3.55 (0.05) mg/kg for zinc and 0.01 to 1.46 (0.01) mg/kg for cadmium.

Water and sun-dried fish samples from 10 different landing sites along Lake Victoria and Lake Kyoga, Uganda, were analysed for heavy metal presence using atomic absorption spectrophotometry (Mbabazi and Wasswa 2010). Total mean levels, in $\mu g\ ml^{-1}$, in water samples from Lake Victoria were 1.478 ± 0.076 (zinc), 1.123 ± 0.208 (copper), 0.093 ± 0.019 (cadmium), and 1.054 ± 0.165 (lead). The maximum permissible limits in drinking water are Zn = 3; Cu = 2; Cd = 0.003; Pb = 0.01 $\mu g\ ml^{-1}$ (WHO, 2008). Concentration ($\mu g\ g^{-1}$) in the silver fish was 5.64 ± 2.16 (Zn), 3.43 ± 2.18 (Cu), 0.57 ± 0.09 (Cd) and 0.17 ± 0.05 (Pb). Cadmium levels were beyond the recommended levels of 0.05–0.3 (Öztürk et al. 2009). Silver fish (*Rastreneobola argentea*), locally known as *mukene*, is widely consumed in Uganda.

Rao and Murthy (2017) determined heavy metal concentration in milk sampled from urban farms in Dodoma, Tanzania. Except for cobalt which was detected at 0.11 ± 0.03ppm, the levels of copper and zinc were found to be within the recommended daily intake levels (the calculated daily intake of cobalt was 13.4 µg/day while the recommended is 5–8 µg/day). Another study in in Entebbe and Kampala, Uganda, analysed heavy metal contamination in raw milk samples collected from dairy farms and shops. Lead (1.57±0.41), zinc (1.43±0.75) and cadmium (0.16±0.08) were found to exceed the recommended daily allowance intake (RDA) (William et al. 2011).

A total of 49 infant formulae milk powder samples (imports to EAC markets, informal micro-retailers in informal markets) from Dar es Salaam were tested for presence of melamine using AgraQuant melamine sensitive test. Six percent of the total samples (3 out of 49) and 11% (3 out of 27) of those supplied by international brands had melamine concentration ranging between 0.5 and 5.5 mg/kg which was above the tolerable daily intake (TD1) of 0.2mg/kg (Schoder 2010).

A cyanide poisoning outbreak was reported in Kasese District, Uganda, in September 2017. A cassava-based dish made from wild cassava cultivar flour consumed during a community gathering was implicated. About 100 probable cases were investigated with a case fatality rate of 2%; 33 persons were hospitalized with symptoms such as vomiting, malaise, dizziness, diarrhoea and abdominal pain. Officials from the Ministry of Public Health withdrew cassava flour from local wholesalers and retailers where the victims said they had obtained their flour (Alitubeera et al. 2019). In Kenya, Rostrup et al. (2016) describes a case of methanol poisoning, reported after consumption of homemade illicit brew. Separately, 314 and 126 cases were reported in the months of May and June 2014, with case fatality rates of about 30% and 20%, respectively.

The East African Rift Valley runs through several EA countries such as South Sudan, Kenya, Uganda and Tanzania. Due to active volcanic activity along the Rift Valley, many drinking water sources are contaminated with elevated levels of fluoride leading to dental and skeletal fluorosis among consumers (Eirik, 2013). A summary of fluoride concentration in drinking water sources in the region is given below (Table 8). The values are compared against the WHO limit of 1.5 mg/l.

Table 8: Occurrence of fluoride in water in East African countries

Country	Region	Source of drinking water	Number of samples / sites	Mean fluoride level(mg/l)	Range (mg/l)	Reference
Tanzania	S1- Chanika School S2- Rundungai School S3- Kibosho School	Springs, Streams, Rivers, Pipes,	S1 = 14 S2 = 13 S3 = 15 samples	S1 = 0.0463 S2 = 5.7170 S3 = 0.7194		Yoder et al. (1998)
	SI- Mtakuja Village S2- Thindigani Village (Hai District)	Hand-dug wells, Pipes, Boreholes, Rivers, Streams	Not specified	S1 = 2.9 S2 = 12.275		Shorter et al. (2010)
	Oldonyosambu Ward	Protected artesian wells	13 samples		0.9–17.1	Shen et al. (2015)
	Singida and Tabora	Dams, wells, boreholes, lakes, spring, rainfall	85 samples	3.74		Smedley et al. (2002)
Rwanda		Springs, boreholes, wells	40 samples	< 0.5		Nsengimana et al. (2012)
Uganda	S1- Kasese S2-Kisoro	Pipe water	Not specified	S1– 0.5 S2– 2.5		Rwenyonyi et al. (2001)
	Tororo	Boreholes and Protected Springs	23 sample points		Spring- (0.3–2.41) Borehole (0.4–3.0)	Egor & Birungi (2020)
Kenya	Nakuru District	Boreholes, wells, rivers, dams, spring	20 sample points		2.5–8.5	Moturi et al. (2002)
	Elementaita	Boreholes	9 sample points	12.11		Kahama et al. (1997)
	Bondo–Rarieda	Boreholes, wells, rivers, dams, Open pans, springs, streams, pipe water	128 samples	0.86	5.18–0.01	Wambu et al. (2014)

4.3 FERG estimates for EAC region

FERG estimates are not available for individual countries but rather for WHO regions that are grouped on the basis of adult and child mortality, with E being the highest category. The top hazards (Table 9) are dominated by bacteria and viruses. Several of the hazards are zoonotic (e.g. non-typhoidal *Salmonella, T. solium*) and others, such as lead and *Vibrio cholerae*, are often found as contaminants of animal-source foods (ASFs). A median burden of 1,179 (726–1,754) DALYs per 100,000 of population was reported, which is far much higher than what was reported in subregions in developed countries, for example 'EUR A' had a burden of 41 (26-64) and 'AMR A' of 35 (23–49) DALYs per 100,000.

Table 9: Disability-adjusted life years (DALYs) lost to foodborne disease in the Africa region (E) per 100,000 people

Foodborne hazard	Common name for disease	DALYs lost per 100,000 people
Non-typhoidal *S. enterica*	Non-typhoidal Salmonella (NTS)	193
Taenia solium	Cysticercosis	176
Vibrio cholerae	Cholera	143
Enteropathogenic *E. coli*	Toxigenic *E. coli* disease	138
Enterotoxigenic *E. coli*	Toxigenic *E. coli* disease	105
Lead	Lead poisoning	82
Norovirus	Norovirus diarrhoea	76
Campylobacter spp	Campylobacteriosis	70
Salmonella typhi	Typhoid	52
Shigella spp	Shigellosis	37
Methylmercury	Mercury poisoning	37
Mycobacterium bovis	Zoonotic tuberculosis	34
Toxoplasma gondii	Toxoplasmosis	20
Hepatitis A virus	Hepatitis	18
Arsenic	Arsenic poisoning	14
Cryptosporidium spp	Cryptosporidiosis	12
Salmonella Paratyphi A	Paratyphoid	12
Entamoeba histolytica	Amoebiasis	5
Ascaris spp	Roundworm infection	5
Aflatoxin	Aflatoxicosis	3
Cassava cyanide	Tropical ataxic neuropathy and konzo	3
Listeria monocytogenes	Listeriosis	1
Cadmium	Cadmium poisoning	1

Source: WHO (2015); Havelaar et al. (2015); Gibb et al. (2019)

3 Only hazards resulting in a loss of one or more DALYs per 100,000 people were included

5.0 Discussion

Food is essential and its safety concerns everyone. The best evidence on the burden associated with unsafe food is that provided by FERG, based on the 2010 data. The estimates are, however, not available for individual countries but rather for WHO regions that are grouped on the basis of adult and child mortality, with E being the subregion with the highest mortality levels (Havelaar et al. 2015). The AFR E region (the focus for the current review) comprises of Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, and Zimbabwe. The included EAC partner states (Burundi, Kenya, Rwanda, Uganda, Tanzania) account for one quarter of the AFR E countries and nearly a third of its population, suggesting that FERG data might give some insight into the burden of FBD in the EAC. In the future, establishing detailed country- and region-specific data will be useful for risk and FBD burden assessment, and consequently in determining public health priorities.

Animal-source foods are responsible for many, and perhaps most, of FBD (Grace et al. 2018). Li et al. (2019) put the global burden associated with consumption of ASFs at 168 DALYs per 100,000 population (equivalent to 35% of the global burden of FBD), but this did not include non-zoonotic pathogens which are common in ASF as it provides a good matrix for pathogen survival. Also, hazards with animal reservoirs have been shown to have a higher proportion of illnesses attributable to food than those involving human-human or waterborne transmission (Hald et al. 2016). The WHO attribution study (Hoffmann et al. 2017) reported the percentage of pathogens transmitted through different foods including vegetables; it, however, did not consider meat that was contaminated by non-zoonotic pathogens, missing an important intervention point. Meat is likely to be contaminated during slaughter especially where good slaughter practices are not observed and cross-contamination is a possibility at both retail and household level. In most cases, food contamination occurs naturally, by toxins and environmental pollutants or during the processing, packaging, preparing, storage, and transportation of food (Rather et al.2017).Processed products are more likely to contain chemical contaminants than the biological ones (Grace 2015).

The hazards found compare with what has been reported globally and justify the need for further research. The WHO study found Campylobacter spp, pathogenic *E. coli*, non-typhoidal *Salmonella* (NTS), and Shigella as the main bacterial agents associated with foodborne diarrhoea (Havelaar et al. 2015). Animals are implicated in transmission of these pathogens. *Salmonella* has been reported in meat products more than any other foodstuff with poultry and poultry products presenting the greatest risks of exposure (Ehuwa et al. 2021). *Campylobacter* -shedding animals, especially poultry, are an important source of food and water contamination (Gölz et al. 2014) with contamination occurring mostly during slaughter. *Escherichia col*i normally inhabits the gastrointestinal system of humans and animals. A few strains are pathogenic and can cause disease in humans (Donnenberg and Whittam 2001), including Enteropathogenic E. coli, which can cause diarrhoea and vomiting; STEC (associated with enterohaemorrhagic strains), which can cause haemorrhagic colitis and haemolytic uremic syndrome; enterotoxigenic *E. coli*, which can cause watery diarrhoea; and entero-invasive *E. coli,* which can also cause watery diarrhoea. Enterohaemorrhagic *E. coli* occurs as a result of consumption of foods tainted with animal faeces (Canpolat 2015). The burden associated with these strains, based on the WHO data, was 2,938,407 DALYs (for Enteropathogenic E. coli), 2,084,229 (Enterotoxigenic *E. coli*), and 12,953 (for STEC). Non-typhoidal *Salmonella* (NTS) often cause gastroenteritis and, in immune-compromised individuals, bacteraemia and faecal infections (Pegues et al. 2001). Salmonella enterica serovar typhimurium and S. enterica serovar *enteritidis* are the most frequently reported serotypes. Invasive NTS is an emerging public health issue in sub-Saharan Africa (SSA), especially in children and the immunocompromised individuals (Gordon 2012). According to Stanaway et al. (2019), a total of 535,000 (95%; 409 000–705 000) cases of invasive NTS occurred in 2017 and the highest incidence was in SSA.

Staphylococcus aureus has been reported in several African countries in humans, animals and food products (Lozano et al. 2016). It should be noted that majority of *S. aureus* strains have the potential to produce enterotoxins (Bennet and Monday 2003) which are responsible for the virulence associated with the bacteria. Moreover, toxins are not destroyed by cooking. Methicillin-resistant *S. aureus* (MRSA) is increasingly being reported in East Africa (Joachim et al. 2017; Masaisa et al. 2018; Wangai et al. 2019). Development of MRSA, both hospital- and community-acquired, present significant public health concerns (David et al. 2008).

Noroviruses are a leading cause of gastroenteritis and can be fatal in vulnerable populations including children and the elderly (Glass et al. 2009). The WHO study found a burden of 2,496,078 (1,175,658–5,511,092) DALYs associated with the virus (Havelaar et al. 2015).

Parasites found in the review included *Cryptosporidia spp, Giardia spp, Taenia cysts, Ascaris, Entamoeba histolytica*, and *Trichinella* spp. *Cryptosporidium* is a protozoa that is transmitted through the faecal-oral route, usually through food and water (Zahedi et al. 2016). The transmission of *T. solium*, which is endemic in many countries, involves pigs as the intermediate hosts and humans as the definitive hosts. Humans can also carry the larval stage, resulting to neurocysticercosis in the case where the cysts lodge in the brain (an important cause of epilepsy in developing countries) (Pall et al. 2000). Pig confinement, improvements in hygiene and sanitation, and meat inspection are required to break the cycle of spread. Exposure of trichinellosis in humans is through consumption of meat with viable *T. spiralis* cysts, when consumed raw or inadequately cooked (Robinson and Dalton 2009). The additional desk work also reported pesticides, heavy metals and aflatoxins, all of which are important for public health. Gibb et al. (2019) analysed the burden associated with four metals and found them to have caused a total of 1,122,436 (333,683–3,899, 318) illnesses and 56,192 (14,299–98,806) deaths resulting to over 9 million DALYs. Fifty-four per cent of the cases were due to lead, 96% of the deaths were due to arsenic (none for lead and methylmercury), and 60% of the DALYs were attributed to lead (of the 9,164,162).

An overview of FBD hazard occurrence in the East African region has been given, however, data on some key hazards are limited. Similar hazards were found to occur in humans, animals and foods, showing the need for a One Health approach to manage them. Additional research is recommended to confirm the occurrence of these pathogens and determine characteristics that may inform future control measures. Although national governments have a role to play in ensuring food safety, the contribution of other players in the value chain including the private sector should be emphasized. Based on the work by the International Livestock Research Institute (ILRI) and partners, three factors are key to successful implementation of dairy projects namely, training of market actors, providing an enabling regulatory environment, and considering incentives that would support behaviour change (Grace et al. 2019). A farm-to-fork approach is recommended. An effective risk management system will require intervening at every stage of the food value chain, not just regulating the end product (Allard 2002; Burlingame and Pineiro 2007). Equity is another important consideration (Grace 2015). Any measure that is proposed should be risk-based. It has been shown that about 61% of infectious diseases are zoonotic (as are 75% of emerging pathogens) (Taylor et al. 2001). The potential for One Health in disease mitigation ought to be considered.

6.0 Conclusion

The current review was implemented within a short time, but that notwithstanding, important information was obtained which can inform future research and policy decisions on food safety. The findings are expected to add to ongoing food safety work in the region and contribute to the implementation of the current EAC's strategy on food and nutrition security. A follow up research activity is proposed to confirm the literature findings and provide evidence where significant data gaps have been found (e.g. in Burundi and South Sudan). A risk assessment would then be planned to determine the priority hazards, based on the risks they pose to public health, and subsequently, guide their management.

7.0 References

Ahlberg, S., Grace, D., Kiarie, G., Kirino, Y. and Lindahl, J. 2018. A risk assessment of aflatoxin M1 exposure in low and mid-income dairy consumers in Kenya. *Toxins* 10: 1–15.

Akoko, J.M., Macleod, E., Thomas, L.F., Alarcon, P., Kang, E., Kivali, V., Muloi, D., Muinde, P., Murungi, M.K., Gachoya, J.M. and Fèvre, E.M. 2019. Detection of circulating antigens for *Taenia spp*. in pigs slaughtered for consumption in Nairobi and surroundings, Kenya. *Parasite Epidemiology and Control* 4: e00093.

Alitubeera, P., Eyu, P., Kwesiga, B., Ario, A. and Zhu, B.-P. 2019. Outbreak of Cyanide Poisoning Caused by Consumption of Cassava Flour — Kasese District, Uganda, September 2017 MMWR. *Morbidity and Mortality Weekly Report* 68: 308–311.

Allard, D.G. 2002. The 'farm to plate' approach to food safety - Everyone's business. *Canadian Journal of Infectious Diseases* 13: 185–190.

Asiimwe, B.B., Baldan, R., Trovato, A. and Cirillo, D.M. 2017. Prevalence and molecular characteristics of *Staphylococcus aureus*, including methicillin resistant strains, isolated from bulk can milk and raw milk products in pastoral communities of South-West Uganda. *BMC Infectious Diseases* 17: 1–8.

Bagumire, A. and Karumuna, R. 2017. Bacterial contamination of ready-to-eat meats vended in highway markets in Uganda *African Journal of Food Science* 11: 160–170.

Bennet, R. and Monday, S. 2003. Staphylococcus aureus. In: *International handbook of foodborne pathogens*. CRC Press.

Braae, U.C., Magnussen, P., Lekule, F., Harrison, W. and Johansen, M.V. 2014. Temporal fluctuations in the sero-prevalence of Taenia solium cysticercosis in pigs in Mbeya Region, Tanzania. *Parasites and Vectors* 7: 1–7.

Burlingame, B. and Pineiro, M. 2007. The essential balance: Risks and benefits in food safety and quality *Journal of Food Composition and Analysis*, 20: 139–146.

Canpolat, N, 2015. Hemolytic uremic syndrome *Turk Pediatri Arsivi* 50: 73–82.

Daniel, J., Lewis, L., Redwood, Y., Kieszak, S., Breiman, R., Flanders, D., Bell, C., Mwihia, J., Ogana, G., Likimani, S., Straetemans, M. and McGeehin, M. 2011. Comprehensive assessment of maize aflatoxin levels in eastern Kenya, 2005-2007. *Environmental Health Perspectives* 119: 1794–1799.

David, M.Z., Glikman, D., Crawford, S.E., Peng, J., King, K.J., Hostetler, M.A., Boyle-Vavra, S. and Daum, R.S, 2008. What is community-associated methicillin-resistant Staphylococcus aureus? *Journal of Infectious Diseases* 197: 1235–1243.

Donnenberg, M.S. and Whittam, T.S. 2001. Pathogenesis and evolution of virulence in enteropathogenic and enterohemorrhagic *Escherichia coli*. *Journal of Clinical Investigation*, 107, 539–548.

Echodu, R., Maxwell Malinga, G., Moriku Kaducu, J., Ovuga, E. and Haesaert, G. 2019. Prevalence of aflatoxin, ochratoxin and deoxynivalenol in cereal grains in northern Uganda: Implication for food safety and health. *Toxicology Reports* 6: 1012–1017.

Egor, M. and Birungi, G. 2020. Fluoride contamination and its optimum upper limit in groundwater from Sukulu Hills, Tororo District, Uganda. *Scientific African* 7: e00241.

Ehuwa, O., Jaiswal, A.K. and Jaiswal, S. 2021. *Salmonella*, food safety and food handling practices. *Foods* 10: 1–16.

Eirik, J. 2013. The effects of fluoride on human health in Eastern Rift Valley, northern Tanzania. Universitetet i Oslo. (Available from https://core.ac.uk/download/pdf/30848945.pdf).

Ekuttan, C., Kangethe, E., Kimani, V. and Randolph, T. 2007. Investigation on the prevalence of antimicrobial residues in milk obtained from urban smallholder dairy and non-dairy farming households in Dagoretti Division, Nairobi, Kenya. *East African Medical Journal* 84: S87-91.

Eom, K.S., Chai, J.Y., Yong, T.S., Min, D.Y., Rim, H.J., Kihamia, C. and Jeon, H.K. 2011. Morphologic and genetic identification of Taenia Tapeworms in Tanzania and DNA genotyping of Taenia solium. *Korean Journal of Parasitology* 49:399–403.

Eshitera, E.E., Githigia, S.M., Kitala, P., Thomas, L.F., Fèvre, E.M. and Harrison, L.J.S. 2012. Prevalence of porcine cysticercosis and associated risk factors in Homa Bay District, Kenya. *BMC Veterinary Research* 8: 234.

Fung, F., Wang, H. and Menon, S. 2018. Food safety in the 21st century. *Biomedical Journal* 41: 88–95.

Gafirita, J., Kiiza, G., Murekatete, A., Ndahayo, L.L., Tuyisenge, J., Mashengesho, V., Ruhirwa, R., Nyandwi, T., Asiimwe-Kateera, B., Ndahindwa, V. and Njunwa, K.J. 2017. Seroprevalence of brucellosis among patients attending a district hospital in Rwanda. *American Journal of Tropical Medicine and Hygiene* 97:831–835.

GFSP (Global Food Safety Partnership). 2019. Food safety in Africa: Past endeavors and future directions.

Gibb, H.J., Barchowsky, A., Bellinger, D., Bolger, P.M., Carrington, C., Havelaar, A.H., Oberoi, S., Zang, Y., O'Leary, K. and Devleesschauwer, B. 2019. Estimates of the 2015 global and regional disease burden from four foodborne metals – arsenic, cadmium, lead and methylmercury *Environmental Research* 174:188–194.

Githigia, S., Murekefu, A. and Otieno, R. 2005. Prevalence of porcine cysticercosis and risk factors for *Taenia solium* taeniosis in Funyula Division of Busia District, Kenya. *Kenya Veterinarian* 29:2005.

Glass, R.I., Parashar, U.D. and Estes, M.K. 2009. Norovirus gastroenteritis *New England Journal of Medicine* 361.

Gölz, G., Rosner, B., Hofreuter, D., Josenhans, C., Kreienbrock, L., Löwenstein, A., Schielke, A., Stark, K., Suerbaum, S., Wieler, L.H. and Alter, T. 2014. Relevance of *campylobacter* to public health–The need for a One Health approach *International Journal of Medical Microbiology* 304: 817–823.

Gordon, M. 2012. Invasive Non-typhoidal Salmonella Disease – epidemiology, pathogenesis and diagnosis *Current Opinion in Infectious Diseases* 24: 484–489.

Grace, D. 2015. Food safety in Low and Middle Income Countries. *Int. J. Environ. Res. Public Health* 12:10490–10507.

Grace, D., Alonso, S., Mutua, F., Roesel, K., Lindahl, J. and Amenu, K. 2018. *Food safety investment expert advice: Burkina Faso, Ethiopia, Nigeria.* Nairobi, Kenya: ILRI.

Grace, D., Dipeolu, M. and Alonso, S. 2019. Improving food safety in the informal sector: nine years later *Infection Ecology and Epidemiology* 9.

Grosshagauer, S., Milani, P., Kraemer, K., Mukabutera, A., Burkon, A., Pignitter, M., Bayer, S. and Somoza, V. 2020. Inadequacy of nutrients and contaminants found in porridge-type complementary foods in Rwanda. *Maternal and Child Nutrition* 16:1–9.

Hald, T., Aspinall, W., Devleesschauwer, B. and Cooke, R. 2016. World Health Organization estimates of the relative contributions of food to the burden of disease due to selected foodborne hazards: a structured expert elicitation. *PLoS One* 1–35.

Havelaar, A., Kirk, M., Torgerson, P., Gibb, H., Hald, T., Lake, R.J., Praet, N., Bellinger, D., de Silva, N., Gargouri, N., Speybroeck, N., Cawthorne, A., Mathers, C., Stein, C., Angulo, F. and Devleesschauwer, B. 2015. World Health Organization Global Estimates and Regional Comparisons of the Burden of Foodborne Disease in 2010. *PLoS Medicine* 12: 1–23.

Heilmann, M., Ndoboli, D., Roesel, K., Grace, D., Huehn, S., Bauer, B. and Clausen, P.-H. 2015. *Occurrence of Salmonella spp in Flies and Foodstuff from Pork Butcheries in Kampala, Uganda.* In:, Proceedings of the annual expert meeting on parasitology and parasitic diseases at the German Veterinary Association, Stralsund, Germany, 29 June–1 July 2015.

Hoffmann, S., Devleesschauwer, B., Aspinall, W., Cooke, R., Corrigan, T., Havelaar, A., Angulo, F., Gibb, H., Kirk, M., Lake, R., Speybroeck, N., Torgerson, P. and Hald, T. 2017. Attribution of global foodborne disease to specific foods : Findings from a World Health Organization structured expert elicitation. *PLoS ONE* 1–26.

Hounmanou, Y.M.G., Mdegela, R.H., Dougnon, T. V., Mhongole, O.J., Mayila, E.S., Malakalinga, J., Makingi, G. and Dalsgaard, A. 2016. Toxigenic Vibrio cholerae O1 in vegetables and fish raised in wastewater irrigated fields and stabilization ponds during a non-cholera outbreak period in Morogoro, Tanzania: An environmental health study. *BMC Research Notes*, 9, 1–8.

Imathiu, S. 2018. Quantitative microbiological risk assessment of two street foods sold in a Kenyan town with regard to *Salmonella* contamination. *Current Research in Nutrition and Food Science*, 6, 41–50.

Iramiot, J.S., Rwego, I.B., Kansiime, C. and Asiimwe, B.B. 2019. Epidemiology and antibiotic susceptibility of Vibrio cholerae associated with the 2017 outbreak in Kasese District, Uganda. *BMC Public Health* 19:1–9.

Jaffee, S., Spencer, H., Laurian, U., Delia, G. and Emilie, C. 2019. *The Safe Food Imperative: Accelerating progress in low- and middle-income countries*. Agriculture and Food Series. Washington, DC: World Bank.

Joachim, A., Moyo, S.J., Nkinda, L., Majigo, M., Mbaga, E., Mbembati, N., Aboud, S. and Lyamuya, E.F. 2017. Prevalence of methicillin-resistant Staphylococcus aureus carriage on admission among patients attending regional hospitals in Dar es Salaam, Tanzania. *BMC Research Notes* 10 1–7.

Kagera, I., Kahenya, P., Mutua, F., Anyango, G., Kyallo, F., Grace, D. and Lindahl, J. 2019. Status of aflatoxin contamination in cow milk produced in smallholder dairy farms in urban and peri-urban areas of Nairobi County: a case study of Kasarani sub county, Kenya. *Infection Ecology and Epidemiology*, 9.

Kagira, J.M., Maingi, N., Kanyari, P.W.N., Githigia, S.M., Ng'ang'a, J.C. and Gachohi, J.M. 2010. Seroprevalence of Cysticercus cellulosae and associated risk factors in free-range pigs in Kenya *Journal of Helminthology* 84: 398–403.

Kahama, R.W., Kariuki, D.N., Kariuki, H.N. and Njenga, L.W. 1997. Fluorosis in children and sources of fluoride around Lake Elementaita region of Kenya. *Fluoride* 30: 19–25.

Kaltenthaler, E., Cooper, K., Pandor, A., Martyn-St James, M., Chatters, R. and Wong, R. 2016. The use of rapid review methods in health technology assessments: 3 case studies. *BMC Medical Research Methodology* 16: 1–10.

Kamana, O., Ceuppens, S., Jacxsens, L., Kimonyo, A. and Uyttendaele, M. 2014. Microbiological quality and safety assessment of the Rwandan milk and dairy chain. *Journal of Food Protection*, 77, 299–307.

Kangethe, E.K., Onono, J.O., McDermott, B. and Arimi, M. 2007. Isolation of E. Coli 0157:h7 from milk and cattle faeces from urban dairy farming and non dairy farming neighbour households in Dagoretti Division, Nairobi, Kenya: Prevalence and risk factors. *East African Medical Journal* 84.

Kapeleka, J.A., Sauli, E., Sadik, O. and Ndakidemi, P.A. 2020. Co-exposure risks of pesticides residues and bacterial contamination in fresh fruits and vegetables under smallholder horticultural production systems in Tanzania *PLoS ONE* 15: 1–23.

Kashoma, I.P., Kassem, I.I., John, J., Kessy, B.M., Gebreyes, W., Kazwala, R.R. and Rajashekara, G. 2016. Prevalence and antimicrobial resistance of *campylobacter* isolated from dressed beef carcasses and raw milk in Tanzania. *Microbial Drug Resistance* 22: 40–52.

Kashoma, I.P., Kassem, I.I., Kumar, A., Kessy, B.M., Gebreyes, W., Kazwala, R.R. and Rajashekara, G. 2015. Antimicrobial resistance and genotypic diversity of campylobacter isolated from pigs, dairy, and beef cattle in Tanzania. *Frontiers in Microbiology* 6: 1–11.

Kasozi, K., Otim, E., Ninsiima, H., Zirintunda, G., Tamale, A., Ekou, J., Musoke, G., Muyinda, R., Matama, K., Mujinya, R., Matovu, H., Ssempijja, F., Eze, E., Atino, M., Udechukwu, B., Kayima, R., Etiang, P., Ayikobua, E., Kembabazi, S., Usman, I., Sulaiman, S., Natabo, P., Kyeyune, G., Batiha, G. and Otim, O. 2021. An analysis of heavy metals contamination and estimating the daily intakes of vegetables from Uganda. *Toxicology Research and Application* 5: 239784732098525.

Khangura, S., Konnyu, K., Cushman, R., Grimshaw, J. and Moher, D. 2012. Evidence summaries: The evolution of a rapid review approach. *Systematic Reviews* 1.

Kiambi, S.G., Fèvre, E.M., Omolo, J., Oundo, J. and de Glanville, W.A. 2020. Risk factors for acute human brucellosis in Ijara, North-Eastern Kenya. *PLoS Neglected Tropical Diseases* 14: 1–16.

Kilonzo, R., Imungi, J., Muiru, W., Lamuka, P. and Njage, P. 2014. Household dietary exposure to aflatoxins from maize and maize products in Kenya. *Food Additives and Contaminants* (A) 31: 2055–2062.

Kimanya, M., De Meulenaer, B., Tiisekwa, B., Ndomondo-Sigonda, M., Devlieghere, F., Van Camp, J. and Kolsteren, P. 2008. Co-occurrence of fumonisins with aflatoxins in home-stored maize for human consumption in rural villages of Tanzania. *Food Additives and Contaminants* A (25): 1353–1364.

Kirino, Y., Makita, K., Grace, D. and Lindahl, J. 2016. Survey of informal milk retailers in Nairobi, Kenya and prevalence of aflatoxin M1 in marketed milk. *African Journal of Food, Agriculture, Nutrition and Development* 16:11022–11038.

Kitya, D., Bbosa, G. and Mulogo, E. 2009. Aflatoxin levels in common foods of South Western Uganda: A risk factor to hepatocellular carcinoma. *European Journal of Cancer Care* 19: 516–521.

Kivaria, F.M., Noordhuizen, J.P.T.M. and Kapaga, A.M. 2006. Evaluation of the hygienic quality and associated public health hazards of raw milk marketed by smallholder dairy producers in the Dar es Salaam region, Tanzania. *Tropical Animal Health and Production* 38: 185–194.

Kunyanga, C., Amimo, J., Njue, L. and Cheminingwa, G. 2018. Consumer Risk Exposure to Chemical and Microbial Hazards Through Consumption of Fruits and Vegetables in Kenya Consumer Risk Exposure to Chemical and Microbial Hazards Through Consumption of Fruits and Vegetables in Kenya. *Food Science and Quality Management* 78.

Kusiluka, L.J.M., Karimuribo, E.D., Mdegela, R.H., Luoga, E.J., Munishi, P.K.T., Mlozi, M.R.S. and Kambarage, D.M. 2005. Prevalence and impact of water-borne zoonotic pathogens in water, cattle and humans in selected villages in Dodoma Rural and Bagamoyo districts, Tanzania/ *Physics and Chemistry of the Earth* A/B/C 30: 818–825.

Kwesiga, B., Pande, G., Ario, A.R., Tumwesigye, N.M., Matovu, J.K.B. and Zhu, B.P. 2017. A prolonged, community-wide cholera outbreak associated with drinking water contaminated by sewage in Kasese District, western Uganda. *BMC Public Health* 18: 1–8.

Lewis, L., Onsongo, M., Njapau, H., Schurz-Rogers, H., Luber, G., Kieszak, S., Nyamongo, J., Backer, L., Dahiye, A., Misore, A., DeCock, K. and Rubin, C. 2005. Aflatoxin contamination of commercial maize products during an outbreak of acute aflatoxicosis in eastern and central Kenya. *Environmental Health Perspectives* 113: 1763–7.

Li, M., Havelaar, A., Hoffman, S., Hald, T., Kirk, M., Torgerson, T. and Devleesschauwer, B. 2019. Global disease burden of pathogens in animal-source foods, 2010. *PLoS ONE* 14.

Lindahl, J.F., Kagera, I.N. and Grace, D., 2018. Aflatoxin M1 levels in different marketed milk products in Nairobi, Kenya. *Mycotoxin Research* 34:289–295.

Lozano, C., Gharsa, H., Ben Slama, K., Zarazaga, M. and Torres, C. 2016. Staphylococcus aureus in Animals and Food: Methicillin Resistance, Prevalence and Population Structure. A Review in the African Continent. *Microorganisms* 4:12.

Luwumba, D., Kusiluka, L. and Shirima, S. 2019. Occupational hazards associated with human brucellosis in abattoir settings: A case study of Dodoma abattoir in Tanzania. *Journal of Veterinary Medicine and Animal Health* 11: 73–80

Martinez, H. and Tomkins, A.M. 1995. Nutritional management of diarrhoea. *Food and Nutrition Bulletin* 16 349–355.

Masaisa, F., Kayigi, E., Seni, J., Bwanga, F. and Muvunyi, C.M. 2018. Antibiotic resistance patterns and molecular characterization of methicillin-resistant Staphylococcus aureus in clinical settings in Rwanda. *American Journal of Tropical Medicine and Hygiene* 99:1239–1245.

Mbabazi, J. and Wasswa, J. 2010. Contamination by heavy metals in silver fish (Rastreneobola argentea) caught from Lakes Kyoga and Victoria, Uganda. *International Journal of Environmental Studies* 67:543–556.

Mdegela, R., Laurence, K., Jacob, P. and Nonga, H. 2011. Occurrences of thermophilic Campylobacter in pigs slaughtered at Morogoro Occurrences of thermophilic Campylobacter in pigs slaughtered at Morogoro slaughter slabs, Tanzania. *Trop Animal Health Production*. doi: 10.1007/s11250-010-9657-4.

Mdegela, R.H., Ryoba, R., Karimuribo, E.D., Phiri, E.J., Løken, T., Reksen, O., Mtengeti, E. and Urio, N.A. 2009. Prevalence of clinical and subclinical mastitis and quality of milk on smallholder dairy farms in Tanzania. *Journal of the South African Veterinary Association* 80:163–168.

Mmongoyo, J.A., Wu, F., Linz, J.E., Nair, M.G., Mugula, K., Tempelman, R.J. and Strasburg, G.M. 2017. Aflatoxin levels in sunflower seeds and cakes collected from micro- and small-scale sunflower oil processors in Tanzania. *PLoS ONE* 12.

Moturi, W., Tole, M. and Davies, T. 2002. The Contribution of Drinking Water towards Dental Fluorosis: A case study of Njoro Division, Nakuru District, Kenya. E*nvironmental geochemistry and Health* 24(2).

Mukantwali, C., Henry, L., Bendantunguka, T. and Simeon, W. 2014. Microbial and heavy metal contamination of pineapple products processed by small and medium scale processing enterprises in Rwanda. *African Journal of Biotechnology* 13: 3977–3984.

Mulindwa, D., Aisu, T., Gleir, K., Zimmermann, S. and Beutin, L. 2001. Occurrence of Shiga toxin-producing Escherichia coli in fecal samples from children with diarrhea and from healthy zebu cattle in Uganda. *International Journal of Food Microbiology* 66: 95–101.

Munimbazi, C. and Bullerman, L. 1996. Molds and mycotoxins in foods from Burundi. *Journal of Food Protection* 59: 869–875.

Mutegi, C.K., Ngugi, H.K., Hendriks, S.L. and Jones, R.B. 2009. Prevalence and factors associated with aflatoxin contamination of peanuts from western, Kenya. *International Journal of Food Microbiology* 130:27–34.

Mutiga, S., Were, V., Hoffmann, V., Harvey, J., Milgroom, M. and Nelson, R. 2014. Extent and drivers of mycotoxin contamination: Inferences from a survey of Kenyan maize mills. *Phytopathology* 104: 1221–1231.

Mutiga, S.K., Hoffmann, V., Harvey, J.W., Milgroom, M.G. and Nelson, R.J. 2015. Assessment of aflatoxin and fumonisin contamination of maize in western Kenya. *Phytopathology* 105:1250–1261.

Mutua, F.K., Randolph, T.F., Arimi, S.M., Kitala, P.M., Githigia, S.M., Willingham, a. L. and Njeruh, F.M. 2007. Palpable lingual cysts, a possible indicator of porcine cysticercosis, in Teso District, Western Kenya. *Journal of Swine Health and Production* 15: 206.

Muwonge, A., Kankya, C., Godfroid, J., Djonne, B., Opuda-Asibo, J., Biffa, D., Ayanaw, T., Munyeme, M. and Skjerve, E. 2010. Prevalence and associated risk factors of mycobacterial infections in slaughter pigs from Mubende district in Uganda. *Tropical Animal Health and Production* 42:905–913.

Mwihia, J., Straetmans, M., Ibrahim, A., Njau, J., Muhenje, O., Guracha, A., Gikundi, S., Mutonga, D., Tetteh, C., Likimani, S., Breiman, R., Njenga, K. and Lewis, L. 2008. Aflatoxin Levels in Locally Grown Maize from Makueni District, Kenya. *East African Medical Journal* 85:311–317.

Nabwire, W., Ombaka, J., Dick, C., Strickland, C., Tang, L., Xue, K. and Wang, J. 2019. Aflatoxin in household maize for human consumption in Kenya. *East Africa Food Additives and Contaminants: Part B Surveillance* 13:45–51.

Nakanwagi, M., Ario, A.R., Kwagonza, L., Aceng, F.L., Mwesigye, J., Bulage, L., Buule, J., Sendagala, J.N., Downing, R. and Zhu, B.P. 2020. Outbreak of gastrointestinal anthrax following eating beef of suspicious origin: Isingiro District, Uganda. *PLoS Neglected Tropical Diseases* 14:1–12.

Nel, E.D. 2010. Diarrhoea and malnutrition. *South African Journal of Clinical Nutrition* 23:15–18

Ngasala, J. uma B., Nonga, H.E. and Mtambo, M.M.A. 2015. Assessment of raw milk quality and stakeholders' awareness on milk-borne health risks in Arusha City and Meru District, Tanzania. *Tropical Animal Health and Production* 47: 927–932.

Ngowi, H.A., Kassuku, A.A., Maeda, G.E.M., Boa, M.E. and Willingham, A.L. 2004. A slaughter slab survey for extra-intestinal porcine helminth infections in Northern Tanzania. *Tropical Animal Health and Production* 36: 335–340.

Nguhiu, P., Kamau, L., Kinyua, K. and Matonge, P. 2017. Seroprevalence of porcine cysticercosis and associated risk factors in pigs slaughtered in abattoirs in Thika, Kiambu County, Kenya. *Journal of Life Sciences* 11.

Niyonzima, E., Ongol, M.P., Brostaux, Y., Korsak Koulagenko, N., Daube, G., Kimonyo, A. and Sindic, M. 2017. Consumption patterns, bacteriological quality and risk factors for Salmonella contamination in meat-based meals consumed outside the home in Kigali, Rwanda. *Food Control* 73546–554.

Niyonzima, E., Ongol, M.P., Brostaux, Y., Korsak, N., Daube, G., Kimonyo, A. and Sindic, M. 2018. Meat retail conditions within the establishments of Kigali city (Rwanda): Bacteriological quality and risk factors for *Salmonella* occurrence. *Tropical Animal Health and Production* 50: 537–546.

Nonga, H.E., Ngowi, H.A., Mdegela, R.H., Mutakyawa, E., Nyahinga, G.B., William, R. and Mwadini, M.M. 2015. Survey of physicochemical characteristics and microbial contamination in selected food locally vended in Morogoro Municipality, Tanzania. *Microbiology BMC Research Notes* 8: 1–10.

Nonga, H.E., Sells, P. and Karimuribo, E.D. 2009. Occurrences of thermophilic Campylobacter in cattle slaughtered at Morogoro municipal abattoir, Tanzania. T*ropical Animal Health and Production* 42:73–78.

Nsengimana, H., Masengesho, F. and Kalisa Nyirimbibi, D. 2012. Some physico-chemical characteristics of ground water in Rwanda. *Rwanda Journal* 25: 101–109.

Nyangi, C., Mugula, J., Beed, F., Boni, S., Koyano, E. and Sulyok, M. 2016. Aflatoxins and fumonisin contamination of marketed maize , maize bran and maize used as animal feed in Northern Tanzania. *African Journal of Food, Agriculture, Nutrition and Development* 16.

Nyarango, R.M., Aloo, P.A., Kabiru, E.W. and Nyanchongi, B.O. 2008. The risk of pathogenic intestinal parasite infections in Kisii Municipality, Kenya. *BMC Public Health* 8: 1–6.

Nzabahimana, I., Mpunga, T., Karenzi, A. and Umubyeyi, A. 2014. Food borne outbreak of salmonellosis at a church gathering, Rwanda. *International Journal of Infectious Diseases* 105–106.

O'Reilly, C.E., Jaron, P., Ochieng, B., Nyaguara, A., Tate, J.E., Parsons, M.B., Bopp, C.A., Williams, K.A., Vinjé, J., Blanton, E., Wannemuehler, K.A., Vulule, J., Laserson, K.F., Breiman, R.F., Feikin, D.R., Widdowson, M.A. and Mintz, E. 2012. Risk factors for death among children less than 5 years old hospitalized with diarrhea in rural Western Kenya, 2005-2007: A cohort study. *PLoS Medicine* 9: 2005–2007.

Odoch, T., Wasteson, Y., L'Abée-Lund, T., Muwonge, A., Kankya, C., Nyakarahuka, L., Tegule, S. and Skjerve, E. 2017. Prevalence, antimicrobial susceptibility and risk factors associated with non-typhoidal Salmonella on Ugandan layer hen farms. *BMC Veterinary Research* 13: 1–10.

Oguttu, D.W., Okullo, A., Bwire, G., Nsubuga, P. and Ario, A.R. 2017. Cholera outbreak caused by drinking lake water contaminated with human faeces in Kaiso Village, Hoima District, Western Uganda. *Infectious Diseases of Poverty* 6: 1–7.

Omwenga, I., Aboge, G.O., Mitema, E.S., Obiero, G., Ngaywa, C., Ngwili, N., Wamwere, G., Wainaina, M. and Bett, B. 2019. *Staphylococcus aureus* enterotoxin genes detected in milk from various livestock species in northern pastoral region of Kenya. *Food Control* 103: 126–132.

Omwenga, I., Kanja, L., Zomer, P., Louisse, J., Rietjens, I.M.C.M. and Mol, H. 2021. Organophosphate and carbamate pesticide residues and accompanying risks in commonly consumed vegetables in Kenya. *Food Additives and Contaminants: Part B Surveillance* 14: 48–58.

Oundo, J.O., Kariuki, S.M., Boga, H.I., Muli, F.W. and Iijima, Y. 2008. High incidence of enteroaggregative *Escherichia coli* among food handlers in three areas of Kenya: A possible transmission route of travelers' diarrhea. *Journal of Travel Medicine* 15: 31–38.

Öztürk, M., Özözen, G., Minareci, O. and Minareci, E. 2009. Determination of heavy metals in fish, water and sediments of Avsar Dam lake in Turkey. *Iranian Journal of Environmental Health Science and Engineering* 6 73–80.

Pall, D., Carpio, A. and Sander, J. 2000. Neurocysticercosis and epilepsy in developing countries. *Journal of Neurology Neurosurgery and Psychiatry* 68:137–143.

Pande, G., Kwesiga, B., Bwire, G., Kalyebi, P., Riolexus, A.A., Matovu, J.K.B., Makumbi, F., Mugerwa, S., Musinguzi, J., Wanyenze, R.K. and Zhu, B.P. 2018. Cholera outbreak caused by drinking contaminated water from a lakeshore water-collection site, Kasese District, south-western Uganda, June-July 2015 *PLoS ONE* 13: 1–11.

Parsons, M.B., Travis, D., Lonsdorf, E. V., Lipende, I., Roellig, D.M.A., Kamenya, S., Zhang, H., Xiao, L. and Gillespie, T.R. 2015. Epidemiology and molecular characterization of cryptosporidium spp in humans, wild primates, and domesticated animals in the Greater Gombe ecosystem, Tanzania. *PLoS Neglected Tropical Diseases* 9:1–13.

Pegues, D.A., Ohl, M.E. and Miller, S.I. 2001. Nontyphoidal Salmonellosis. *Clinical Infectious Diseases* 32: 263–269.

Probst, C., Njapau, H. and Cotty, P.J. 2007. Outbreak of an acute aflatoxicosis in Kenya in 2004: Identification of the causal agent. *Applied and Environmental Microbiology* 73: 2762–2764.

Rao, V.M. and Murthy, H.C.A. 2017. Determination of Concentrations of Selected Heavy metals in Cow's Milk: Dodoma Urban District, Tanzania Int. *Journal of Engineering Research and Application* 7: 76–84.

Robinson, M.W. and Dalton, J.P. 2009. Zoonotic helminth infections with particular emphasis on fasciolosis and other trematodiases. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364:2763–2776.

Roesel, K., Nöckler, K., Baumann, M.P.O., Fries, R., Dione, M.M., Clausen, P.H. and Grace, D. 2016. First report of the occurrence of trichinella-specific antibodies in domestic pigs in central and eastern Uganda. *PLoS ONE* 11: 1–16.

Rostrup, M., Edwards, J.K., Abukalish, M., Ezzabi, M., Some, D., Ritter, H., Menge, T., Abdelrahman, A., Rootwelt, R., Janssens, B., Lind, K., Paasma, R. and Hovda, K.E. 2016. The methanol poisoning outbreaks in Libya 2013 and Kenya 2014. *PLoS ONE* 11: 1–10.

Rwenyonyi, C.M., Birkeland, J.M., Haugejorden, O. and Bjorvatn, K. 2001. Dental caries among 10- to 14-year-old children in Ugandan rural areas with 0.5 and 2.5 mg fluoride per liter in drinking water. *Clinical Oral Investigations* 5:45–50.

Saidi, S.M., Iijima, Y., Sang, W.K., Mwangudza, A.K., Oundo, J.O., Taga, K., Aihara, M., Nagayama, K., Yamamoto, H., Waiyaki, P.G. and Honda, T. 1997. Epidemiological study on infectious diarrheal diseases in children in a coastal rural area of Kenya. *Microbiology and Immunology* 41: 773–778.

Schoder, D. 2010. Melamine milk powder and infant formula sold in East Africa. *Journal of Food Protection* 73:1709–1714.

Schoder, D., Maichin, A., Lema, B. and Laffa, J. 2013. Microbiological quality of milk in Tanzania: From Maasai stable to African consumer table. *Journal of Food Protection* 76: 1908–1915.

Seetha, A., Munthali, W., Msere, H.W., Swai, E., Muzanila, Y., Sichone, E., Tsusaka, T.W., Rathore, A. and Okori, P. 2017. Occurrence of aflatoxins and its management in diverse cropping systems of central Tanzania. *Mycotoxin Res* 33:323–331.

Senerwa, D., Sirma, J., Mtimet, N., Kangethe, E., Grace, D. and Lindahl, J. 2016. Prevalence of aflatoxins in feeds and cow milk from five counties in Kenya. *African Journal of Food, Agriculture, Nutrition and Development* 16:11004–11021.

Shen, J., Mkongo, G., Abbt-Braun, G., Ceppi, S., Richards, B. and Schäfer, A. 2015. Renewable energy powered membrane technology: Fluoride removal in a rural community in northern Tanzania. *Separation and Purification Technology* 149:349–361.

Shitandi, A. and Sternesjö, A. 2001. Detection of antimicrobial drug residues in Kenyan milk. *Journal of Food Safety* 21:205–214.

Shorter, J.P., Massawe, J., Parry, N. and Walker, R.W. 2010. Comparison of two village primary schools in northern Tanzania affected by fluorosis *International Health* 2: 269–274.

Sirma, A. Lindahl, J., Makita, K., Senerwa, D., Mtimet, N., Kang'ethe, E. and Grace, D. 2018. The impacts of aflatoxin standards on health and nutrition in sub-Saharan Africa: The case of Kenya. *Global Food Security* 18: 57–61.

Sirma, A.J., Makita, K., Randolph, D.G., Senerwa, D. and Lindahl, J.F. 2019. Aflatoxin exposure from milk in rural Kenya and the contribution to the risk of liver cancer. *Toxins* 11: 1–12.

Smedley, P.L., Nkotagu, H., Pelig-Ba, K., MacDonald, A.M., Whittle, R.T., Whitehead, E.J. and Kinniburgh, D.G. 2002. Fluoride in groundwater from high-fluoride areas of Ghana and Tanzania. (Available from http://resources.bgs.ac.uk/sadcreports/tanzania2002smedleyfluoridecr02316n.pdf).

Ssemanda, J.N., Reij, M.W., van Middendorp, G., Bouw, E., van der Plaats, R., Franz, E., Muvunyi, C.M., Bagabe, M.C., Zwietering, M.H. and Joosten, H. 2018. Foodborne pathogens and their risk exposure factors associated with farm vegetables in Rwanda. *Food Control* 89:86–96.

Stanaway, J.D., Parisi, A., Sarkar, K., Blacker, B.F., Reiner, R.C., Hay, S.I., Nixon, M.R., Dolecek, C., James, S.L., Mokdad, A.H., Abebe, G., Ahmadian, E., Alahdab, F., Alemnew, B.T.T., Alipour, V., Allah Bakeshei, F., Animut, M.D., Ansari, F., Arabloo, J., Asfaw, E.T., Bagherzadeh, M., Bassat, Q., Belayneh, Y.M.M., Carvalho, F., Daryani, A., Demeke, F.M., Demis, A.B.B., Dubey, M., Duken, E.E., Dunachie, S.J., Eftekhari, A., Fernandes, E., Fouladi Fard, R., Gedefaw, G.A., Geta, B., Gibney, K.B., Hasanzadeh, A., Hoang, C.L., Kasaeian, A., Khater, A., Kidanemariam, Z.T., Lakew, A.M., Malekzadeh, R., Melese, A., Mengistu, D.T., Mestrovic, T., Miazgowski, B., Mohammad, K.A., Mohammadian, M., Mohammadian-Hafshejani, A., Nguyen, C.T., Nguyen, L.H., Nguyen, S.H., Nirayo, Y.L., Olagunju, A.T., Olagunju, T.O., Pourjafar, H., Qorbani, M., Rabiee, M., Rabiee, N., Rafay, A., Rezapour, A., Samy, A.M., Sepanlou, S.G., Shaikh, M.A., Sharif, M., Shigematsu, M., Tessema, B., Tran, B.X., Ullah, I., Yimer, E.M., Zaidi, Z., Murray, C.J.L. and Crump, J.A. 2019. The global burden of non-typhoidal salmonella invasive disease: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet Infectious Diseases* 19:1312–1324.

Steinbaum, L., Swarthout, J., Mboya, J. and Pickering, A.J. 2017. Following the worms: Detection of soil-transmitted helminth eggs on mothers ' hands and household produce in rural Kenya. *American Journal Tropical Med Hygiene* 97: 1616–1618.

Swai, E. and Schoonman, L. 2011. Microbial quality and associated health risks of raw milk marketed in the Tanga region of Tanzania. *Asian Pacific Journal of Tropical Biomedicine*: 1, 217–222.

Swai, E.S. and Kaaya, J.E. 2013. A survey of Toxoplasma gondii antibodies by latex agglutination assay in dairy goats in Northern Tanzania. *Tropical Animal Health and Production* 45: 211–217.

Taylor, L.H., Latham, S.M. and Woolhouse, M.E.J. 2001. Risk factors for human disease emergence Philosophical Transactions of the Royal Society. *B. Biological Sciences* 356: 983–989.

Thomas, L.F., Jayne, L., Harrison, S., Toye, P., Glanville, W.A. De, Anne, E., Cook, J., Wamae, C.N. and Fèvre, E.M. 2016. Prevalence of Taenia solium cysticercosis in pigs entering the food chain in western Kenya. *Tropical Animal Health and Production* 48:233–238.

Tsai, K., Simiyu, S., Mumma, J., Aseyo, R.E., Cumming, O., Dreibelbis, R. and Baker, K.K. 2019. Enteric pathogen diversity in infant foods in low-income neighborhoods of Kisumu, Kenya. *International Journal of Environmental Research and Public Health*:16.

Udomkun, P., Mutegi, C., Wossen, T., Atehnkeng, J., Nabahungu, N.L., Njukwe, E., Vanlauwe, B. and Bandyopadhyay, R. 2018. Occurrence of aflatoxin in agricultural produce from local markets in Burundi and Eastern Democratic Republic of Congo. *Food Science and Nutrition*, 6:2227–2238.

Viray, M., Wamala, J., Fagan, R., Luquez, C., Maslanka, S., Downing, R., Biggerstaff, M., Malimbo, M., Kirenga, J., Nakibuuka, J., Ddumba, E., Mbabazi, W. and Swerdlow, L. 2015. Outbreak of Type A Foodborne Botulism in a Boarding School – Uganda, 2008. *Epidemiol Infect* 142: 2297–2301.

Wainaina, E., Otieno, C.A., Kamau, J., Nyachieo, A. and Lowther, S.A., 2020. Norovirus infections and knowledge, attitudes and practices in food safety among food handlers in an informal urban settlement, Kenya 2017. *BMC Public Health* 20:1–8.

Wambu, E.W., Agong, S.G., Anyango, B., Akuno, W. and Akenga, T. 2014. High fluoride water in Bondo-Rarieda area of Siaya County, Kenya: A hydro-geological implication on public health in the Lake Victoria Basin. *BMC Public Health* 14: 1–8

Wangai, F.K., Masika, M.M., Maritim, M.C. and Seaton, R.A. 2019. Methicillin-resistant Staphylococcus aureus (MRSA) in East Africa: Red alert or red herring? *BMC Infectious Diseases* 19: 1–10.

WHO (World Health Organization). 2008. Guidelines for drinking-water quality. (Available from https://www.who.int/water_sanitation_health/dwq/fulltext.pdf).

WHO, 2015. WHO estimates of the global burden of foodborne diseases. (Available from https://apps.who.int/iris/bitstream/handle/10665/199350/9789241565165_eng.pdf;jsessionid=3F0E1E5C0D6D716BA0F08C961EBC9929?sequence=1).

William, N., Godfrey, M. and Savino, B. 2011. Assessment of Heavy Metals in Milk from Selected Dairy Farms and Shops in Wakiso District, Uganda. *Suza Journal of Naturaal and Social Science* 1: 36–52.

Yoder, K., Mabelya, L., Robison, V., Dunipace, A., Brizendine, E. and Stookey, G. 1998. Severe dental fluorosis in a Tanzanian population consuming water with negligible fluoride concentration. *Community Dentistry and Oral Epidemiology* 26: 382–393

Zahedi, A., Paparini, A., Jian, F., Robertson, I. and Ryan, U. 2016. Public health significance of zoonotic Cryptosporidium species in wildlife: Critical insights into better drinking water management International Journal for Parasitology: *Parasites and Wildlife* 5:88–109.