*zoonotic diseases*

MDPI

*Systematic Review*

# Identifying Pig- and Pork-Associated Zoonotic and Foodborne Hazards in Eastern and Southern Africa: A Systematised Review

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**Simple Summary:** Through a systematized literature review we have identified a wide variety of pig- and pork-associated zoonotic and foodborne hazards in Eastern and Southern Africa (ESA). Of 60 pig- and pork-associated hazards identified in the region, *Salmonella* spp., *Escherichia coli*, *Staphylococcus* spp., and *Taenia* spp. were the most often studied. Country-specific and pig- and pork-specific research is crucial to reduce the risk these hazards pose to communities.

**Abstract:** Zoonotic and foodborne diseases are a major cause of morbidity and mortality, especially in low- and middle-income countries. Pork is a potential source of zoonotic and foodborne diseases, and pork consumption is rapidly increasing in Eastern and Southern Africa (ESA). Here, studies conducted in ESA describing pig- and pork-associated zoonotic and foodborne hazards were identified to clarify the distribution and prevalence of these hazards and identify research gaps in this region. A systematised literature review was conducted using MEDLINE and Web of Science to identify relevant articles according to pre-determined inclusion/exclusion criteria. In total, 140 articles from 14 countries were identified for review. A total of 42 hazards were identified, categorised as bacterial, viral, parasitic, arthropodal, or other, including drug residues. Among all identified hazards, *Taenia* spp. (n=40) was the most often studied, followed by *Salmonella* spp. (21), *Escherichia coli* (17), and *Staphylococcus* spp. (9). Further research is required to determine baseline data on the epidemiology and health and economic burden associated with pig- and pork-borne hazards and appropriate strategies are needed to mitigate the risk these hazards pose to communities.

**Keywords:** zoonoses; foodborne disease; pigs; pork; Eastern & Southern Africa



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## 1. Introduction

Zoonotic diseases have become increasingly problematic in recent decades owing to farmland expansion and climate change [1,2]. The current COVID-19 pandemic, which is of probable animal origin, has shown that zoonotic diseases can spread rapidly worldwide, affecting health, social activities, and economies [3]. Hence, the clinical and social impacts of emerging zoonotic disease have become apparent. At the same time, a high health and economic burden are imposed by endemic zoonoses including those transmitted through food. Foodborne zoonoses are major causes of morbidity and mortality predominately in low- and middle-income countries (LMICs). The World Health Organization (WHO) estimated that 33 million (95% uncertainty interval [UI]: 25–46 million) disability-adjusted life years (DALYs) were lost to foodborne diseases in 2010 with a disproportionate burden on sub-Saharan Africa [4]. Approximately 35% of this burden was attributable to animal source foods [5]. Annual productivity loss in LMICs due to foodborne disease has been estimated at $95.5 billion [6]. Despite this considerable burden, food-safety receives relatively

little policy attention and there is an urgent need to motivate and empower food sector actors to comply with safety regulations [6].

Among the variety of animal products worldwide, pork is a high-risk source of foodborne diseases [7]. Pork is a major, or sole, food product through which the many important foodborne pathogens are transmitted including *Taenia solium*, *Trichinella* spp., *Brucella* spp., Non-typhoidal *Salmonella enterica*, shiga-toxin producing *E. coli*, and *Campylobacter* spp., [5]. Globally, pork consumption is rising from 9.1 kg/capita in 1964 to a projected 15.1 kg/capita in 2030 [8], and is projected to account for 33% of a total increase in meat consumption by 2030 [9]. This trend is also seen across much of ESA; for example, pork consumption in Kenya is projected to increase by 203% between 2000 and 2030 [10]. In 2020, pork consumption in Kenya, Uganda, and South Africa is estimated to be 0.42, 2.96, and 4.19 kg/capita, respectively [11]. Regardless of its potential, a variety of pig production systems are recognized in ESA, from smallholder to commercial farms, which have been expanding in recent years, and in some areas home consumption still accounts for a large proportion [12].

Despite the significant efforts of the WHO Foodborne Disease Epidemiology Reference Group (WHO-FERG) study, there were challenges with the quality and quantity of African datasets due to data scarcity, which could result in wide error margins in the African datasets for the different diseases [4]. To understand and prepare for the potential risks associated with the increasing production and consumption of pigs and pork, a systematic approach is required to identify the zoonotic and foodborne hazards associated with pigs and pork in ESA. To our knowledge, the present study is the first to identify and map the zoonotic and foodborne hazards relevant to pigs and pork by country in ESA. The objectives of the present study were to (i) systematically search the literature to identify studies conducted in ESA describing pig- and pork-associated zoonotic and foodborne hazards, (ii) describe the distribution and prevalence of these hazards, and (iii) identify gaps in the research to determine the risk to humans from zoonotic and foodborne hazards in pigs and pork.

## 2. Materials and Methods

### *2.1. Review Protocol and Search Strategy*

We conducted a systematised literature review [13] guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach [14]. A syntax was developed for the MEDLINE (PubMed) and Web of Science databases to find relevant articles.

The following search terms were used: (zoono* OR food OR foodborne OR foodborne OR "food safety" OR illness OR pathogen* OR disease* OR hazard* OR risk* OR poison* OR toxin OR microb* OR virus* OR bacter* OR parasite* OR residue NOT "African swine fever") AND (pig OR pigs OR pork OR porcine OR swine) AND (Angola OR Botswana OR Burundi OR Comoros OR Djibouti OR Eritrea OR Ethiopia OR Kenya OR Lesotho OR Madagascar OR Malawi OR Mauritius OR Mayotte OR Mozambique OR Namibia OR Réunion OR Rwanda OR Seychelles OR Socotra OR Somalia OR Puntland OR Somaliland OR South Africa OR Swaziland OR Tanzania OR Zanzibar OR Uganda OR Zambia OR Zimbabwe). Time limits were imposed for studies published between January 2000 to May 2020.

### *2.2. Screening and Data Extraction*

Research articles published between January 2000 and May 2020 documenting evidence of the presence, absence, prevalence, or incidence of zoonotic and foodborne diseases associated with pigs and pork in ESA were included in this review. Studies were excluded for the following reasons: studies focusing on non-zoonotic or non-foodborne domestic pig- or pork-related diseases, experimental laboratory studies, studies conducted outside the geographical region of interest, commentaries and literature reviews (i.e., non-original research publications), conference abstracts, studies relating to human cases that did not

detect a direct relationship between pigs and humans, studies not published in English, studies focusing on non-domestic pigs such as wild pigs or warthogs.

The web application 'Rayyan QCRI' (https://rayyan.qcri.org/welcome, accessed initially on 1 May 2020) was used to manage the articles returned by the searches. After removing duplicate articles, the author and one postgraduate student screened the titles and abstracts according to the inclusion and exclusion criteria. The full texts of the articles were divided between and screened by the author and three collaborators (one postgraduate and two undergraduate students) who consistently followed the inclusion and exclusion criteria.

### *2.3. Data Extraction*

The collaborators and the author extracted the following information from the eligible articles: country, year of the study, study objectives, study type (cross-sectional, cohort study, case-control study, other, or unspecified), pig-farming system (free-range, tethered, housed, combination, or unspecified), sample size, hazard type (virus, bacterium, parasite, mould, chemical, other, or unspecified), specific hazard, sample type (whole blood, sera, meat, faeces, other, or unspecified), assay type (culture, PCR, ELISA, mass spectrometry, other, or unspecified), outcome of the hazard (prevalence, presence, or other), number of cases identified, outcome, 95% confidence interval (CI), and denominator for incidence.

### *2.4. Data Analysis and Quality Assessment*

To quantify the ascertainment and uncertainty of hazards, pooled prevalence was estimated for the top four hazards identified (by number of publications) where sufficient data was present for each country (i.e., more than two prevalence studies). The 'meta' package in R was used to do so. Because the number of positive samples was not available for some studies, we then calculated them from the prevalence estimated in the article. If the studies conducted multiple methods to detect the hazard, the highest reported prevalence was used for our analysis.

Relevant information was extracted into Microsoft Excel (version 2013) for later analysis (see https://doi.org/10.17638/datacat.liverpool.ac.uk/2132, accessed on 21 February 2023 for the data extraction tool) and extracted data were analysed using Microsoft Excel (version 2013) and R (version 4.0.2). We included a subjective appraisal of publication quality, assessed by reading the methods section of each publication, especially the sampling strategy. We report on the presence of sample size calculation, description of sampling method used and whether the publication included a 95% confidence interval calculation around the reported prevalence.

### *2.5. Ethical Approval Statement*

No ethical approval was required for this study which reviews previously published literature.

## 3. Results

### *3.1. Database Search Output and Screening*

The search yielded 1319 articles which were screened according to the predefined criteria above and reported according to the PRISMA approach as shown in Figure 1. After excluding duplicates, 883 articles remained. After screening the titles, 256 articles were identified. After screening the abstracts, 199 articles were eligible for full-text screening, resulting in 140 articles being eligible for qualitative synthesis. The data extracted from the 140 articles can be found in the openly accessible data.

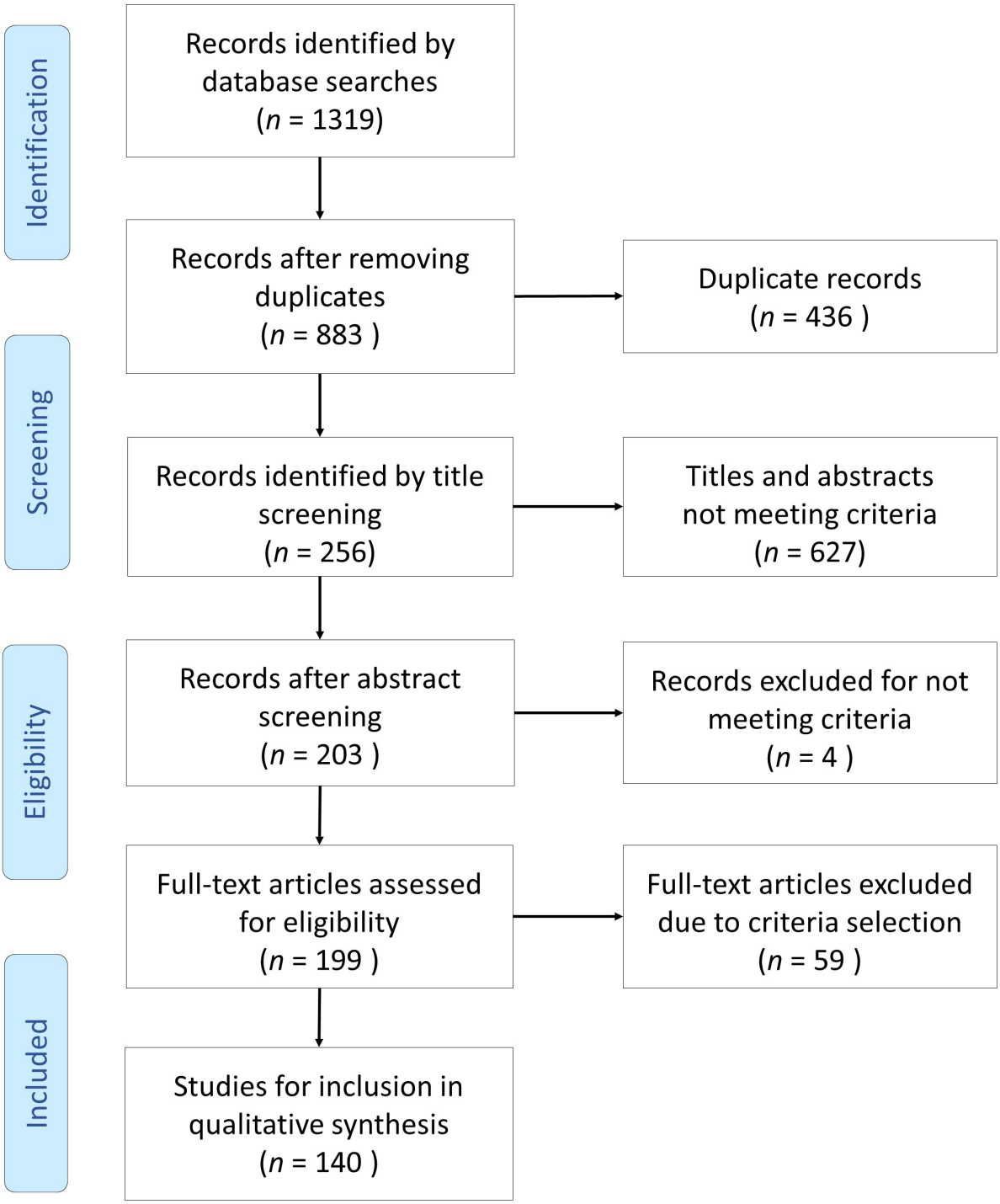


**Figure 1.** Flowchart of the review procedure.

### *3.2. Characteristics of Identified Publications*

In total, 140 articles detailing zoonotic and foodborne hazards relevant to pigs and pork in ESA were identified. Among them, 14 countries were represented: Botswana (3 articles), Ethiopia (11), Kenya (21), Lesotho (1), Madagascar (9), Mauritius (2), Mozambique (4), Réunion (2), Rwanda (1), South Africa (35), Tanzania (14), Uganda (24), Zambia (9), and Zimbabwe (4).

More than 90% of the publications (129 articles) were cross-sectional studies, followed by case studies (6 articles), and cohort studies (2 articles). The remaining studies were

classified as case-control studies, investigations of assay sensitivity and specificity, and development of new hazard detection approaches. For the study outcomes, 75% of the articles (105/140) determined the prevalence of a hazard, while 20% (28/140) focused on hazard presence. The remaining 5% were categorized as "other", including the assessment of diagnostic performance and genomic analysis.

The research quality varied greatly. Only 28 articles provided sample size calculation in the study; 112 articles did not. Forty-eight and 29 articles identified the sampling methods as random and non-random, respectively. Sixty-three articles did not specify the sampling method. Interestingly, although 48 articles mentioned that the sampling method was random, the authors provided no details of the calculations or references. Although prevalence was reported in 105 articles, 107 studies lacked the 95% CIs. Furthermore, few articles specified the type of production system in which the pigs were raised.

### *3.3. Zoonotic and Foodborne Hazards Identified in Pigs and Pork*

More than 60 individual hazards were identified in pigs or pork within the region. Table 1 shows the hazard types (viral, bacterial, parasitic, or other) by country. Parasites were the most commonly studied hazards in pigs and pork in ESA (77 articles), followed by bacteria (71 articles), and viruses (13 articles).

**Table 1.** Hazard types identified in ESA.

| Country | Virus | Bacterium | Parasite | Other ** | Total |
|---|---|---|---|---|---|
| Botswana | 0 | 1 | 4 | 0 | 5 |
| Ethiopia | 1 | 6 | 10 | 0 | 17 |
| Kenya | 3 | 6 | 20 | 2 | 29 |
| Lesotho | 0 | 3 | 0 | 1 | 4 |
| Madagascar | 1 | 4 | 4 | 0 | 9 |
| Mauritius | 0 | 2 | 0 | 0 | 2 |
| Mozambique | 0 | 0 | 4 | 0 | 4 |
| Réunion | 1 | 1 | 0 | 0 | 2 |
| Rwanda | 0 | 3 | 0 | 0 | 3 |
| South Africa | 3 | 26 | 8 | 4 | 41 |
| Tanzania | 0 | 4 | 10 | 0 | 14 |
| Uganda | 4 | 12 | 8 | 0 | 24 |
| Zambia | 0 | 0 | 10 | 0 | 10 |
| Zimbabwe | 0 | 3 | 1 | 0 | 4 |
| Total | 13 | 71 | 77 | 7 | 168 * |

* Because some articles analysed more than one hazard type, the total number of studies was 168 rather than 140; ** The category "other" included fungi, arthropods, and chemicals.

In decreasing order, influenza A virus, hepatitis E virus, rotavirus, henipavirus, norovirus, and Rift Valley fever virus were identified as zoonotic viruses related to pigs and pork as shown in Table 2. Fourteen zoonotic bacteria were identified: *Salmonella* spp., *Escherichia coli*, *Staphylococcus* spp., *Mycobacterium* spp., *Campylobacter* spp., *Leptospira* spp., *Brucella* spp., *Enterococcus* spp., extended-spectrum beta-lactamase (ESBL)-producing bacteria, *Listeria monocytogenes*, *Vibrio cholerae*, *Pasteurella multocida*, *Streptococcus suis*, and mesophilic bacteria. ESBL and mesophilic bacteria were not specifically identified; thus, they were classified as described in the research articles. Of the zoonotic and foodborne parasites identified, *Taenia* spp., mostly *solium*, was the most studied (40 articles), followed by *Trypanosoma* spp., *Ascaris* spp., *Trichostrongylus* spp., *Trichuris* spp., *Cryptosporidium* spp., *Toxoplasma gondii*, *Coccidia* spp., *Echinococcus* spp., *Giardia duodenalis*, *Strongyle* spp., *Trichinella* spp., *Babesia* spp., *Fasciola hepatica* and *Strongyloides* spp. Other pig- and pork-associated zoonotic and foodborne hazards identified in ESA included fungi, arthropods, and chemicals, including drug residues, which were categorised as 'other' as shown in Table 1.

**Table 2.** Zoonotic and foodborne hazards associated with pigs and pork identified in ESA through this systematized review.

| Type * | Hazard | Number of Publications | Individual Hazard | Focus ** | Included in FERG Burden Estimate *** |
|---|---|---|---|---|---|
| Virus (13) | Influenza A | 4 | Influenza A, Influenza A/H1N1/pdm09 | Pigs | - |
| | Hepatitis E | 3 | Hepatitis E | Pigs and pork | - |
| | Rotavirus | 3 | Rotavirus A | Pigs | - |
| | Henipavirus | 1 | Henipavirus | Pigs | - |
| | Norovirus | 1 | Norovirus | Pigs | ✓ |
| | RVF | 1 | Rift Valley Fever | Pigs | - |
| Bacteria (71) | *Salmonella* | 21 | *Salmonella* spp., *S. Choleraesuis*, *S. Enteritidis*, *S. Agona*, *S. Typhimurium*, *S. Derby*, *S. Weltevreden*, *S. Livingstone* | Pigs and pork | ✓ |
| | *Escherichia* | 17 | *Escherichia coli*, Enterotoxigenic *E. coli*, *E. coli*: multi-drug resistance, Coliforms, Shiga toxin-producing *E. coli* (STEC) | Pigs and pork | ✓ |
| | *Staphylococcus* | 9 | *Staphylococcus aureus*, Coagulase-negative *staphylococci*, *S. epidermidis* | Pigs and pork | ✓ |
| | *Mycobacterium* | 6 | *Mycobacterium tuberculosis*, Non-tuberculous *M. M. avium* subsp. *Hominissus*, *M. avium* subsp. *avium* | Pigs | ✓ |
| | *Campylobacter* | 4 | *Campylobacter* spp., *C. jejuni*, *C. coli* | Pork | ✓ |
| | *Leptospira* | 3 | *Leptospira santarosai*, *L. interrogans*, *L. kirschneri*, *L. borgpetersenii* | Pigs | - |
| | *Brucella* | 2 | *Brucella* spp., *B. suis* | Pigs | ✓ |
| | *Enterococcus* | 2 | *Enterococci* spp. | Pork | - |
| | ESBL | 2 | Extended-spectrum beta-lactamase (ESBL)-producing bacteria (*Enterobacteriaceae*) | Pigs and pork | - |
| | *Listeria* | 1 | *Listeria monocytogenes* | Pork | ✓ |
| | *Vibrio* | 1 | *Vibrio cholerae* | Pigs | ✓ |
| | *Pasteurella* | 1 | *Pasteurella multocida* | Pigs | - |
| | *Streptococcus* | 1 | *Streptococcus suis* | Pigs | - |
| | Mesophilic | 1 | Mesophilic bacteria | Pork | - |

**Table 2.** *Cont.*

| Type * | Hazard | Number of Publications | Individual Hazard | Focus ** | Included in FERG Burden Estimate *** |
|---|---|---|---|---|---|
| Parasite (77) | *Taenia* | 40 | *Taenia solium*, *T. hydatigena* | Pigs and pork | ✓ |
| | *Trypanosome* | 7 | *Trypanosome brucei*, *T. brucei rhodesiense*, (*T. vivax*, *T. congolense*, *T. godfreyi*) | Pigs | - |
| | *Ascaris* | 4 | *Ascaris suum*, *A.* spp. | Pigs | ✓ |
| | *Trichuris* | 4 | *Trichuris suis*, *T.* spp. | Pigs | - |
| | *Cryptosporidium* | 3 | *Cryptosporidium* spp. | Pigs | ✓ |
| | *Toxoplasma* | 3 | *Toxoplasma gondii* | Pigs | ✓ |
| | *Coccidia* | 3 | *Coccidia* spp., *Eimeria* spp. | Pigs | - |
| | *Echinococcus* | 2 | *Echinococcus granulosis*, *E. granulosus* G1, *E. ortleppi* | Pork | ✓ |
| | *Giardia* | 2 | *Giardia duodenalis* | Pigs | ✓ |
| | *Strongyle* | 2 | *Strongyle* spp. | Pigs | - |
| | *Trichinella* | 2 | *Trichinella* spp. | Pigs and pork | ✓ |
| | *Trichostrongylus* | 1 | *Trichostrongylus* spp. | Pigs | - |
| | *Babesia* | 1 | *Babesia* spp. | Pigs | - |
| | *Fasciola* | 1 | *Fasciola hepatica* | Pigs | ✓ |
| | *Strongyloides* | 1 | *Strongyloides* spp., *S. ransomi* | Pigs | - |
| Fungi (1) | Fungi | 1 | Fungi (not specified in the genus/species) | Pork | ✓ |
| Arthropod (4) | Tunga | 3 | *Tunga penetrans* | Pigs | - |
| | Sarcoptes | 1 | *Sarcoptes scabiei* | Pigs | - |
| Chemicals (6) | Streptomycin | 2 | Streptomycin-resistance genes | Pork | - |
| | Ciprofloxacin | 1 | Ciprofloxacin | Pork | - |
| | Sulphanilamide | 1 | Sulphanilamide | Pork | - |
| | Tetracycline | 1 | Tetracycline | Pork | - |
| | Metallic compounds | 1 | Metallic compounds (Lead, Cadmium, Silver, Molybdenum, Arsenic, Zinc, Copper, Nikel) | Pigs | - |

* Values inside parentheses represent the total number of studies identifying that hazard type. ** The column "Focus" describes the research focus, i.e., whether the study explored pigs (production) or pork (consumption). *** describes whether the identified hazard is explored in the WHO estimates of the global burden of foodborne diseases [4].

### *3.4. Estimates of Pooled Prevalence*

Figure 2 maps the locations of the four pathogens, *Salmonella* spp., *Escherichia coli*, *Staphylococcus* spp., and *Taenia* spp., which were eligible hazards for pooled prevalence estimates based on a sufficient number of publications. Only *Taenia* spp. had sufficient data to allow for us to estimate pooled prevalence by country; there was not sufficient available information about the number of samples and positives for other hazards. The pooled prevalence, using a random effects model, of *Taenia* spp. were estimated to be 0.17 (95% CI: 0.08–0.32), I2 = 98% in Kenya; 0.23 (95% CI: 0.07–0.54), I2 = 97% in Mozambique; 0.24 (95% CI: 0.09–0.49), I2 = 99% in South Africa; 0.12 (95% CI: 0.04–0.29), I2 = 100% in Tanzania; 0.11 (95% CI: 0.07–0.19), I2 = 96% in Uganda; and 0.26 (95% CI: 0.13–0.44), I2 = 98% in Zambia (Figure 3). It is noted that the aggregated summary estimates of cysticercosis included both farms and slaughterhouses where the hazard was detected and pooled prevalence was estimated by country rather than by sampling site.

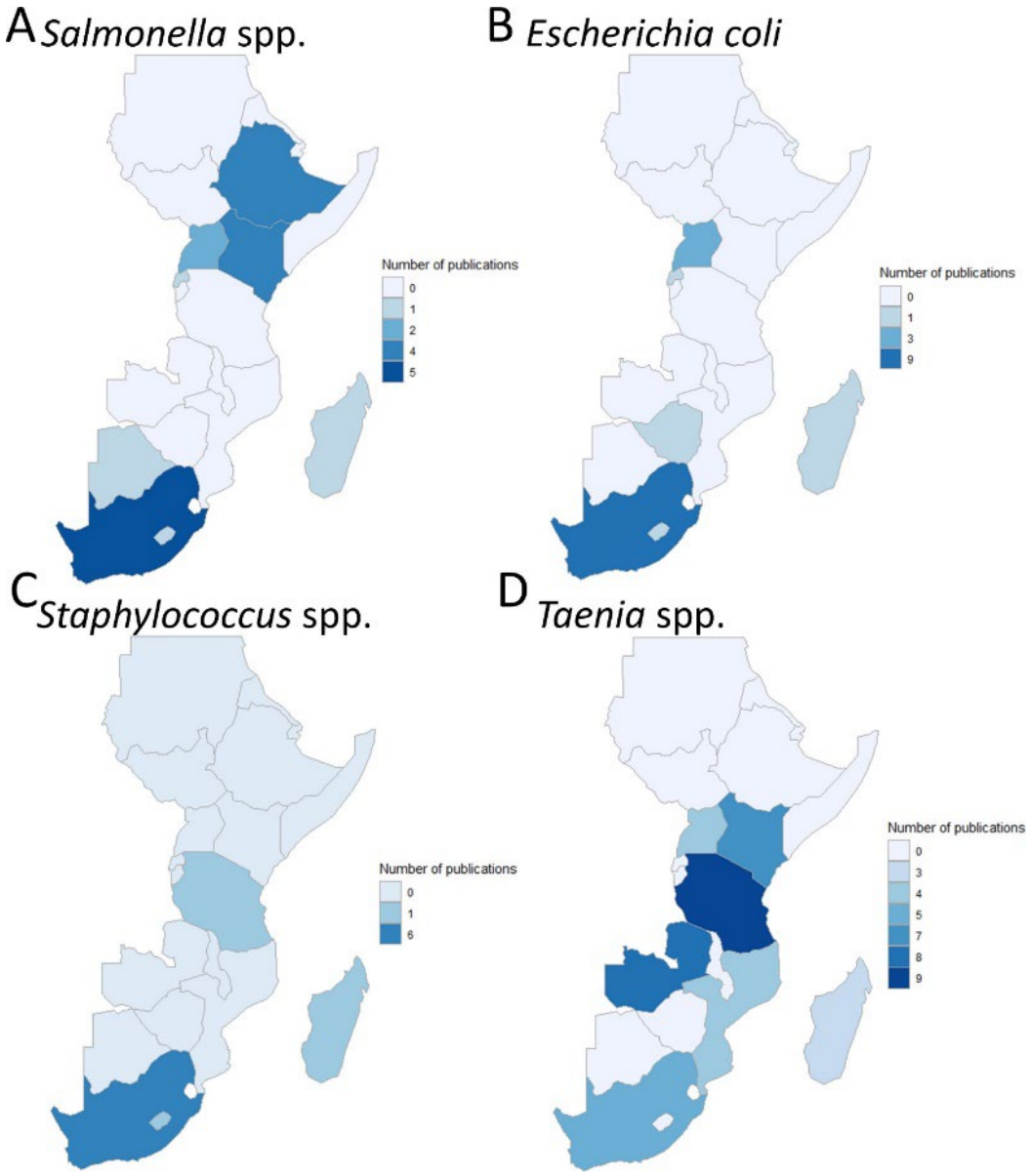


**Figure 2.** Locations of studies published on (**A**) *Salmonella* spp. (**B**) *Escherichia* coli (**C**) *Staphylococcus* spp. and (**D**) *Taenia* spp. in ESA are shown (Lesotho is not shown because of area limitations).

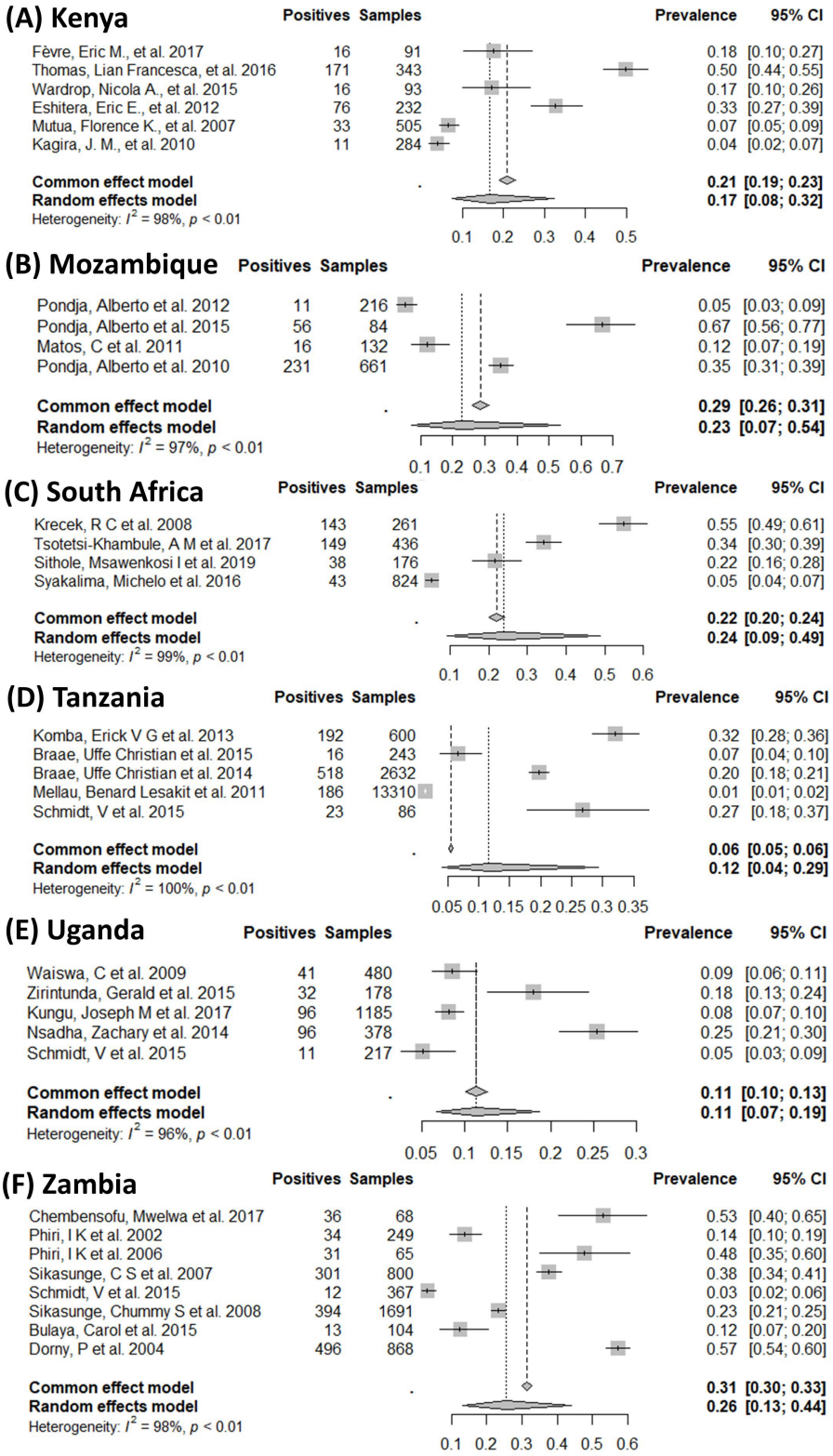


**Figure 3.** Pooled prevalence estimates of *Taenia* spp. in (**A**) Kenya, (**B**) Mozambique, (**C**) South Africa, (**D**) Tanzania (**E**) Uganda, and (**F**) Zambia. Grey squares represent prevalence estimated from the number of positives and samples of studies and error bars are 95% confidence intervals. Grey diamonds represent pooled prevalence based on the random effects model with 95% confidence intervals. This analysis used research articles exploring *Taenia* spp. with sufficient sample information in ESA [15–44].

## 4. Discussion

In the present study, a systematised literature review was conducted to identify pig- and pork-associated zoonotic and foodborne hazards reported in ESA. In total, 140 articles were identified documenting studies undertaken across 14 countries. Sixty identified hazards were described according to type: bacterium, virus, parasite, arthropod, or other, including drug residues. Seventy-seven articles described parasites, which were the most commonly studied pig- and pork-associated zoonotic and foodborne hazards in ESA. Of all identified hazards, *Taenia* spp. (40 articles) was the most explored in ESA, followed by *Salmonella* spp. (21 articles), *Escherichia coli* (17 articles), and *Staphylococcus* spp. (9 articles). Only *Taenia* spp. had sufficient data available for a pooled prevalence analysis and the highest prevalence was estimated to be 26% (95% CI: 13–44%) in Zambia followed by South Africa (24%, 95% CI: 9–49%), and Mozambique (23%, 95% CI: 7–54%).

We checked whether identified hazards were described in the burden of pathogens of animal source foods based upon WHO-FERG data [4,5]. The most studied hazard in the literature (*Taenia* spp.) appropriately corresponds with the highest disease burden pathogen associated with pork consumption in the Africa region D & Africa region E. Li et al. report that *Taenia solium* was estimated to be responsible for 170–176 DALYs per 100,000 people within these regions [5]. We do, however, note the paucity of data for many other hazards associated with pigs and pork, with only seven of the hazards identified in this review having estimates reported by Li et al., [5]. The hazards with current disease burden estimates attributable to pork consumption are listed: *T. solium*, *Toxoplasma gondii*, *Trichinella* spp., *Brucella* spp., Non-Typhoidal *Salmonella*, *Campylobacter* spp., and STEC [5].

WHO-FERG has not yet calculated DALYs related to *Staphylococcus aureus* as insufficient data were available in low-income countries [45]. However, foodborne diseases caused by *S. aureus* are common worldwide, mostly stemming from food products associated with animals, such as raw meat [46]. This review identified nine articles studying *Staphylococcus* spp. in pigs or pork in ESA demonstrating a potential risk of exposure to humans. Staphylococcal enterotoxins can lead to severe clinical conditions, while livestock-associated MRSA has become problematic worldwide in recent decades [47]. MRSA has been recognized in Africa, especially in sub-Saharan and South Africa in recent years, indicating an increased demand for potential sources of MRSA, such as meat [48–50]. In this analysis, only two articles studied MRSA prevalence indicating a gap for further research in the region.

Although 26 countries in ESA were investigated in the literature search, only 14 were identified in published studies; thus, approximately half of the countries in ESA do not yet appear to have empirical evidence on pig- and pork-associated zoonotic and foodborne hazards and more evidence is required in these countries. This might be because research in LMICs tends to rely on the interests of external donors and/or funds which usually come from foreign countries [51]. Muslim populations following religious restrictions on pork consumption may also affect identification of these hazards [52,53]. Of the 12 countries lacking empirical evidence on these hazards, five have Muslim population percentages over 90% (Comoros (98.3%), Djibouti (96.9%), Mayotte (98.4%), Socotra (99.1%), and Somalia (98.5%) [54] and it is likely that research on pigs and pork is not applicable in these countries. The remaining seven countries have predominately non-Muslim populations and acknowledging the world-wide increase in pork consumption, studies on human health hazards related to pigs and pork in these countries would be appropriate. The results of this review are important for those involved, including policy makers and researchers, as they provide a better understanding of the hazards associated with pig and pork consumption in ESA. The present study also demonstrates that there is room for future exploration, with the identified gaps providing valuable insights for stakeholders working to improve food safety and public health in the regions.

The present study identified a broad range in the quality of articles exploring the pig- and pork-associated zoonotic and foodborne hazards in ESA. For example, only 25% of the articles mentioned sample size calculations in their methodologies. Some studies

did not describe the numerator or denominator, thus only showing the prevalence value without detail. The sample size should follow scientific evidence to allow valid and reliable results [55] and to allow using the minimum sampling size, which enables scientific validity and cost-effective analyses [56]. Focusing on research that showed the hazard prevalence, less than half the articles included the 95% CIs. The point prevalence gives us the definitive value; however, adding the margin of error to the point estimate provides robust results and methods and better enables cross-study comparison [57,58].

Several limitations of this study must be acknowledged. First, MEDLINE (PubMed) and Web of Science, were used to search relevant articles which may not have provided full coverage to eligible studies, including grey literature. Second, broad search terms such as "zoonotic" and "foodborne" were used to find articles associated with zoonotic and foodborne diseases rather than more specific terms such as '*Toxoplasma gondii*' and 'cysticercosis'. Thus, articles not mentioning these search terms in the manuscript may have been missed. Third, in this study, publications were singularly screened; i.e., a proportion of the publications were allocated to each reviewer. Although single screening is appropriate for rapid research, screening by two or more reviewers are less likely to miss relevant studies [59]. Owing to a paucity of data, we were unable to estimate pooled prevalence split by sampling site type (e.g., farm or slaughterhouse). In addition, the present study did not explicitly account for heterogeneity in prevalence estimates (e.g., within-herd or between-herd prevalence). Therefore, it should be noted that the results should be interpreted with caution if the reviewed articles contain a bias that would allow, for example, sampling in high-risk settings. Despite these limitations, the present review successfully identified the most studied zoonotic and foodborne hazards associated with pigs and pork in ESA.

## 5. Conclusions

This review has identified numerous hazards associated with pigs and pork in Eastern and Southern Africa. Eastern and Southern Africa is predicted to see a large rise in pork consumption over the next decade and this will likely be associated with increasing exposure to these identified pig- and pork-associated zoonotic and foodborne hazards. Data on these hazards is not, however, comprehensive, with many countries lacking basic descriptive epidemiological data and with the data available being of variable quality. The current situation limits the ability to generate robust disease burden data for use in the planning and monitoring of interventional strategies. A strategic approach to filling data gaps, focusing on hazards and the geographical localities where data is missing will be important if the potential risks posed by continued growth of the pig and pork sectors in the region are to be appropriately mitigated.

**Author Contributions:** T.K. developed the study protocol, ran the searches, led the screening and data extraction and wrote the first draft of the manuscript, J.P. and L.F.T. conceptualized the study, provided input on the study protocol, analysis and assisted in writing the manuscript. All authors have read and agreed to the published version of the manuscript.

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