

Review

Prevalence of *Campylobacter* and *Salmonella* in African food animals and meat: A systematic review and meta-analysis

Kate M. Thomas^{a,b,*}, William A. de Glanville^c, Gary C. Barker^d, Jackie Benschop^e, Joram J. Buza^f, Sarah Cleaveland^c, Margaret A. Davis^g, Nigel P. French^{e,h}, Blandina T. Mmbaga^b, Gerard Prinsenⁱ, Emmanuel S. Swai^j, Ruth N. Zadoks^c, John A. Crump^a

^a Centre for International Health, Dunedin School of Medicine, University of Otago, Dunedin, New Zealand

^b Kilimanjaro Clinical Research Institute, Good Samaritan Foundation, Moshi, United Republic of Tanzania

^c Institute of Biodiversity Animal Health and Comparative Medicine, College of Medical Veterinary & Life Sciences, University of Glasgow, Glasgow, United Kingdom

^d Norwich, United Kingdom

^e mEpiLab, Massey University, Palmerston North, New Zealand

^f School of Life Sciences and Bio-Engineering, Nelson Mandela African Institution of Science and Technology, Arusha, United Republic of Tanzania

^g Paul G. Allen School for Global Animal Health, Washington State University, Pullman, WA, United States of America

^h New Zealand Food Safety Science and Research Centre, New Zealand

ⁱ School of People, Environment and Planning, Massey University, Palmerston North, New Zealand

^j State Department of Veterinary Services, Ministry of Livestock and Fisheries, Dodoma, United Republic of Tanzania

ARTICLE INFO

Keywords:

Africa
Campylobacter
 Food animals
 Food safety
 Prevalence
Salmonella

ABSTRACT

Background: *Campylobacter* and *Salmonella*, particularly non-typhoidal *Salmonella*, are important bacterial enteric pathogens of humans which are often carried asymptotically in animal reservoirs. Bacterial foodborne infections, including those derived from meat, are associated with illness and death globally but the burden is disproportionately high in Africa. Commercial meat production is increasing and intensifying in many African countries, creating opportunities and threats for food safety.

Methods: Following Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines, we searched six databases for English language studies published through June 2016, that reported *Campylobacter* or *Salmonella* carriage or infection prevalence in food animals and contamination prevalence in food animal products from African countries. A random effects meta-analysis and multivariable logistic regression were used to estimate the species-specific prevalence of *Salmonella* and *Campylobacter* and assess relationships between sample type and region and the detection or isolation of either pathogen.

Results: Seventy-three studies reporting *Campylobacter* and 187 studies reporting *Salmonella* across 27 African countries were represented. Adjusted prevalence calculations estimate *Campylobacter* detection in 37.7% (95% CI 31.6–44.3) of 11,828 poultry samples; 24.6% (95% CI 18.0–32.7) of 1975 pig samples; 17.8% (95% CI 12.6–24.5) of 2907 goat samples; 12.6% (95% CI 8.4–18.5) of 2382 sheep samples; and 12.3% (95% CI 9.5–15.8) of 6545 cattle samples. *Salmonella* were detected in 13.9% (95% CI 11.7–16.4) of 25,430 poultry samples; 13.1% (95% CI 9.3–18.3) of 5467 pig samples; 9.3% (95% CI 7.2–12.1) of 2988 camel samples; 5.3% (95% CI 4.0–6.8) of 72,292 cattle samples; 4.8% (95% CI 3.6–6.3) of 11,335 sheep samples; and 3.4% (95% CI 2.2–5.2) of 4904 goat samples. 'External' samples (e.g. hide, feathers) were significantly more likely to be contaminated by both pathogens than 'gut' (e.g. faeces, cloaca) while meat and organs were significantly less likely to be contaminated than gut samples.

Conclusions: This study demonstrated widespread prevalence of *Campylobacter* species and *Salmonella* serovars in African food animals and meat, particularly in samples of poultry and pig origin. Source attribution studies could help ascertain which food animals are contributing to human campylobacteriosis and salmonellosis and direct potential food safety interventions.

* Corresponding author at: Centre for International Health, Dunedin School of Medicine, University of Otago, Dunedin, New Zealand.

E-mail address: k.thomas@otago.ac.nz (K.M. Thomas).

<https://doi.org/10.1016/j.ijfoodmicro.2019.108382>

Received 25 May 2019; Received in revised form 20 August 2019; Accepted 2 October 2019

Available online 31 October 2019

0168-1605/ © 2019 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license

(<http://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Campylobacter and non-typhoidal *Salmonella* (NTS) are bacterial enteric pathogens associated with food animal reservoirs. They are transmitted to humans predominantly by contaminated food and water. Foodborne zoonoses, including those caused by *Campylobacter* and NTS, are recognised by the World Health Organization (WHO) as important causes of human illness and death worldwide (Havelaar et al., 2015). It is estimated that *Campylobacter* are responsible for > 95 million foodborne illnesses and > 21,000 deaths and NTS for > 78 million foodborne illnesses and > 59,000 deaths globally (Havelaar et al., 2015). The burden of bacterial foodborne disease, including disease caused by *Campylobacter* and NTS, is disproportionately higher in African regions compared with other parts of the world, with the number of Disability Adjusted Life Years (DALYs) per 100,000 exceeding that of other global regions (Havelaar et al., 2015).

While *Campylobacter* and NTS infections are usually self-limiting in healthy humans, complicated disease may develop in some. Bacteraemia and immunological syndromes such as reactive arthritis have been linked to both pathogens (Carter and Hudson, 2009; Sandhu and Paul, 2014) while Guillain-Barré syndrome is associated with *Campylobacter* infection (Esan et al., 2017, World Health Organization (WHO), 2012). For both *Campylobacter* and NTS, bacteraemia is more common among children, the elderly, and immunocompromised persons, especially those with HIV/AIDS (Food and Drug Administration (FDA), 2012). Almost 70% of the global HIV burden is in sub-Saharan Africa (Joint United Nations (UN) Programme on HIV/AIDS, 2017). An increased risk of NTS bacteraemia has also been linked with recent or current malaria, and malnutrition (Feasey et al., 2012).

Campylobacter are usually a non-pathogenic component of the gastrointestinal tract microbiota of livestock such as cattle, pigs, and sheep, with poultry considered to be the major reservoir, particularly of *C. jejuni* (Sahin et al., 2002; Skarp et al., 2016). Similarly, NTS have been isolated from the gastrointestinal tract of birds and mammals, including poultry and livestock (Barrow et al., 1988; Ellis, 1969; Gay et al., 1994). The transmission of potentially pathogenic *Campylobacter* or NTS from animal hosts to humans is predominantly via faecally contaminated food and water. However, humans may be infected by contact with live animals and environments contaminated with animal faeces and subsequent incidental ingestion of pathogens (Cummings et al., 2012, World Health Organisation (WHO), 2017). During processing for meat, animal gut microbiota and associated pathogens from the caecum, cloaca, intestines, or faeces may be transferred directly to the carcass or meat and organ surfaces. Transfer may also be indirect, such as from human hands and equipment. Both pathways may result in transfer of gastro-intestinal flora to meat and organ surfaces or to external animal surfaces such as feathers, fleece, hide, and skin. Such transfer is associated with increased risk for human infection from consumption of contaminated meat and cross-contamination of other foods. Uncooked produce may also be a direct source of human infection with zoonotic pathogens through contamination by animal faeces or untreated irrigation water (Food and Drug Administration (FDA), 2012).

Meat production is central to livelihoods in many African countries, with meat from livestock and poultry being a key protein source in subsistence communities (OECD/FAO, 2016). In many low-resource settings, industrialisation, urbanisation, and the shift from planned to market economies are leading to rapid changes in the way that food is produced, distributed, sold, and consumed (Carron et al., 2018; Grace, 2017). Such market-driven changes within agricultural production towards wider distribution networks, centralised processing, larger-scale and more intensive systems, have been linked to the emergence of zoonotic diseases (Jones et al., 2013) and the potential impact on food safety within low- and middle-income countries is increasingly recognised (World Health Organisation (WHO) Regional Office for Africa, 2017). Data on key bacterial pathogens in the meat production pathway in Africa are limited and are not currently available in aggregate form.

To inform food safety policy and to identify data gaps, we undertook a systematic review on *Campylobacter* and *Salmonella* prevalence in food animals and meat in Africa.

2. Methods

2.1. Study design and systematic review protocol

References were sought and identified following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Moher et al., 2009) (Supplementary File 1 checklist). Studies were searched in African Index Medicus (AIM), CABI Global Health, Proquest Health and Medicine, PubMed, Scopus, and Web of Science. Search terms are listed in Table 1 and no date restrictions were applied. The last search took place on 21 July 2016.

2.2. Search strategy

Article titles and abstracts were reviewed for suitability for inclusion by KMT. They were selected for full text review if the studies investigated *Campylobacter* or *Salmonella*, reported on samples collected from food animals, their organs or meat, and data collection took place in African regions or countries as defined by the United Nations (UN) statistics division (United Nations (UN) Statistics Division, 2016). Full text articles were reviewed independently by two authors (KMT, WdG) to determine if each article met pre-determined inclusion and exclusion criteria (Supplementary File 2). Articles were included for full text review if the full text article could be retrieved, if it reported primary data, if the article reported isolation by culture or detection by PCR of *Campylobacter* or *Salmonella*, in individual food animals or meat products, regardless of laboratory methods used, if the prevalence of contamination with either pathogen could be calculated from information available in the paper, and if the materials tested represented 'gut', 'external', or meat and organ samples from individual animals. Gut samples were defined as caecal, intestinal, cloacal contents and faeces, which have the potential to contaminate 'external' and meat and organ samples from individual animals. External samples were defined as those from the exterior of individual animals, including hide, skin, or feathers. Meat and organ samples included bile, lymph nodes, raw organs, or meat. Serological studies were excluded. Studies were excluded if the numerator (i.e. number positive) and denominator (i.e. number tested) information were not reported at the species and sample type level. Studies were excluded if samples were frozen at the time of sample collection to avoid underestimates of prevalence data, particularly of *Campylobacter*, as a result of loss of viable cells due to freezing. Studies were excluded if they were solely from sick animals, from free-living wildlife, or from farmed game animals. Studies were also excluded if they were in a language other than English. When required, a third author (JAC) served as tiebreaker, independently reviewing articles to resolve disagreement between the two primary reviewers.

2.3. Data extraction

From each included article, we extracted information on source food animal species, sample type, the total number of samples tested. The number of *Campylobacter* or *Salmonella* isolated or detected was extracted to determine pathogen prevalence. Sample location data, including UN statistics division African geographic region (United Nations (UN) Statistics Division, 2016), country, administrative level, city, town or village, and Global Positioning System (GPS) coordinates were extracted from articles when reported. Where available, data were recorded on the prevalence of individual *Campylobacter* species, and *Salmonella enterica* serovars or serogroups, as per standards of the WHO Collaborating Centre for Reference and Research on *Salmonella* (Grimont and Weill, 2007). During data extraction, elements of sample selection, sample handling, and laboratory methods were noted,

Table 1

Full search strategies for database searches, date searched, database name, and number of articles retrieved systematic review of prevalence of *Campylobacter* and *Salmonella* in African food animals and meat, 1953–2016.

Date Search performed	Database	Number of articles retrieved	Search string/terms and limits
11 Jul 16	Africa Index Medicus	46	Campylobacter OR Salmonella
21 Jul 16	CABI Global Health	2251	All = (Search #1) AND All = (Search #2) AND All = (Search #3)
11 Jul 16	ProQuest	774	Anywhere = (Search #1) AND All = (Search #2) AND All = (Search #3)
11 Jul 16	PubMed	1423	All = (Search #1) AND All = (Search #2) AND All = (Search #3)
11 Jul 16	Scopus	2059	Abstract, Title, Keyword = (Search #1) AND Abstract, Title, Keyword = (Search #2) AND Abstract, Title, Keyword = (Search #3) in the categories of Life Sciences and Health Sciences
11 Jul 16	Web of Science	1051	TOPIC = (Search #1) AND TOPIC = (Search #2) AND TOPIC = (Search #3)
	Where:		
	Search #1		(Campylobacter*) OR (Salmonell*)
	Search #2		(cattle) OR (cow) OR (bull) OR (beef) OR (heifer) OR (steer) OR (bovine) OR (calf) OR (calves) OR (sheep) OR (mutton) OR (hogget) OR (lamb) OR (ovine) OR (goat) OR (caprine) OR (chicken) OR (avian) OR (poultry) OR (hen) OR (chick) OR (broiler) OR (layer) OR (pork) OR (porcine) OR (pig) OR (camel) OR (offal) OR (food) OR (meat)
	Search #3		(Africa*) OR (algeria) OR (angola) OR (benin) OR (botswana) OR (burkina faso) OR (burundi) OR (cameroon) OR (cape verde) OR (central african republic) OR (chad) OR (comoros) OR (congo) OR (cote d'ivoire) OR (ivory coast) OR (democratic republic of the congo) OR (zaire) OR (djibouti) OR (egypt) OR (equatorial guinea) OR (eritrea) OR (ethiopia) OR (gabon) OR (gambia) OR (ghana) OR (guinea) OR (guinea-bissau) OR (kenya) OR (lesotho) OR (liberia) OR (libya) OR (madagascar) OR (malawi) OR (mali) OR (mauritania) OR (mauritius) OR (mayotte) OR (morocco) OR (mozambique) OR (namibia) OR (niger) OR (nigeria) OR (reunion) OR (rwanda) OR (saint helena) OR (sao tome and principe) OR (senegal) OR (seychelles) OR (sierra leone) OR (somalia) OR (south africa) OR (south sudan) OR (sudan) OR (swaziland) OR (tanzania) OR (togo) OR (tunisia) OR (uganda) OR (western sahara) OR (zambia) OR (zimbabwe)

including length of study, conditions and time of transport to laboratory, amount of sample tested, media used, and temperature and gas conditions of incubation. A formal bias assessment was established (Supplementary Table 1), assigning low (L), moderate (M), high (H), unknown (U), implied (I), yes (Y), no (N), or not applicable (NA) to each potential introduction of bias. The bias elements considered in the formal assessment relating to sample selection and handling were study length, temperature and time of transport to the laboratory. The bias elements relating to laboratory testing were amount of sample tested, type of isolation or detection methods, incubation conditions, and the quality of the serotyping methods used. An overall assessment of low, moderate or high risk of bias was assigned to each included article.

2.4. Data analysis

Prevalence estimates were calculated from pooled data for each pathogen by livestock species, geographic region and sample type, and for each geographic region and sample type by livestock species. An inverse variance approach with study ID as a random effect was used to derive weighted prevalence estimates (Marín-Martínez and Sánchez-Meca, 2010). In the presence of small numbers of total samples for some studies, the logit transformation was used (Barendregt et al., 2013). Between study heterogeneity was quantified using the I^2 statistic, which provides an estimate of the percentage of total variation between studies that is due to prevalence differences rather than to chance variation (Higgins et al., 2003). Eighty percent prediction intervals (80% PI) were derived to provide an estimate of the interval between which the prevalence of a future study of *Campylobacter* or *Salmonella* prevalence could be expected to fall with 80% probability (Int'Hout et al., 2016). Weighted average prevalence estimates, their 95% confidence intervals (95% CI), 80% PI and the I^2 statistic were derived using the *meta* package (Schwarzer, 2007) in the R statistical environment, version 3.4.2. (<http://cran.r-project.org/>).

Mixed effects logistic regression was used to explore predictors of *Campylobacter* and *Salmonella* infection or colonisation and contamination. Publication ID was included as a random effect and geographic region, sample type (i.e. 'gut', 'external', 'meat and organ') and species type were included as fixed effects. Data were then

disaggregated by host species and separate mixed effects logistic regression models constructed for each pathogen for camels, cattle, goats, pigs, poultry, and sheep. Host species-specific models included publication ID as a random effect and sample type and geographic region as fixed effects. Where data were available, Northern Africa was used as the referent region and 'gut' as the baseline sample type. Deviations are stated when chosen referent baselines did not have data. Poultry was used as the baseline for species type and compared to pigs and a combined category containing all other species (buffalo, camels, cattle, goats, and sheep). The overall contribution of each fixed effect to model fit was assessed using a likelihood ratio test. In addition to the I^2 statistic described above, between study heterogeneity in prevalence was quantified for the overall logistic regression model and species-specific logistic regression models using the median odds ratio (MOR). This statistic represents the median value of the odds ratio when comparing group (study) level residuals from randomly selected pairs of samples from different studies (Larsen and Merlo, 2005). It can be considered to provide an indication of the magnitude of the difference in odds of animal infection or carriage or sample contamination when comparing two studies: where there is little between study variation, the MOR would be close to one. Mixed effects logistic regression models were constructed using the *lme4* package (Bates et al., 2015) in R.

3. Results

After removing duplicate articles from the searches of six selected databases, 4954 articles were available for title and abstract screening. Of these 531 (10.7%) were identified as potentially relevant and 247 (5.0%) were eligible for inclusion after full text review (Fig. 1). Sixty articles from 14 countries reported prevalence data on *Campylobacter*, 174 articles from 27 countries reported prevalence data on *Salmonella*, and 13 articles from eight countries reported prevalence data on both pathogens. No prevalence data were excluded as a result of the quality assessment. Table 2 shows the decades in which the sampling began in each study. The geographic location of included studies is represented in Fig. 2. The number of studies from each country and the animal species investigated are listed in Table 3.

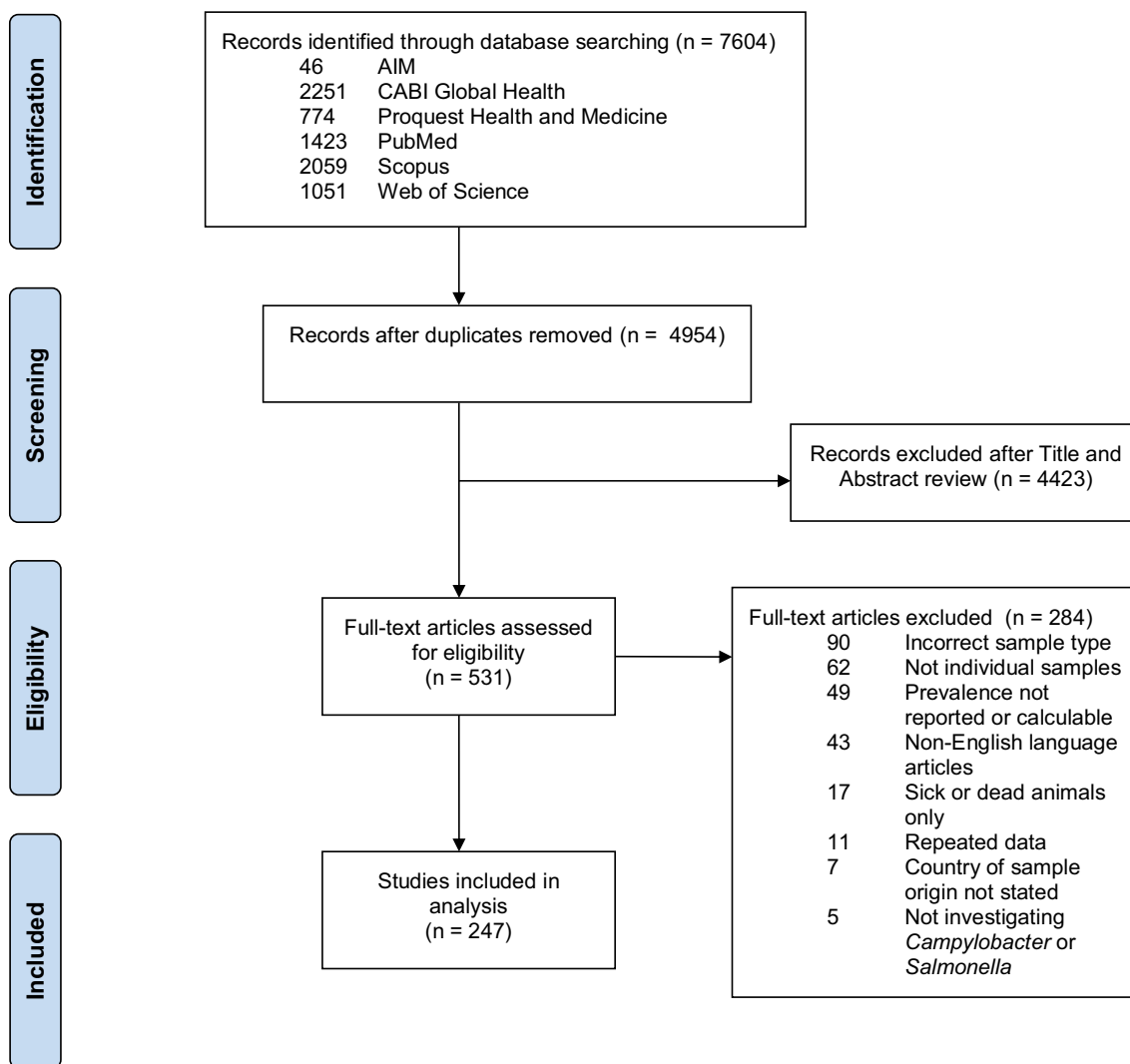


Fig. 1. PRISMA flowchart showing identification, screening, and selection of eligible articles for inclusion in systematic review, 1953–2016.

Table 2

Numbers of articles on *Campylobacter* or *Salmonella* and *Campylobacter* and *Salmonella* prevalence included in the systematic review by year of when sampling and testing began.

Years	Campylobacter	Salmonella	Campylobacter and Salmonella
1951–1959	0	4	0
1960–1969	0	6	0
1970–1979	0	3	0
1980–1989	0	2	1
1990–1999	1	8	0
2000–2009	24	41	3
2010–2016	10	34	0
Unspecified	25	76	9
TOTAL	60	174	13

3.1. *Campylobacter*

The unadjusted prevalence of *Campylobacter* by animal species among various sample types for each African region by source animal species is shown in Table 4. The weighted prevalence of *Campylobacter* by animal species, sample type, and geographic region is summarized in Fig. 3. The prevalence was highest in poultry samples (37.7%, 95% CI 31.6–44.3, 80% PI 12.1–72.7) followed by pig samples (24.6%, 95% CI 18.0–32.7, 80% PI 11.2–45.9), goat samples (17.8%, 95% CI 12.6–24.5, 80% PI 7.8–35.6), sheep samples (12.6%, 95% CI 8.4–18.5, 80% PI

4.3–31.7), and cattle samples (12.3%, 95% CI 9.5–15.8, 80% PI 5.1–26.7). One study reported attempted isolation or detection of *Campylobacter* from camels and buffalo, with zero positive cases for both species. Fig. 4 shows the breakdown of *Campylobacter* species between food animals. For all animal samples, *Campylobacter* were significantly less likely to be isolated or detected from meat or organ samples than from gut samples (OR = 0.67, 95% CI 0.56–0.80), and significantly more likely to be isolated or detected from external samples than gut samples (OR = 1.77, 95% CI 1.19–2.65) (Table 5). With adjustment for sample and species type, the odds of contamination of food animal samples with *Campylobacter* from Central Africa was significantly higher than the referent region of Northern Africa (OR = 9.06, 95% CI 1.92–42.70). The odds of contamination were significantly lower in samples from pigs (OR = 0.60, 95% CI 0.49–0.73) and all other species (OR = 0.29, 95% CI 0.25–0.33) when compared to samples from poultry. There was evidence that the inclusion of region, sample and species type as fixed effects improved model fit ($X^2 = 10.6$, $p = 0.03$; $X^2 = 32.8$, $p \leq 0.001$; $X^2 = 332.7$, $p \leq 0.001$, respectively).

Between study heterogeneity on the basis of the I^2 statistic was high (> 90%) for all livestock species, except cattle for which a relatively small proportion of the between study variation (15.8%) was estimated to be due to prevalence differences rather than chance variation. This is supported by values for MOR, which suggest that when comparing pairs of samples from two randomly selected studies, the odds of *Campylobacter* sample contamination in the study reporting higher

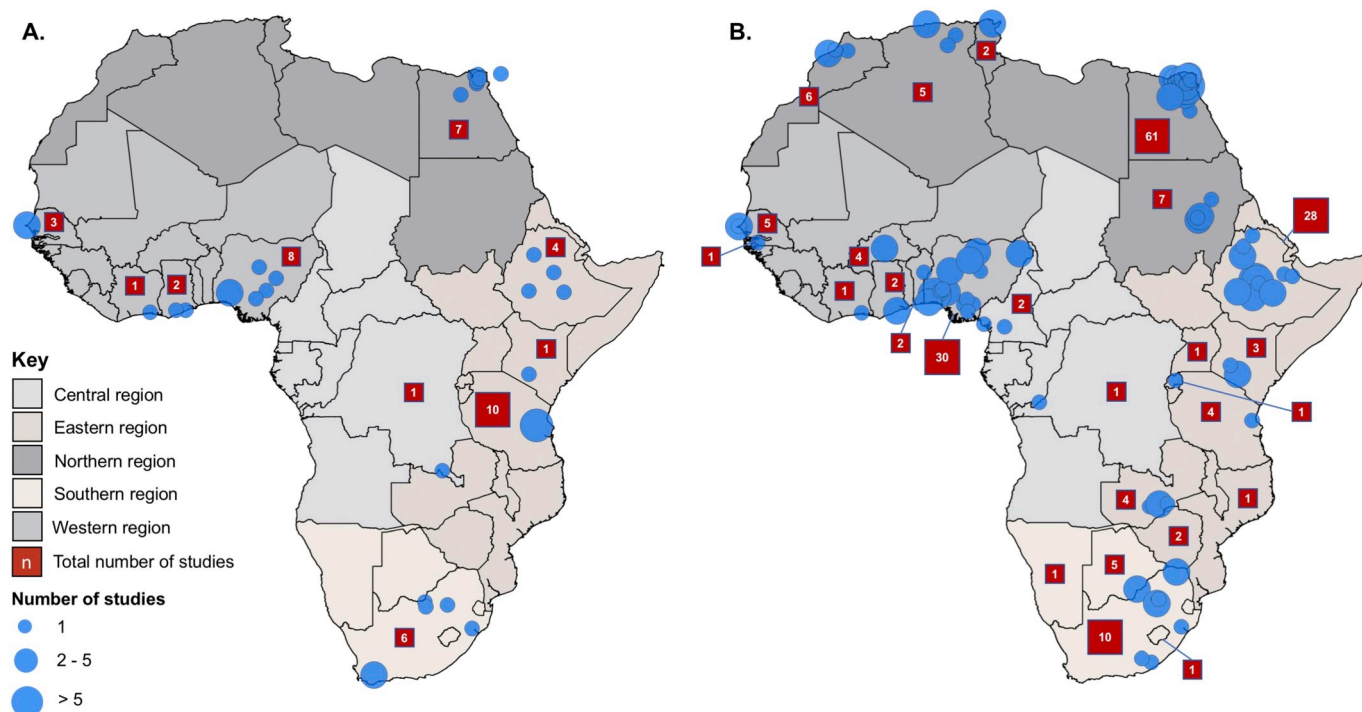


Fig. 2. Map showing location of included studies describing (A) *Campylobacter* and (B) *Salmonella* contamination prevalence where geographic information was available (blue circles), 1953–2016. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

prevalence would, in median, be 3.2 times the odds of sample contamination in the lower prevalence study, with control for region, sample type, and species type. For the species-specific models, between study heterogeneity on the basis of MOR was notably high for poultry, in which the estimated median difference in odds of sample contamination between a low and high prevalence study was 4.1 (Table 6).

3.1.1. Poultry

The adjusted prevalence on the basis of 7450 poultry gut samples was 40.2% (95% CI 32.7–48.2), 73.8% (95% CI 63.5–82.0) in 1405 poultry external samples, and 21.3% (95% CI 13.3–32.2), among 2973 meat or organ samples (Fig. 3). On the basis of the multivariable model, *Campylobacter* were significantly less likely to be isolated or detected in meat or organ samples than gut samples (OR = 0.55, 95% CI 0.41–0.73), but significantly more likely to be isolated or detected in external samples than gut samples (OR = 1.57, 95% CI 1.03–2.39) (Table 5). The adjusted *Campylobacter* prevalence was highest in Central Africa (91.2, 95% CI 87.4–94.0) and lowest in Northern Africa (24.2%, 95% CI 17.3–32.6) (Fig. 3). On the basis of the multivariable model, *Campylobacter* were significantly more likely to be isolated or detected in poultry samples from Central Africa than the referent region of Northern Africa (OR = 13.3, 95% CI 4.35–40.74) (Table 5). However, there was no evidence that the inclusion of region as a fixed effect improved model fit ($X^2 = 7.4$, $p = 0.11$). There was strong evidence for an improvement in model fit with the inclusion of sample type ($X^2 = 28.1$, $p \leq 0.001$).

Among the 4922 poultry samples from which *Campylobacter* was isolated or detected, 4200 (85.7%) isolates were speciated. Of 4200 speciated isolates, 3092 (73.6%) were *C. jejuni*, 885 (21.1%) were *C. coli*, 152 (3.6%) were reported as ‘other’, 56 (1.3%) were *C. lari*, 10 (0.2%) were *C. upsaliensis*, and five (0.1%) were *C. fetus* (Table 4).

3.1.2. Pigs

The adjusted prevalence on the basis of 1862 pig gut samples was 27.8% (95% CI 20.4–36.7). No pig external samples were tested for *Campylobacter*. Among 113 pig meat or organ samples, the adjusted

prevalence was 9.8% (95% CI 5.5–16.8) (Fig. 3). *Campylobacter* were significantly less likely to be isolated or detected from pig meat or organ samples than from pig gut samples (OR = 0.19, 95% CI 0.09–0.40) (Table 5). The adjusted *Campylobacter* prevalence was 30.9% (95% CI 21.6–42.1) for samples from Eastern Africa, 26.6% (95% CI 20.4–33.8) for samples from Western Africa, and 8.6% (95% CI 0.7–55.9) for samples from Southern Africa (Fig. 3). No studies from Central or Northern Africa reported on *Campylobacter* prevalence in pigs. When adjusted for sample type, the prevalence of *Campylobacter* in samples from Southern Africa was significantly lower (OR = 0.17, 95% CI 0.06–1.15) than the referent region of Eastern Africa (Table 5). There was evidence that the inclusion of region and sample type improved model fit ($X^2 = 7.7$, $p = 0.02$; $X^2 = 24.0$, $p \leq 0.001$, respectively).

Among the 537 pig samples from which *Campylobacter* was isolated or detected, 535 isolates (99.6%) were speciated. Of 535 speciated isolates, 126 (23.6%) were *C. jejuni*, 380 (71.1%) were *C. coli*, 22 (4.1%) were reported as ‘other’, three (0.6%) were *C. hyointestinalis*, three (0.6%) were *C. faecalis*, and one (0.2%) was *C. lari* (Table 4).

3.1.3. Goats

The adjusted *Campylobacter* prevalence on the basis of 2372 goat gut samples was 16.8% (95% CI 11.4–24.6). No goat external samples were tested. Among 535 goat meat or organ samples, the adjusted prevalence was 20.2% (95% CI 8.2–41.6) (Fig. 3). After controlling for region, goat meat or organ samples were significantly more likely to be contaminated than gut samples (OR = 1.5, 95% CI 1.1–2.1) (Table 5). The adjusted prevalence of *Campylobacter* contamination was highest in the Central region (37.7%, 95% CI 33.5–42.0) and lowest in the Eastern region (5.4%, 95% CI 2.9–9.9) (Fig. 3). No samples were collected from the Northern region. There were significant differences in the odds of *Campylobacter* contamination when comparing samples from Central, Southern and Western regions with the Eastern baseline (Table 5). There was evidence that the inclusion of region and sample type as fixed effects improved model fit ($X^2 = 23.3$, $p \leq 0.001$; $X^2 = 6.3$, $p = 0.01$, respectively).

For *Campylobacter* from goats, 616 isolates were speciated from 601

Table 3

Studies included in systematic review of the prevalence of *Campylobacter* and *Salmonella* in African food animals and animal food products by region, country, and animal species, 1953–2016.

Pathogen	Region	Country	No. of studies	Animal type investigated	References
Campylobacter	Central Africa	Cameroon	2	Chicken	(Garin et al., 2012, Nzouankeu et al., 2010) (a Mpalang et al., 2014)
		Democratic Republic of Congo	1	Goat	
		TOTAL	3		
	Eastern Africa	Ethiopia	6	Cattle, Goat, Pig, Poultry, Sheep	(Chanyalew et al., 2013, Dadi and Asrat, 2008, Ewnetu and Mihret, 2010, Kassa et al., 2007, Nigatu et al., 2015, Woldemariam et al., 2009)
		Kenya	2	Cattle, Goat, Pig, Poultry, Sheep	(Osano and Arimi, 1999, Turkson et al., 1988)
		Madagascar	1	Poultry	(Garin et al., 2012)
		Mozambique	1	Cattle	(Acha et al., 2004)
		Tanzania	11	Camel, Cattle, Goat, Pig, Poultry, Sheep	(Jacob et al., 2011, Jiwa et al., 1994, Kashoma et al., 2016, Kashoma et al., 2015, Komba et al., 2014, Kusiluka et al., 2005, Mdegela et al., 2011, Mdegela et al., 2007, Mdegela et al., 2006, Nonga and Muhairwa, 2010, Nonga et al., 2010)
		TOTAL	21		
	Northern Africa	Algeria	1	Poultry	(Messad et al., 2014)
		Egypt	17	Buffalo, Cattle, Goat, Poultry, Sheep	(Abd el-Aziz et al., 2002, Ali and Ouf, 2005, Awadallah et al., 2014, El-Gamal Galal et al., 1992, El-Jakee et al., 2015, El-Shibiny et al., 2012, El-Tras et al., 2015, Hassanain, 2011, Khadr et al., 2006, Khalafalla, 1990, Khalafalla et al., 2015, Khalifa et al., 2013, Nassar and El-Ela, 2000, Omara et al., 2015, Rady et al., 2011, Ramadan et al., 2015, Samaha et al., 2012)
		TOTAL	18		
	Southern Africa	South Africa	11	Cattle, Goat, Pig, Poultry, Sheep	(Beste and Essack, 2012, Cooper et al., 2001, Jonker and Picard, 2010, Mabote et al., 2011, Montwedi and Ateba, 2012, Richardson and Koornhof, 1979, Uaboi-Egbenni et al., 2010, Uaboi-Egbenni et al., 2011a, Uaboi-Egbenni et al., 2011b, Uaboi-Egbenni et al., 2012, van Nierop et al., 2005)
		TOTAL	11		
	Western Africa	Cote d'Ivoire	2	Poultry	(Gblossi Bernadette et al., 2012, Goualie et al., 2007)
		Ghana	2	Goat, Pig, Poultry	(Abrahams et al., 1990, Sackey et al., 2001)
		Nigeria	14	Cattle, Goat, Pig, Poultry, Sheep	(Adekeye et al., 1989, Akwuobu et al., 2010, Elegbe, 1983, Elegbe et al., 1987, Ngulukun et al., 2011, Ngulukun et al., 2010, Ofukwu et al., 2008, Okunlade et al., 2015, Olubunmi and Adeniran, 1986, Raji et al., 2000, Salihu et al., 2009a, Salihu et al., 2012, Salihu et al., 2009b, Uaboi-Egbenni et al., 2008)
		Senegal	4	Poultry	(Cardinale et al., 2003a, Cardinale et al., 2003b, Cardinale et al., 2006, Garin et al., 2012)
		TOTAL	22		
		Cameroon	2	Cattle, Pig, Poultry	(Akoachere et al., 2009, Nzouankeu et al., 2010)
	Salmonella	Central Africa	Democratic Republic of Congo	1	Cattle, Goat, Pig, Poultry, Sheep
TOTAL			3		
Eastern Africa			Ethiopia	28	Camel, Cattle, Goat, Pig, Poultry, Sheep
		Kenya	3	Cattle, Pig, Poultry	(Gitter and Brand, 1970, Kikui et al., 2007, Wesonga et al., 2010)
		Mauritius	1	Poultry	(Phagoo and Neetoo, 2015)
		Mozambique	1	Cattle	(Acha et al., 2004)
		Rhodesia	1	Cattle	(Chambers, 1977)
		Rwanda	1	Cattle	(Niyonzima et al., 2016)
		Tanzania	4	Cattle, Goat, Poultry	(Hummel, 1974, Kusiluka et al., 2005, Mdegela et al., 2000, Otaru et al., 1990)
		Uganda	1	Pig	(Ikwap et al., 2014)
		Zambia	4	Cattle, Pig, Poultry	(Hang'ombe et al., 1999, Isogai et al., 2005, Kuroda et al., 2013, Ngoma et al., 1996)
		Zimbabwe	1	Poultry	(Gopo and Banda, 1997)

(continued on next page)

Table 3 (continued)

Pathogen	Region	Country	No. of studies	Animal type investigated	References
	Northern Africa	TOTAL	45		
		Algeria	5	Cattle, Poultry, Sheep	(Akam et al., 2004, Ammar et al., 2010, Guergueb et al., 2014, Mezali and Hamdi, 2012, Nouichi and Hamdi, 2009)
		Egypt	59	Buffalo, Camel, Cattle, Goat, Pig, Poultry, Sheep	(Abd el-Aziz et al., 2002, Abd El-Ghany et al., 2012, Abd-Elghany et al., 2015, Abdel-Maksoud et al., 2015, Abou El Hassan, 1996, Ahmed and Shimamoto, 2014, Ahmed et al., 2016, Ahmed et al., 2014, Al-Hazmi et al., 2013, Ali and Ouf, 2005, Aliaa et al., 2014, Amal et al., 2014, Amin and El-Rahman, 2015, Ammar et al., 2009, Eisa and Mohamed, 2004, Eissa et al., 2014, El-Gamal and El-Bahi, 2016, El-Naker et al., 2008, El-Tras et al., 2010, Elmossalami and Yassein, 1994, Farrag et al., 1954, Farrag and El-Afify, 1956, Farrag et al., 1962, Floyd et al., 1953, Ghariieb et al., 2015, Ghoneim et al., 2015, Hamada et al., 1963, Hassb-Elnaby et al., 2011, Ibrahim, 2016, Khalafalla et al., 2015, Lotfi and Kamel, 1964b, Mahmoud and Hamouda, 2006, Mira and Eskandar, 2007, Moawad et al., 2013, Mohamed et al., 2014, Mohamed and Dapgh, 2007, Mousa et al., 1993, Moussa et al., 2013, Moussa et al., 2014, Nabawy et al., 2016, Nassar and El-Ela, 2000, Nawar and Khedr, 2014, Nossair et al., 2015, Osman et al., 2014a, Osman et al., 2014b, Osman et al., 2014c, Osman et al., 2010, Ouf, 2004, Rady et al., 2011, Randa et al., 2014, Refai et al., 1984, Sallam et al., 2014, Samaha et al., 2011, Samaha et al., 2012, Scharawe et al., 2009, Shaltout and Abdel-Aziz, 2004, Zahran and El-Behiry, 2014, Samaha et al., 2002, Lotfi and Kamel, 1964a)
	Morocco	6	Cattle, Poultry, Sheep	(Abdellah et al., 2008, Amara et al., 1994, Bouchrif et al., 2009, Cohen et al., 2007, Cohen et al., 2006, Khallaf et al., 2014)	
		Sudan	7	Camel, Cattle, Goat, Poultry, Sheep	(Hag Elsafi et al., 2009, Ibrahim, 1974, Khan, 1970a, Khan, 1970c, Khan, 1970b, Mohammed et al., 2003, Yagoub and Mohamed, 1987)
		Tunisia	2	Cattle, Poultry, Sheep	(Abbassi-Ghozzi et al., 2012, Oueslati et al., 2016)
	Southern Africa	TOTAL	78		
		Botswana	5	Cattle, Poultry	(Gaedirelwe and Sebunya, 2008, Gashe and Mpuchane, 2000, Kapondorah and Sebunya, 2007, Miller, 1971, Motsola et al., 2002)
		Namibia	1	Cattle	(Shilangale et al., 2015)
		South Africa	10	Cattle, Goat, Pig, Poultry, Sheep	(Iwu et al., 2016, Madoroba et al., 2016, Mathole et al., 2017, Nyamakwere et al., 2016, Prior and Badenhorst, 1974, Richardson et al., 1968, Tanih et al., 2015, van Nierop et al., 2005, Zishiri et al., 2016, Meara et al., 1977)
	Western Africa	TOTAL	16		
		Benin	2	Pig, Poultry	(Boko et al., 2013, Kpodekon et al., 2013)
		Burkina Faso	4	Cattle, Pig, Poultry, Sheep	(Bawa et al., 2015, Kagambèga et al., 2012, Kagambèga et al., 2011, Kagambèga et al., 2013)
		Cote d'Ivoire	1	Poultry	(Rene et al., 2014)
		Gambia, The	1	Goat, Poultry, Sheep	(Dione et al., 2011)
		Ghana	2	Cattle, Poultry	(Hughes et al., 2015, Sackey et al., 2001)
		Nigeria	30	Camel, Cattle, Goat, Pig, Poultry, Sheep	(Adesiji et al., 2011, Adesiyun and Oni, 1989, Adeyanju and Ishola, 2014, Adu-Gyamfi et al., 2012, Ajayi and Egbebi, 2011, Alao et al., 2012, Bata et al., 2016, Collard and Sen, 1956, Daniyan, 2011, Elegbe, 1983, Falade and Ehizokhale, 1981, Fashae et al., 2010, Iroha et al., 2011, Jajere et al., 2015, Kwaga, 1985, Nwachukwu et al., 2010, Oboegbulem and Muogbo, 1981, Ola Ojo, 1974, Olatoye, 2011, Olayemi et al., 1979, Oluyeye and Ojo-Bola, 2015, Onyekaba and Njoku, 1986, Orji et al., 2005, Raufu et al., 2013, Raufu et al., 2009, Sen and Collard, 1957b, Sen and Collard, 1957a, Smith et al., 2016, Smith et al., 2009, Tafida et al., 2013)
		Senegal	5	Cattle, Poultry	(Bada-Alamedji et al., 2006, Cardinale et al., 2003b, Dione et al., 2009, Missohou et al., 2009, Stevens et al., 2006)
		TOTAL	45		

Table 4
Combined unadjusted *Campylobacter* prevalence and species for food animal type and various sample types, 1979–2015.

Host animal type	Sample stage	Sample type	No. of samples tested	No. of samples positive (%)	<i>Campylobacter</i> species when isolates were typed from positive samples				
					<i>C. jejuni</i> (%)	<i>C. coli</i> (%)	Other <i>C. spp.</i> ^a (%)		
Buffalo	Gut	Intestinal contents	55	0 (0.0)	–	–	–	–	–
		TOTAL	55	0 (0.0)	–	–	–	–	–
Camel	Gut	Faeces/Rectal swab	3	0 (0.0)	–	–	–	–	–
		TOTAL	3	0 (0.0)	–	–	–	–	–
Cattle	Gut	Faeces/Rectal swab	4957	733 (14.8)	512 (68.7)	187 (25.1)	46 (6.2)		
		Intestinal contents	80	4 (5.0)	NT	–	NT	–	–
	Meat/organ	Carcass	827	55 (6.7)	37 (67.3)	16 (29.1)	2 (3.6)		
		Gallbladder	100	12 (12.0)	0 (0.0)	12 (100)	0 (0.0)		
	Meat/organ	Liver	30	8 (26.7)	5 (62.5)	3 (37.5)	0 (0.0)		
		Meat	521	25 (4.8)	21 (84.0)	4 (16.0)	0 (0.0)		
	Meat/organ	Tripe	30	1 (3.3)	NT	–	NT	–	–
		TOTAL	6545	838 (12.8)	575 (68.0)	222 (26.3)	48 (5.7)		
	Goat	Gut	Faeces/Rectal swab	2372	472 (19.9)	283 (59.0)	149 (31.0)	48 (10.0)	
Carcass			180	17 (9.4)	12 (70.6)	5 (29.4)	0 (0.0)		
Meat/organ		Meat	269	80 (29.7)	17 (20.7)	65 (79.3)	0 (0.0)		
		Stomachs	86	32 (91.3)	7 (21.9)	25 (78.1)	0 (0.0)		
TOTAL		2907	601 (20.7)	319 (53.1)	244 (40.6)	48 (8.0)			
Pigs	Gut	Caeca/Intestine	454	59 (13.0)	36 (61.0)	23 (39.0)	0 (0.0)		
		Faeces/Rectal swab	1408	467 (33.2)	83 (17.8)	354 (76.1)	28 (6.0)		
	Meat/organ	Carcass	66	7 (10.6)	6 (85.7)	1 (14.3)	0 (0.0)		
		Meat	47	4 (8.5)	1 (25.0)	2 (50.0)	1 (25.0)		
TOTAL	1975	537 (27.2)	126 (23.6)	380 (71.0)	29 (5.4)				
Poultry	Gut	Caeca	1902	759 (39.9)	442 (71.9)	161 (26.2)	12 (2.0)		
		Faeces/Cloaca swab	5548	2457 (44.3)	1893 (82.6)	276 (12.0)	122 (5.3)		
	Meat/organ	Carcass	653	335 (51.3)	130 (55.3)	97 (41.3)	8 (3.4)		
		Gallbladder or bile	65	3 (4.6)	3 (100)	0 (0.0)	0 (0.0)		
	Meat/organ	Giblet	37	15 (40.5)	5 (100)	0 (0.0)	0 (0.0)		
		Gizzard	250	43 (17.2)	43 (100)	0 (0.0)	0 (0.0)		
	Meat/organ	Heart	250	11 (4.4)	11 (100)	0 (0.0)	0 (0.0)		
		Kidney	25	2 (8.0)	2 (100)	0 (0.0)	0 (0.0)		
	Meat/organ	Liver	300	75 (25.0)	68 (100)	0 (0.0)	0 (0.0)		
		Meat	1193	257 (21.5)	132 (71.4)	10 (5.4)	43 (23.2)		
	Meat/organ	Spleen	200	17 (8.5)	17 (100)	0 (0.0)	0 (0.0)		
		External	1405	948 (67.5)	346 (47.7)	341 (47.0)	38 (5.2)		
	TOTAL	11,828	4922 (41.6)	3092 (73.6)	885 (21.1)	223 (5.3)			
Sheep	Gut	Faeces/Rectal swab	1430	248 (17.3)	148 (59.7)	87 (35.1)	13 (5.2)		
		Intestinal contents	300	17 (5.7)	11 (64.7)	4 (23.5)	2 (11.8)		
	Meat/organ	Carcass	288	38 (13.2)	31 (81.6)	7 (18.4)	0 (0.0)		
		Gallbladder	250	10 (4.0)	8 (80.0)	1 (10.0)	1 (10.0)		
	Meat/organ	Meat	114	12 (10.5)	10 (83.3)	2 (16.7)	0 (0.0)		
		TOTAL	2382	325 (13.6)	208 (64.0)	101 (31.1)	16 (4.9)		

^a Where “Other” *Campylobacter* species include: *C. faecalis*, *C. fetus*, *C. hyointestinalis*, *C. lari*, *C. sputorum*, *C. upsaliensis*.

samples. Of these 616 isolates, 321 (52.1%) were *C. jejuni*, 246 (39.9%) were *C. coli*, 28 (4.5%) were *C. lari*, 13 (2.1%) were *C. upsaliensis*, and eight (1.3%) were *C. sputorum* (Table 4).

3.1.4. Sheep

The adjusted prevalence of *Campylobacter* contamination in 1730 sheep gut samples was 13.6%, (95% CI 8.5–21.1) and 10.2% (95% CI 5.4–18.2) on the basis of 652 meat or organ samples (Fig. 3). No external samples were reported. There was no evidence of a difference between the odds of contamination between sample types in the multivariable regression (Table 5). The adjusted prevalence of *Campylobacter* contamination was highest in the Southern region (30.0%, 95% CI 25.1–35.4) and lowest in the Northern region (5.7%, 95% CI 0.4–51.0) (Fig. 3). There was no evidence that including region or sample type improved model fit ($X^2 = 2.5$, $p = 0.48$; $X^2 = 0.9$, $p = 0.35$, respectively).

For *Campylobacter* from sheep, 323 isolates were speciated. Of these 323 isolates, 208 (64.4%) were *C. jejuni*, 101 (31.3%) were *C. coli*, nine (2.8%) were *C. fetus*, three (0.9%) were *C. lari*, and two (0.6%) were *C. faecalis* (Table 4).

3.1.5. Cattle

The adjusted prevalence derived from 5037 cattle gut samples was 15.4% (95% CI 11.7–20.0, 80% PI 6.9–30.8) compared to 7.4% (95% CI

4.6–11.6, 80% PI 2.9–17.9) from 1508 meat or organ samples (Fig. 3). No cattle external samples were tested for *Campylobacter*. On the basis of the cattle-specific multivariable model, *Campylobacter* were significantly less likely to be isolated or detected from meat or organ samples than from gut samples (OR = 0.40, 95% CI 0.26–0.61) (Table 5). The adjusted prevalence of contamination was highest in Northern Africa (23.2%, 95% CI 15.2–33.8) and lowest in Eastern Africa (7.5%, 95% CI 4.7–11.7) (Fig. 3), but there was no evidence of a difference in the odds of *Campylobacter* contamination between samples from Northern Africa and any other region from the multivariable model (Table 5). No studies from Central Africa reported on *Campylobacter* prevalence in cattle samples. There was evidence that the inclusion of sample type as a fixed effect improved model fit ($X^2 = 18.6$, $p \leq 0.001$), but no evidence for geographic region ($X^2 = 4.0$, $p = 0.26$).

For *Campylobacter* from cattle, 845 isolates were speciated. Of these 845 isolates, 575 (68.0%) were *C. jejuni*, 222 (26.3%) were *C. coli*, 18 (2.1%) were *C. lari*, 17 (2.0%) were *C. fetus*, eight (0.9%) were reported as ‘other’, and five (0.6%) were *C. hyointestinalis* (Table 4).

3.2. Salmonella

The unadjusted prevalence of *Salmonella* and serovar composition in the various sample types for each African region for each host animal species is shown in Table 7. The weighted prevalence of *Salmonella* by

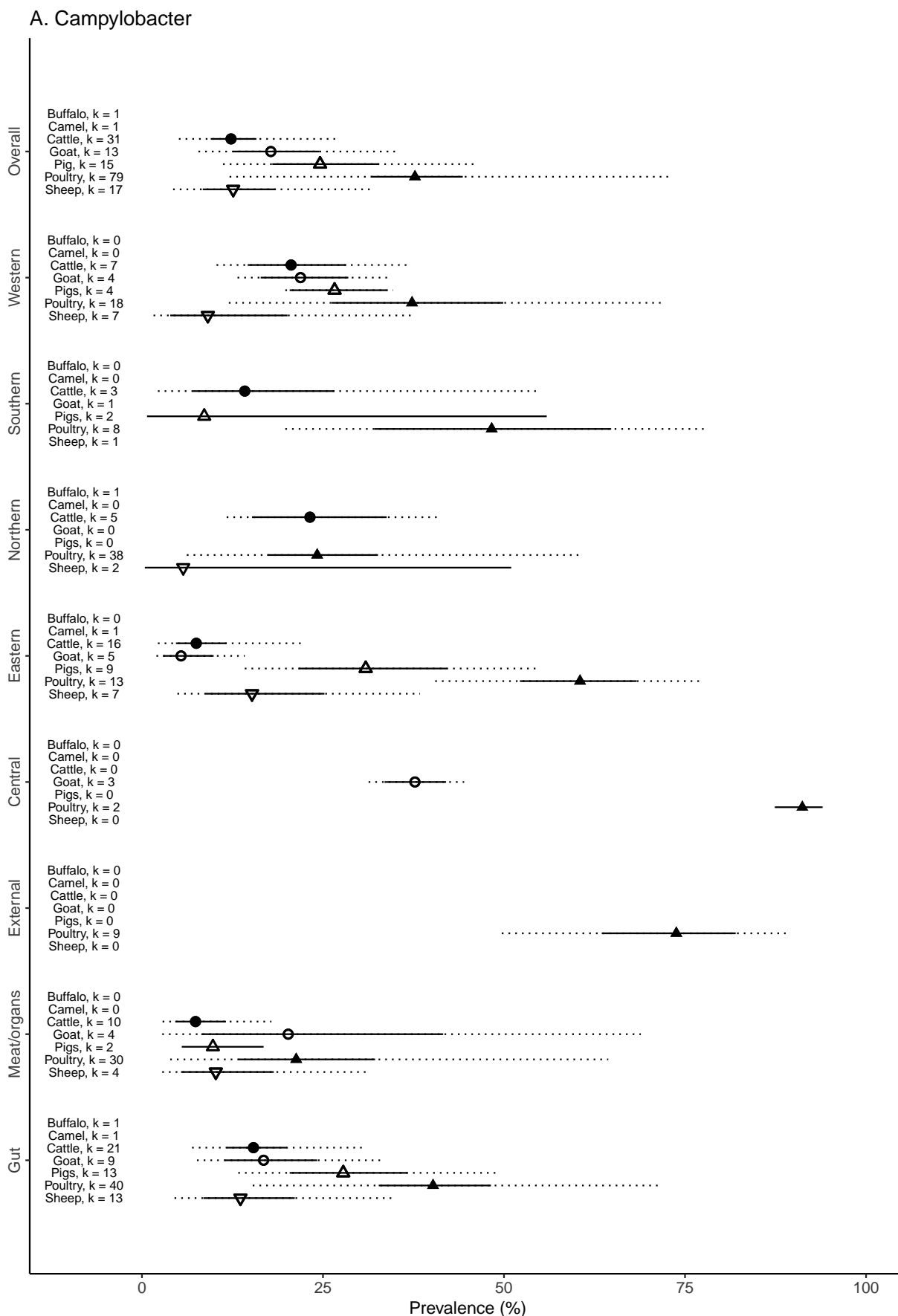


Fig. 3. Forest plot with adjusted prevalence estimates for *Campylobacter* in food animals and meat for each animal species, sample type and African region, 1953–2016. 95% confidence intervals shown in solid line. 80% prediction intervals shown with dotted line. Adjusted prevalence not estimated when number of studies (k) < 2, 1979–2015.

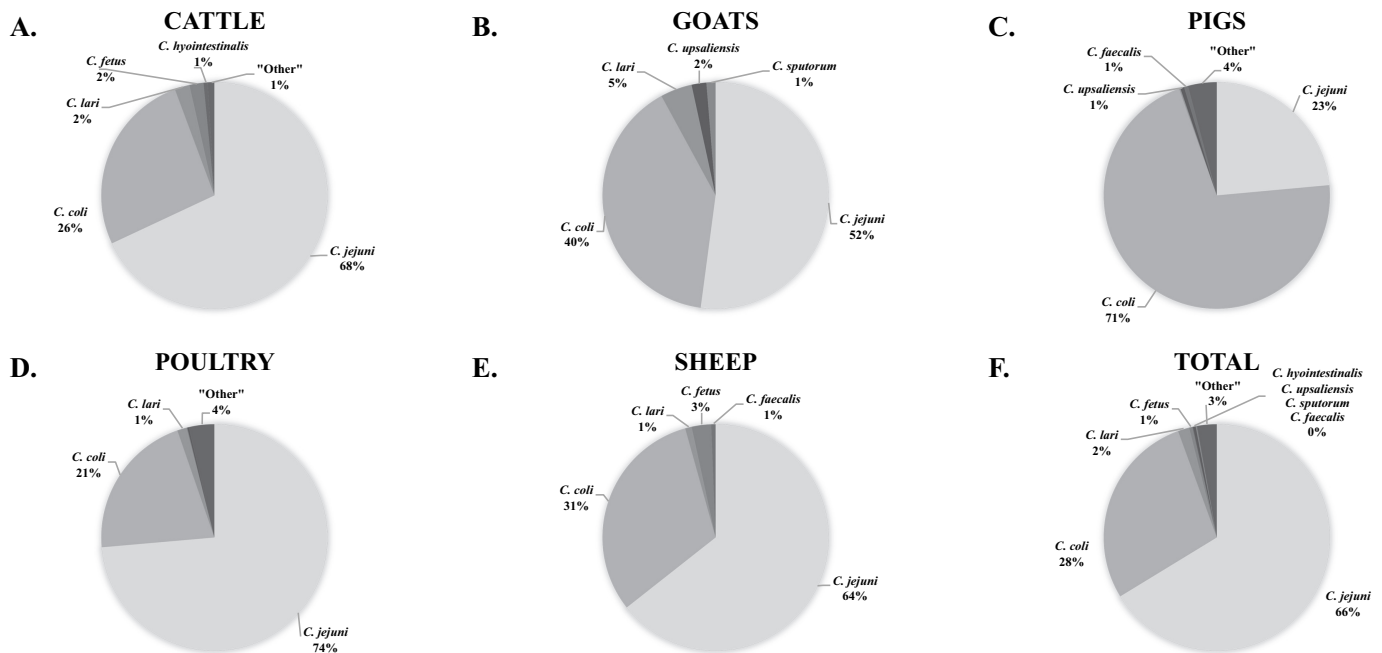


Fig. 4. Pie graphs showing the breakdown of *Campylobacter* species reported when typed from (A) Cattle, (B) Goats, (C) Pigs, (D), Poultry, (E) Sheep and (F) all African food animal species combined, 1953–2016.

animal species, sample type, and geographic region is summarized in Fig. 5. The prevalence of *Salmonella* was highest in poultry samples (13.9% (95% CI 11.7–16.4, 80% PI 3.5–41.5)), followed by pig samples (13.1% (95% CI 9.3–18.3, 80% PI 3.3–39.9)), camel samples (9.3% (95% CI 7.2–12.1, 80% PI 4.7–17.8)), cattle samples (5.3% (95% CI 4.0–6.8, 80% PI 4.0–6.8)), sheep samples (4.8% (95% CI 3.6–6.3, 80% PI 1.8–12.0)), goat samples (3.4% (95% CI 2.2–5.2, 80% PI 2.2–5.2)) and buffalo samples (2.9% (95% CI 1.1–7.1, 80% PI 1.1–7.1)). *Salmonella* were significantly more likely to be detected in samples from Central and Western Africa compared to the referent region of North Africa (OR = 6.64, 95% CI 1.37–32.24 and OR = 1.79, 95% CI 1.01–2.92, respectively). Samples from pigs and all other species were less likely to be found to be contaminated than samples from poultry, but this was only significant in the case of the all other species category (OR = 0.47, 95% CI 0.42–0.54) (Table 5). There was weak evidence that the inclusion of region improved model fit ($X^2 = 8.9$, $p = 0.06$) with stronger evidence for an improvement with the inclusion of sample type ($X^2 = 48.9$, $p \leq 0.001$) and species type ($X^2 = 134.2$, $p \leq 0.001$). Supplementary Table 2 details all reported *Salmonella* serovars quantified in each animal species by region.

Between study heterogeneity was high for all studies, and above 90% for cattle, pigs, and poultry. Values of MOR suggest that a sample collected in a higher prevalence study would have, in median, around 3.7 times the odds of *Salmonella* sample contamination than a sample collected from a lower prevalence study, with control for region, sample type, and species type. For the species-specific models, between study heterogeneity on the basis of MOR was notably high for cattle and poultry, in which the estimated median difference in odds of sample contamination between a low and high prevalence study was 4.5 and 4.0, respectively (Table 6).

3.2.1. Poultry

The adjusted prevalence on the basis of 12,057 poultry gut samples was 13.4% (95% CI 9.8–18.0), 28.5% (95% CI 17.1–43.6) on the basis of 1027 external samples, and 13.2% (95% CI 10.6–16.3) on the basis of 12,346 poultry meat or organ samples. *Salmonella* were significantly less likely to be isolated or detected from both external (OR = 0.73, 95% CI 0.55–0.98) and meat or organ samples (OR = 0.45, 95% CI

0.39–0.53) when compared with the poultry gut sample baseline (Table 5). The adjusted prevalence in poultry samples was highest in the Southern region (28.2%, 95% CI 17.8–41.7) and lowest in the Northern region (10.5%, 95% CI 8.0–13.6) (Fig. 5). There was no evidence for improvement in model fit with the inclusion of region ($X^2 = 4.1$, $p = 0.4$), but strong evidence for improvement with the inclusion of sample type ($X^2 = 97.1$, $p \leq 0.001$).

In total, *Salmonella* was isolated or detected in 3615 poultry samples and 2236 (61.9%) were serotyped. Among the 2236 isolates serotyped from poultry samples, 464 (20.8%) were *Salmonella enterica* serovar Enteritidis, 311 (13.9%) were *Salmonella enterica* serovar Typhimurium, and 174 (7.8%) were *Salmonella enterica* serovar Typhi (Table 7).

3.2.2. Pigs

The adjusted *Salmonella* prevalence on the basis of 2584 pig gut samples was 15.4% (95% CI 8.4–26.6). No pig external samples were tested for *Salmonella*. Among 2883 pig meat or organ samples, the adjusted prevalence was 11.9% (95% CI 7.6–18.1) (Fig. 5). There was no evidence for differences in the odds of *Salmonella* contamination when comparing pig gut and meat or organ samples. The adjusted *Salmonella* prevalence was highest in Central Africa (33.2% (95% CI 16.3–56.0)) and lowest in Northern Africa (6.8% (95% CI 3.1–14.2)). The odds of *Salmonella* contamination were significantly higher in the Central region than the Northern region baseline (OR = 10.9 (95% CI 1.36–87.5)) (Table 5). There was no evidence for improvement in model fit with the inclusion of either region ($X^2 = 4.8$, $p = 0.3$) or sample type ($X^2 = 0.29$, $p = 0.59$).

In total, *Salmonella* was isolated or detected in 762 pig samples and 428 (56.2%) of these were serotyped. Among the 494 isolates serotyped from pig samples, 85 (19.9%) were *Salmonella enterica* serovar Hadar, 46 (10.7%) were *Salmonella enterica* Saintpaul and 40 (9.3%) *Salmonella enterica* serovar Eastbourne (Table 7).

3.2.3. Cattle

The adjusted *Salmonella* prevalence on the basis of 11,773 cattle gut samples was 4.5% (95% CI 2.9–6.9), 5.2% on the basis of 60,342 meat or organ samples, and 41.2% on the basis of 177 external samples (Fig. 5). *Salmonella* were significantly more likely to be isolated or

Table 5

Odds Ratios (OR) with 95% Confidence intervals (CI) for fixed effects from multi-level multivariable logistic regression models for *Campylobacter* and *Salmonella* prevalence for sample types, 1953–2016.

Model	Fixed effects	Campylobacter		Salmonella		
		OR	95% CI	OR	95% CI	
All	Region	Baseline		Baseline		
	Northern	Baseline		Baseline		
	Central	9.06	(1.92–42.70)*	6.64	(1.37–32.24)*	
	Eastern	1.23	(0.61–2.46)	1.36	(0.91–2.05)	
	Southern	2.08	(0.81–5.39)	1.35	(0.69–2.68)	
	Western	1.59	(0.79–3.21)	1.79	(1.10–2.92)*	
	Sample type	Baseline		Baseline		
	Gut	Baseline		Baseline		
	External	1.77	(1.19–2.65)*	1.77	(1.44–2.18)*	
	Internal	0.67	(0.56–0.80)*	0.86	(0.79–0.95)*	
	Species type	Baseline		Baseline		
	Poultry	Baseline		Baseline		
Pigs	0.60	(0.49–0.73)*	0.82	(0.63–1.07)		
All other	0.29	(0.25–0.33)*	0.47	(0.42–0.54)*		
Cattle	Region	Baseline		Baseline		
	Northern	Baseline		Baseline		
	Central	–	–	6.53	(0.66–64.87)	
	Eastern	0.60	(0.19–1.86)	1.07	(0.53–2.17)	
	Southern	0.96	(0.19–4.76)	0.57	(0.18–1.83)	
	Western	1.45	(0.42–5.02)	1.88	(0.77–4.61)	
	Sample type	Baseline		Baseline		
	Gut	Baseline		Baseline		
	External	–	–	8.11	(5.5–11.96)*	
	Internal	0.40	(0.26–0.61)*	0.97	(0.81–1.17)	
	Goats	Region	Baseline		Baseline	
		Northern	–	–	Baseline	
Central		10.3	(7.0–15.1)*	17.3	(0.65–461.6)	
Eastern		Baseline	–	4.8	(0.74–31.8)	
Southern		8.7	(5.3–14.1)*	0.45	(0.02–12.8)	
Western		5.5	(3.7–8.1)*	3.4	(0.5–22.5)	
Sample type		Baseline		Baseline		
Gut		Baseline		Baseline		
External		–	–	0.91	(0.23–3.6)	
Internal		1.5	(1.1–2.1)*	1.3	(0.68–2.6)	
Sheep		Region	Baseline		Baseline	
		Northern	Baseline		Baseline	
	Central	–	–	6.5	(1.4–30.3)*	
	Eastern	2.4	(0.42–13.8)	1.1	(0.55–2.2)	
	Southern	7.1	(0.63–79.5)	0.25	(0.07–0.98)*	
	Western	2.2	(0.35–13.6)	3.1	(1.3–7.1)*	
	Sample type	Baseline		Baseline		
	Gut	Baseline		Baseline		
	External	–	–	1.4	(0.93–2.0)	
	Internal	1.27	(0.78–2.1)	0.85	(0.4–2.1)	
	Pigs	Region	Baseline		Baseline	
		Northern	Baseline		Baseline	
Central		–	–	10.92	(1.36–87.54)*	
Eastern		Baseline	–	2.67	(0.53–13.44)	
Southern		0.17	(0.06–0.52)*	2.56	(0.39–16.70)	
Western		0.42	(0.16–1.15)	3.46	(0.67–18.03)	
Sample type		Baseline		Baseline		
Gut		Baseline		Baseline		
External		–	–	–	–	
Internal		0.19	(0.09–0.40)*	1.07	(0.83–1.39)	
Poultry		Region	Baseline		Baseline	
		Northern	Baseline		Baseline	
	Central	13.3	(4.35–40.74)*	3.53	(0.42–29.93)	
	Eastern	1.87	(0.73–4.83)	1.12	(0.45–2.81)	
	Southern	2.89	(0.78–10.68)	2.11	(0.63–7.06)	
	Western	1.45	(0.56–3.71)	1.81	(0.86–3.80)	
	Sample type	Baseline		Baseline		
	Gut	Baseline		Baseline		
	External	1.57	(1.03–2.39)*	0.73	(0.55–0.98)*	
	Internal	0.55	(0.41–0.73)*	0.45	(0.39–0.53)*	

* $p < 0.05$.

detected from cattle external samples than cattle gut samples (OR = 8.11, 95% CI 5.5–11.96) (Table 5). The prevalence in cattle samples was highest in the Central region (25.9%, 95% CI 19.6–33.4)

Table 6

Inter-study heterogeneity based on the I^2 statistic and median odds ratio (MOR) for *Campylobacter* and *Salmonella* for all included studies (overall) and for included studies for each African food animal species for included studies, 1953–2016.

	Campylobacter		Salmonella	
	I^2	MOR	I^2	MOR
Overall	96.7%	3.2	98.3%	3.7
Camels	–	–	72.9%	3.0
Cattle	15.8%	2.2	97.1%	4.5
Goats	92.1%	n.d.	80.6%	3.6
Pigs	90.4%	1.8	93.5%	2.7
Poultry	96.9%	4.1	95.3%	4.0
Sheep	90.8%	2.4	77.6%	1.7

and lowest in the Eastern region (3.9%, 95% CI 2.7–5.5) (Fig. 5). There was no evidence for improvement in model fit with the inclusion of region ($X^2 = 6.0$, $p = 0.2$), but strong evidence for improvement with the inclusion of sample type ($X^2 = 112.1$, $p \leq 0.001$).

In total, *Salmonella* was isolated or detected in 2509 cattle samples and 1750 (69.7%) of those were serotyped. Among the 1750 isolates serotyped from cattle, 289 (16.5%) were *Salmonella enterica* serovar Typhimurium, 124 (7.1%) were *Salmonella enterica* serovar Anatum, and 120 (6.9%) were *Salmonella enterica* serovar Enteritidis (Table 7).

3.2.4. Sheep

The adjusted *Salmonella* prevalence on the basis of 4167 sheep gut samples was 4.5% (95% CI 2.8–7.2), and 4.8% (95% CI 3.4–6.8) on the basis of 7026 meat or organ samples (Fig. 5). A single study reported a prevalence of 4.9% for sheep external samples ($n = 142$). There was no evidence for a difference in the odds of contamination by sample type (Table 5). Like goats, the adjusted prevalence was highest in sheep samples from the Central region (25.0%, based on a single study) and lowest in the Southern region (2.5%, 95% CI 1.2–5.3) (Fig. 5). The odds of sample contamination were significantly elevated in Central (OR = 6.5, 95% CI 1.4–30.3) and Western regions (OR = 3.1, 95% CI 1.3–7.1), and significantly reduced in the Southern region (OR = 0.25, 95% CI 0.07–0.98) (Table 5). There was no evidence for improvement in model fit with the inclusion of sample type ($X^2 = 4.9$, $p = 0.29$), but strong evidence for region ($X^2 = 14.4$, $p = 0.006$).

In total, *Salmonella* was isolated or detected in 332 sheep samples and 165 (49.7%) of these were serotyped. Among the 165 isolates serotyped from sheep samples, 69 (41.8%) were *Salmonella enterica* serovar Typhimurium, 14 (8.5%) were *Salmonella enterica* Enteritidis and 11 (6.7%) *Salmonella enterica* serovar Eastbourne (Table 7).

3.2.5. Goats

The adjusted *Salmonella* prevalence on the basis of 2096 goat gut samples was 2.2% (95% CI 1.1–4.3). Among 2748 goat meat or organ samples, the adjusted prevalence was 4.4% (95% CI 2.6–7.5) (Fig. 5). A single study reported on *Salmonella* detection in goat external samples. The adjusted prevalence was highest in the Central region (16.7%) and lowest in the Southern region (0.4%) (both based on a single study). There was no evidence of a difference in the odds of contamination by sample type or geographic region on the basis of a multivariable model (Tables 3 and 4). There was also no evidence for an improvement in model fit following inclusion of either region ($X^2 = 4.9$, $p = 0.29$) or sample type ($X^2 = 0.9$, $p = 0.6$) as fixed effects.

In total, *Salmonella* was isolated or detected in 145 goat samples and 47 (32.4%) of these were serotyped or serogrouped. Among the 47 isolates serotyped from goat samples, 19 (40.4%) were *Salmonella enterica* serovar Typhimurium, five (10.6%) were *Salmonella enterica* Typhi and two (4.3%) each of *Salmonella enterica* serovar Amersfoort, *Salmonella enterica* serovar Derby, *Salmonella enterica* serovar Poona,

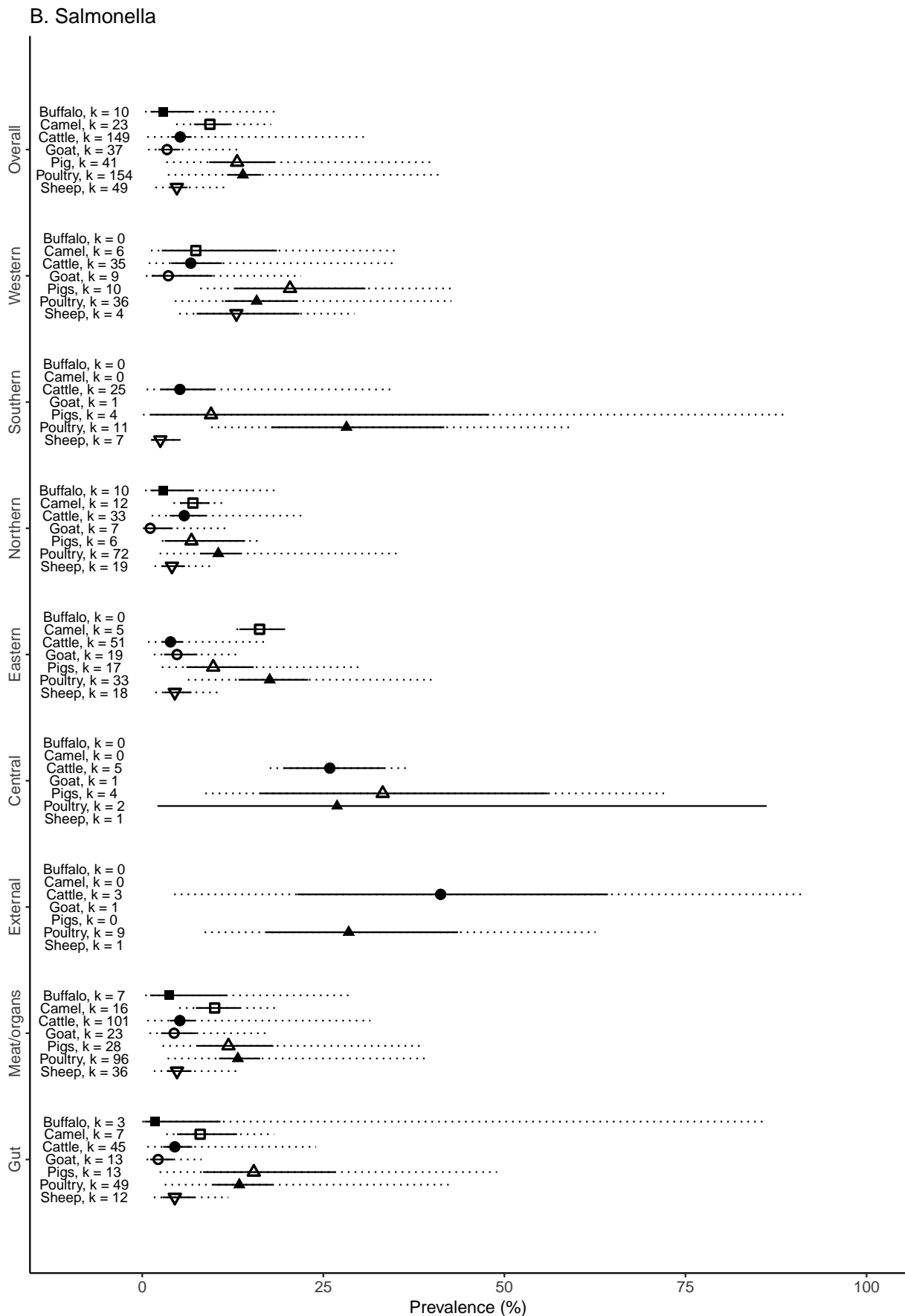


Fig. 5. Forest plot with adjusted prevalence estimates for *Salmonella* in food animals and meat for each animal species, sample type and African region, 1953–2016. 95% confidence intervals shown in solid line. 80% prediction intervals shown with dotted line. Adjusted prevalence not estimated when number of studies (k) < 2, 1953–2016.

Table 7
 Combined unadjusted *Salmonella* prevalence and three most numerous serovars for food animal type and various sample types, 1953–2016.

Animal species	Sample stage	Sample type	No. of samples tested	No. of samples positive (%)	Number of isolates typed to serovar ^a (%)	Ranking of most commonly typed <i>Salmonella enterica</i> serovars							
						1		2		3			
						Serovar name	No. (%)	Serovar name	No. (%)	Serovar name	No. (%)		
Buffalo	Gut	Faeces/Rectal swab	2237	53	(2.4)								
		Meat/organ	Bile	900	12	(1.3)							
		Meat/organ	Lymph node	999	8	(0.8)							
		Meat/organ	Meat	88	10	(11.4)							
		TOTAL	4224	83	(2.0)	83	(100)	Typhimurium	35 (42.2)	Dublin	13 (15.7)	Anatum	8 (9.6)
Camel	Gut	Faeces/Rectal swab	811	33	(4.1)								
		Gut	Intestine	450	32	(7.1)							
		Meat/organ	Liver	269	20	(7.4)							
		Meat/organ	Lymph node	886	95	(10.7)							
		Meat/organ	Meat	403	54	(13.4)							
		Meat/organ	Spleen	169	24	(14.2)							
			TOTAL	2988	258	(8.6)	251	(97.3)	Saintpaul	49 (19.5)	Typhimurium	27 (10.8)	Branderup
Cattle	Gut	Faeces/Rectal swab	8683	517	(6.0)								
		Gut	Intestine	3090	143	(4.6)							
		Meat/organ	Carcass	6019	162	(2.7)							
		Meat/organ	Gallbladder/bile	6558	135	(2.1)							
		Meat/organ	Heart	37	1	(2.7)							
		Meat/organ	Kidney	126	6	(4.8)							
		Meat/organ	Liver	1248	40	(3.2)							
		Meat/organ	Lymph node	3835	139	(3.6)							
		Meat/organ	Meat	23,998	1050	(4.4)							
		Meat/organ	Meat rinse	4396	19	(0.4)							
		Meat/organ	Spleen	42	1	(2.4)							
		Meat/organ	Tongue	13,680	199	(1.5)							
		Meat/organ	Tripe	403	23	(5.7)							
		External	Hide	177	74	(41.8)							
	TOTAL	72,292	2509	(3.5)	1637	(65.2)	Typhimurium	289 (17.7)	Anatum	124 (7.6)	Enteritidis	120 (7.3)	
Goat	Gut	Faeces/Rectal swab	1411	30	(2.1)								
		Gut	Intestine	685	5	(0.7)							
		Meat/organ	Carcass	309	49	(15.9)							
		Meat/organ	Gallbladder/bile	625	0	(0.0)							
		Meat/organ	Liver	160	3	(1.9)							
		Meat/organ	Lymph node	911	33	(3.6)							
		Meat/organ	Meat	583	24	(4.1)							
		Meat/organ	Spleen	160	2	(1.3)							
		External	Skin	60	3	(5.0)							
			TOTAL	4904	149	(3.0)	47	(32.4)	Typhimurium	18 (12.4)	Typhi	5 (3.4)	Amersfoort
										Poona			
										Derby			
										“Other”/UT			
Pig	Gut	Caeca/Intestine	510	92	(18.0)								
		Gut	Faeces/Rectal swab	2074	372	(17.9)							
		Meat/organ	Carcass	371	22	(5.9)							
		Meat/organ	Gallbladder/bile	660	4	(0.6)							
		Meat/organ	Heart	1	0	(0.0)							
		Meat/organ	Kidney	4	0	(0.0)							
		Meat/organ	Liver	121	18	(14.9)							
		Meat/organ	Lymph node	1184	173	(14.6)							
		Meat/organ	Meat	425	51	(12.0)							
		Meat/organ	Tongue	117	30	(25.6)							
	TOTAL	5467	762	(13.9)	478	(62.7)	Hadar	85 (17.9)	Group O:2	48 (10.0)	Saintpaul	46 (9.6)	
Poultry	Gut	Caeca/Intestine	1997	360	(18.0)								
		Gut	Faeces/Cloaca swab	10,060	1321	(13.1)							
		Meat/organ	Carcass	1752	335	(19.1)							
		Meat/organ	Gallbladder	279	19	(6.8)							

(continued on next page)

Table 7 (continued)

Animal species	Sample stage	Sample type	No. of samples tested	No. of samples positive (%)	Number of isolates typed to serovar ^a (%)	Ranking of most commonly typed <i>Salmonella enterica</i> serovars					
						1		2		3	
						Serovar name	No. (%)	Serovar name	No. (%)	Serovar name	No. (%)
	Meat/organ	Giblets	42	18 (42.9)							
	Meat/organ	Gizzard	876	267 (30.5)							
	Meat/organ	Heart	452	38 (8.4)							
	Meat/organ	Kidney	90	0 (0.0)							
	Meat/organ	Liver	1852	180 (9.7)							
	Meat/organ	Meat	6578	712 (27.3)							
	Meat/organ	Spleen	425	20 (4.7)							
	External	Feathers	120	61 (50.8)							
	External	Skin	907	284 (31.3)							
		TOTAL	25,430	3615 (14.2)	2098 (58.0)	Enteritidis	464 (22.1)	Typhimurium	311 (14.8)	Typhi	174 (8.3)
Sheep	Gut	Faeces/Rectal swab	2370	97 (4.1)							
	Gut	Intestine	1797	28 (1.6)							
	Meat/organ	Carcass	381	25 (6.6)							
	Meat/organ	Gallbladder/bile	2305	31 (1.3)							
	Meat/organ	Heart	207	0 (0.0)							
	Meat/organ	Kidney	9	0 (0.0)							
	Meat/organ	Liver	190	4 (2.1)							
	Meat/organ	Lymph node	2817	71 (2.5)							
	Meat/organ	Meat	936	68 (7.3)							
	Meat/organ	Spleen	181	1 (0.6)							
	External	Skin	142	7 (4.9)							
		TOTAL	11,335	332 (2.9)	165 (49.7)	Typhimurium	68 (20.5)	Enteritidis	14 (4.2)	Eastbourne	11 (3.3)

UT = Untypeable.

^a Serovars were excluded from number of isolates typed to serovar if numbers of isolates identified were not stated.

and untypeable *Salmonella* species (Table 7).

3.3. Typhoidal *Salmonella*

Salmonella enterica serovar Typhi isolates were reported from 201 samples in nine studies from Eastern, Northern, and Western African regions. Among the 201 *Salmonella enterica* serovar Typhi isolated or detected, 165 (82.1%) were from poultry gut samples from one study and 36 (17.9%) were from cattle, goat, pig, poultry, and sheep meat or organ samples.

Salmonella enterica serovar Paratyphi A were reported from 40 samples in five studies in Northern and Western African regions. Among the 40 *Salmonella enterica* serovar Paratyphi A isolated or detected, 33 (82.5%) were isolated from cattle, and poultry gut samples and 7 (17.5%) were isolated from cattle, poultry, and sheep meat or organ samples.

3.4. Risk of bias

Forty four of 246 studies (17.9%) had an overall low risk of bias, 178 (72.4%) had an overall moderate risk of bias, and 24 (9.8%) had an overall high risk of bias (S1 file - B). In regards to sample selection and transport, the number of days, months, or years over which a particular study took place was specified in 127 (51.6%) studies. The time from sampling to laboratory was specified as less than 4 h in 54 (22.0%) studies and unspecified in 181 (73.6%) studies. Temperature during transport was at refrigeration temperatures in 25 (10.2%) studies, chilled in 82 (33.3%) studies, and unspecified in 137 (55.7%) of studies. With regards to laboratory testing, the amount of any individual sample tested was specified in 182 (74.0%) of 246 studies. *Campylobacter* or *Salmonella* specific liquid and solid media were used in 150 (61.0%) of studies. *Campylobacter* were incubated microaerophilically or in a candle jar in 61 (83.6%) of the 73 studies focusing

on that organism. *Campylobacter* and *Salmonella* were specified as incubated between 35 °C and 42 °C in 48 (65.8%) of 73 and 120 (64.5%) of 186 studies, respectively. The speciation methods of *Campylobacter* isolates were deemed to have low or moderate risk of bias in 50 (68.5%) of 73 studies. The typing methods for *Salmonella* isolates was deemed to have low or moderate risk of bias in 91 (48.9%) of 186 studies.

Forty-three (8.3%) of 518 articles were excluded at the full text screening stage for being in a language other than English.

4. Discussion

Our systematic review has demonstrated widespread prevalence of *Campylobacter* species and *Salmonella* serovars in food animal species or meat across Africa. Both *Campylobacter* and *Salmonella* were most prevalent among samples from poultry and pigs, and were less common among samples from ruminant livestock and other animals. *C. jejuni* was the most predominant *Campylobacter* species and *Salmonella enterica* serovar Typhimurium was the most commonly identified *Salmonella* serovar in African food animals and meat products.

Campylobacter and *Salmonella* were present in animal gut, external, and meat or organ animal samples, but patterns of carriage or contamination varied among host species. Pathogen contamination during slaughter and meat processing may be more important in some animal species than others. The finding that *Campylobacter* were more likely to be isolated or detected from poultry external samples than poultry gut samples may result from contamination of feathers and skin by gut contents of many different animals, both while alive and during slaughter. On-farm environmental sources, both inside and outside housing, waterways and wildlife, including wild birds, have been identified as sources of *Campylobacter* (Agunos et al., 2014). In contrast, *Salmonella* were significantly more likely to be isolated or detected in poultry gut samples than poultry external and meat or organ samples. This may be, in part, due to relative concentration of carriage of the two

pathogens in poultry, which a report has shown to be > 5 log cfu/g greater for *Campylobacter* than *Salmonella* in poultry faecal samples (FSANZ and the South Australian Research and Development Institute, 2010). Environmental contamination of cattle hides from multiple sources may explain why *Salmonella* were significantly more likely to be isolated or detected from cattle external samples than cattle gut samples. No cattle external samples were tested for *Campylobacter* to compare these findings. *Campylobacter* were significantly more likely to be isolated or detected from cattle gut samples than cattle meat or organ samples, while *Salmonella* were significantly more likely to be isolated or detected from goat meat or organ samples than goat gut samples. *Campylobacter* are micro-aerophilic organisms and sensitive to extra-intestinal environments (Cools et al., 2005). From extra-intestinal samples types, *Campylobacter* cells may be present but damaged and therefore not culturable in the laboratory. The difference for *Salmonella* isolation and detection between goats and cattle may be a result of differences in the slaughter and production, differences in sample consistency (particularly faecal samples) or handling of meat products. Goats are more easily hung for dressing than cattle, likely decreasing floor-to-carcass contact and therefore faecal contamination. Larger slaughter facilities in Africa have been shown to have greater incidence of *Salmonella*, at all stages of the slaughter process, than smaller facilities (Hassanien et al., 2006).

We have shown that *Campylobacter* were significantly more likely to be isolated or detected in Central African food animal samples than those from other African regions following adjustment for types of samples tested. The prevalence of *Campylobacter* detection was particularly high among Central African poultry and was significantly higher than that of other regions (Fig. 3). *Salmonella* were significantly more likely to be isolated or detected from Central and Western African food animal samples than the referent region of Northern Africa. Unlike for *Campylobacter*, no single food animal species contributed to the higher *Salmonella* prevalence in Central and Western Africa. Rather, it seems that the *Salmonella* prevalence across all food animal species drove the regional differences. The finding that Southern African studies isolated or detected significantly more *Campylobacter* in goat and sheep samples but significantly less *Campylobacter* in pig samples, than the referent region of Northern Africa, reinforces that the contamination or carriage may vary between animal species within the same region.

Campylobacter jejuni was the predominant *Campylobacter* species isolated from food animals in Africa. However, goat and sheep, and poultry samples from Central Africa and pig faecal samples and pork regardless of region of origin, had a higher prevalence of *C. coli*. The observation that *C. coli* predominates in pig and pork samples agrees with studies from North and South America (Cummings et al., 2018; Modolo et al., 1999; Varela et al., 2007), and Europe (Boes et al., 2005; Kempf et al., 2017) with varying predominance in Asia (Haruna et al., 2013; Carrique-Mas et al., 2014). Thermophilic *Campylobacter* species, *C. jejuni*, *C. coli*, *C. lari*, and *C. upsaliensis* accounted for the majority of *Campylobacter* species isolated. Thermophilic *Campylobacter* cause the majority of human *Campylobacter* infection but non-thermophilic species also cause human illness (Lastovica and le Roux, 2000). *C. sputorum*, *C. hyointestinalis*, *C. faecalis*, and *C. fetus* are non-thermophilic *Campylobacter* species, and were identified in low numbers from African food animals. For non-thermophilic species underestimation is particularly likely where studies use an elevated temperature for isolation.

Campylobacter were not recovered from African camel samples. *Campylobacter* have been recovered from camel faecal and meat samples elsewhere (Mohammed et al., 2015; Rahimi et al., 2010). As so few camel samples were tested for *Campylobacter* ($n = 3$), there is a need for more sampling of camels in Africa.

Salmonella enterica serovar Typhimurium was the most commonly identified serovar in African food animals in our review. This contrasts with findings in a report from the WHO Global Salm-Surv database (Galanis et al., 2006); a now discontinued web-based country databank of *Salmonella* serovars from human and non-human sources. In the

WHO report, *Salmonella enterica* serovar Typhimurium was not in the top five *Salmonella* serovars submitted from non-human sources from African countries between 2000 and 2002. Instead, *Salmonella enterica* serovar Anatum (16%), *Salmonella enterica* serovar Enteritidis (16%), *Salmonella enterica* serovar Corvalis (8%), *Salmonella enterica* serovar Amsterdam (8%), and *Salmonella enterica* serovar Braenderup (8%) were the most common from non-human sources across the continent (Galanis et al., 2006). This may result in bias of reporting of non-human *Salmonella* strains isolates to the databank, particularly if submissions came from sick animals by way of veterinary laboratories. It should be noted that the Global Salm-Surv database had only three African countries contributing non-human data, compared to 27 countries represented in our analyses. The Global Salm-Surv database was also more restricted in time, reporting contributed data between 2000 and 2002, compared to between 1953 and 2016 for our analyses.

Common *Salmonella enterica* serovars from pigs varied from those isolated from other food animals. *Salmonella enterica* serovar Hadar, *Salmonella enterica* serovar Saintpaul, and *Salmonella enterica* serovar Eastbourne were the three most frequently identified serovars. The low proportion of porcine *Salmonella enterica* serovar Typhimurium isolates contrasts with reports from Europe (Animal and Plant Health Agency (APHA), 2014; Hald et al., 2003; Pires et al., 2011), North America (Letellier et al., 1999), South America (Kich et al., 2011) and Asia (Amal et al., 2014; Thai et al., 2012) where *Salmonella enterica* serovar Typhimurium is a common serovar in pig and pig products.

Typhoidal and Paratyphoidal *Salmonella enterica* serovars Typhi, Paratyphi A, Paratyphi B, with the exception of the biovar Java, and Paratyphi C are not known to have animal or environmental reservoirs (Centers for Disease Control and Prevention (CDC), 2017). One *Salmonella* isolate reported as *Salmonella enterica* serovar Paratyphi B was from a study published in 1953, prior to *Salmonella enterica* serovar Java first being redefined as a biovar of *Salmonella enterica* serovar Paratyphi B in 1988 by Le Minor (Le Minor, 1988). The majority of the *Salmonella enterica* serovar Typhi reported as isolated or detected was from a single Western African poultry study whose typing methods were questionable and considered high risk for bias. However, three other studies from Western Africa reported *Salmonella enterica* serovar Typhi in poultry. Of 11 studies reporting the isolation of *Salmonella enterica* serovar Typhi from meat pathway samples, one (9.1%) reported farm production type, slaughter facility size, or characteristics of meat retail facilities. The isolation of *Salmonella enterica* serovar Typhi and *Salmonella enterica* serovar Paratyphi from gut, external and meat or organ sample types likely suggests contamination from human faeces indicating serious breaches in sample collection and processing, or extremely poor farm or slaughter facility hygiene practices.

We have shown that African food animals and meat may be an important source of campylobacteriosis and salmonellosis as has been shown worldwide (Barrow et al., 1988; Ellis, 1969; Sahin et al., 2002; Skarp et al., 2016). Source attribution studies have implicated chicken as a cause of $> 70\%$ of human campylobacteriosis cases in studies from Germany (Rosner et al., 2017) and Switzerland (Kittl et al., 2013). Other studies report chicken consumption to be the predominant source of campylobacteriosis in other parts of Europe, Canada and New Zealand (Bessell et al., 2012; Boysen et al., 2011; Levesque et al., 2013; Mughini Gras et al., 2012; Ravel et al., 2017; Smid et al., 2013; Mullner et al., 2009). Ruminants appear to be the source of $\sim 15\text{--}30\%$ human campylobacteriosis in some studies, but as low as 1% in Germany (Rosner et al., 2017). Poultry was the most common source of food-borne salmonellosis in both the US and Japan where $\sim 70\%$ of human cases were attributable to chicken, turkey and egg products (Guo et al., 2011; Pires et al., 2014; Toyofuku and Hald, 2011). Poultry was similarly found to be the most important source of human salmonellosis in Europe. According to a European Food Safety Authority (EFSA) report, poultry was the greatest food animal contributor to human illness, with 51.2% of cases attributed to laying hens, broilers, and turkeys. We have shown that poultry in Africa have a higher prevalence of both

Campylobacter and *Salmonella* than other food animals and meat suggesting that poultry may be an important source of human illness in Africa too. The second most common attributable source of illness in both the EU and Japan were pigs with 26.9% and 5.3% of cases respectively (Pires et al., 2011; Pires et al., 2014). Beef was the second most common attributable source in the US with 29% of cases (Guo et al., 2011).

While source attribution studies have been performed in some parts of the world, few are available for *Campylobacter* and *Salmonella* in Africa (Mather et al., 2015). It is important to ascertain whether or not increasing scales and intensification of meat production are contributing to human disease in Africa. The presence of *Campylobacter* and *Salmonella* in food animals and meat products may or may not indicate human disease risk. As we have shown, *Campylobacter* species and *Salmonella* serovars identified, vary between animal species. Without a more in depth look at the link between animal and human isolates, such as whole genome sequencing and patterns of human exposure, including raw meat handling and cooking practices, we have less information about whether or not *Campylobacter* and *Salmonella* from African food animals are contributing to human disease.

Foodborne diseases are 'widespread and represent significant threats to health and economies of countries' according to the WHO Regional Office for Africa (World Health Organisation (WHO) Regional Office for Africa, 2017). It has been shown that implementation of greater hygiene measures in slaughter systems has been successful in reducing the numbers of cases of salmonellosis in Europe (European Food Safety Authority (EFSA): European Centre for Disease Prevention Control, 2012) and campylobacteriosis in New Zealand (Cressey and Lake, 2011). There are many challenges to improving food safety in Africa. Some are logistical, such as reliable access to electricity and safe water, others are social, such as population changes, and some are environmental, such as extreme weather conditions (Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO), 2005). Where prevalence data show that end product samples are highly contaminated with *Campylobacter* or *Salmonella*, as was the case for poultry meat and organs, local and national policy makers and enforcers may be able to more effectively develop control measures to reduce potential pathogens in the food chain.

4.1. Limitations of the study

Our formal bias assessment determined the overall risk of bias from sample selection, sample transport and laboratory methods used. One hundred and eighty-two (73.7%) of 247 studies did not specify sample transport time, and 138 (55.9%) did not specify temperature of sample transport, both of which can affect the survival of pathogen before testing.

Most of the included studies either began testing samples in the years between 2000 and 2016 or did not specify when the study began. The analyses are therefore weighted more heavily on more recent studies as opposed to results uniformly spread over the years since 1951 when earliest sampling was stated to have taken place.

Laboratory methods varied between studies limiting direct comparability between analyses. Sixty-four (26.0%) of 247 studies did not specify the amount of sample tested. The weight of sample tested has been shown to influence the estimates of prevalence of *Salmonella* (Funk et al., 2000). Forty (16.2%) of 247 studies did not specify culture methods used. Among the 73 *Campylobacter* studies that used culture techniques for isolation, nine different broths were used as selective enrichment and 14 different agars were used. Among the 177 *Salmonella* studies that used culture techniques, eight different primary enrichment broths, six different selective enrichment broths, and 24 different agars were used for isolation. Speciating emerging *Campylobacter* requires tests beyond basic phenotypic and biochemical assays. The prevalence of these *Campylobacter* species is therefore likely

underestimated. Prevalence estimates were not corrected for test sensitivity and specificity, implying that the true prevalence in each study is likely to differ from the apparent prevalence, and that the magnitude of this difference may be affected by sampling and testing methodology in an unquantified manner. No study was excluded due to chosen sampling or testing methodologies. Potential biases involving study size and sample type were adjusted for in the data analysis.

4.2. Conclusion

For many subsistence households and communities in many African countries, meat is a key protein source and livestock and poultry production is central to people's livelihoods. As market-driven changes occur within agricultural production towards wider distribution networks, centralised processing, and more large-scale and intensive systems, have been linked to the emergence of zoonotic diseases. Both *Campylobacter* and *Salmonella* were most prevalent among samples from poultry and pigs, and were less common among samples from ruminant livestock species. *C. jejuni* was the predominant *Campylobacter* species and *Salmonella enterica* serovar Typhimurium was the most commonly identified *Salmonella* serovar in African food animals and animal products. The presence of *Salmonella enterica* serovar Typhi and *Salmonella enterica* serovar Paratyphi in samples of food animal origin is particularly troubling and strongly indicates the need for increased hygiene measures to ensure food animals are not exposed to human faeces and human faeces do not contaminate the community meat supply.

The high prevalence of these organisms in livestock and poultry, their important role as human pathogens, and lack of evidence on which animal hosts contribute most to human illness in Africa, indicate source attribution studies would be a useful tool to more definitively identify priorities for food safety interventions.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijfoodmicro.2019.108382>.

Author contributions

All authors have contributed the concept or design of the work. KMT organised and populated the database. KMT wrote the first draft and subsequent revisions of the manuscript. WdG performed the meta-analysis. JAC, RNZ, NPF, JJB, SC, MAD, GB, ESS, JB, and WdG made substantial contributions to the manuscript. All authors contributed to manuscript revisions, read and approved the submitted version.

Funding

The authors were funded by the UK Biotechnology and Biological Sciences Research Council, Department for International Development, UK, UK Economic and Social Research Council, UK Medical Research Council, UK Natural Environment Research Council and UK Defence Science and Technology Laboratory, under the Zoonoses and Emerging Livestock Systems (ZELS) programme (grant numbers BB/L017679/1 and BB/L018926/1). The funders were not involved in study design, analysis or interpretation of data, writing or decision to submit for publication.

Declaration of competing interest

The authors declare that the submitted work was conducted in the absence of any commercial or financial relationships that could be construed as a conflict of interest.

Acknowledgements

The authors would like to thank the University of Otago Distance Library Service for sourcing full text articles not available online.

References

- a Mpalang, R.K., Boreux, R., Melin, P., Akir Ni Bitiang, K., Daube, G., De Mol, P., 2014. Prevalence of *Campylobacter* among goats and retail goat meat in Congo. *J. Infect. Dev. Ctries* 8, 168–175.
- Abbassi-Ghozzi, I., Jaouani, A., Hammami, S., Martinez-Urtaza, J., Boudabous, A., Gtari, M., 2012. Molecular analysis and antimicrobial resistance of *Salmonella* isolates recovered from raw meat marketed in the area of “Grand Tunis”, Tunisia. *Pathol. Biol. (Paris)* 60, e49–e54.
- Abd el-Aziz, A.S., Elmossalami, M.K., el-Neklawy, E., 2002. Bacteriological characteristics of dressed young pigeon (squabs) *Columba livia domesticus*. *Nahrung* 46, 51–53.
- Abd El-Ghany, W.A., El-Shafii, S.S.A., Hatem, M.E., 2012. A survey on *Salmonella* species isolated from chicken flocks in Egypt. *Asian J. Anim. Vet. Adv.* 7, 489–501.
- Abd-Elghany, S.M., Sallam, K.I., Abd-Elkhalek, A., Tamura, T., 2015. Occurrence, genetic characterization and antimicrobial resistance of *Salmonella* isolated from chicken meat and giblets. *Epidemiol. Infect.* 143, 997–1003.
- Abdellah, C., Fouzia, R.F., Abdelkader, C., Rachida, S.B., Mouloud, Z., 2008. Occurrence of *Salmonella* in chicken carcasses and giblets in Meknès-Morocco. *Pak. J. Nutr.* 7, 231–233.
- Abdel-Maksoud, M., Abdel-Khalek, R., El-Gendy, A., Gamal, R.F., Abdelhady, H.M., House, B.L., 2015. Genetic characterisation of multidrug-resistant *Salmonella enterica* serotypes isolated from poultry in Cairo, Egypt. *Afr. J. Lab. Med.* 4.
- Abebe, M., Tafese, B., 2014. Zoonotic bacterial pathogens isolated from food of bovine in selected Woredas of Tigray, Ethiopia. *World Appl. Sci. J.* 31, 1864–1868.
- Abou El Hassan, D.G., 1996. Neonatal diarrhoea in lambs and goat kids. *Vet. Med. J. Giza* 44, 371–380.
- Abrahams, C.A., Agbodaze, D., Nakano, T., Afari, E.A., Longmately, H.E., 1990. Prevalence and antibiogram of *Campylobacter jejuni* in domestic animals in rural Ghana. *Arch. Environ. Health* 45, 59–62.
- Acha, S.J., Kuhn, I., Jonsson, P., Mbazima, G., Katouli, M., Mollby, R., 2004. Studies on calf diarrhoea in Mozambique: prevalence of bacterial pathogens. *Acta Vet. Scand.* 45, 27–36.
- Addis, Z., Kebede, N., Worku, Z., Gezahegn, H., Yirsaw, A., Kassa, T., 2011. Prevalence and antimicrobial resistance of *Salmonella* isolated from lactating cows and in contact humans in dairy farms of Addis Ababa: a cross sectional study. *BMC Infect. Dis.* 11.
- Adekeye, J.O., Abdu, P.A., Bawa, E.K., 1989. *Campylobacter fetus* subsp. *jejuni* in poultry reared under different management systems in Nigeria. *Avian Dis.* 33, 801–803.
- Adesiji, Y.O., Alli, O.T., Adekanle, M.A., Jolayemi, J.B., 2011. Prevalence of *Aerobacter*, *Escherichia coli*, *Staphylococcus aureus* and *Salmonella* species in retail raw chicken, pork, beef and goat meat in Osogbo, Nigeria. *Sierra Leone J. Biomed. Res.* 3.
- Adesiyun, A.A., Oni, O.O., 1989. Prevalence and antibiograms of *Salmonellae* in slaughter cattle, slaughter areas and effluents in Zaria abattoir, Nigeria. *J. Food Prot.* 52, 232–235.
- Adeyanju, G.T., Ishola, O., 2014. *Salmonella* and *Escherichia coli* contamination of poultry meat from a processing plant and retail markets in Ibadan, Oyo State, Nigeria. SpringerPlus 3.
- Adu-Gyamfi, A., Torgby-Tetteh, W., Appiah, V., 2012. Microbiological quality of chicken sold in Accra and determination of D10-value of *E. coli*. *Food Nutr. Sci.* 3, 693–698.
- Agunos, A., Waddell, L., Léger, D., Taboada, E., 2014. A systematic review characterizing on-farm sources of *Campylobacter* spp. for broiler chickens. *PLoS One* 9, e104905.
- Ahmed, A.M., Shimamoto, T., 2014. Isolation and molecular characterization of *Salmonella enterica*, *Escherichia coli* O157:H7 and *Shigella* spp. from meat and dairy products in Egypt. *Int. J. Food Microbiol.* 168, 57–62.
- Ahmed, H.A., Ibrahim, A.F., Hussein, M.A., El-Bayomi, R.M., 2014. ERIC-PCR fingerprinting of some *S. Typhimurium* isolates from chicken and humans with reference to the microbiological quality of retail chicken meat in Dakahlia, Egypt. *Glob. Vet.* 13, 95–104.
- Ahmed, H.A., El-Hofy, F.I., Shafik, S.M., Abdelrahman, M.A., Elsaid, G.A., 2016. Characterization of virulence-associated genes, antimicrobial resistance genes, and class 1 integrons in *Salmonella enterica* serovar *Typhimurium* isolates from chicken meat and humans in Egypt. *Foodborne Pathog. Dis.* 13, 281–288.
- Ajayi, A.O., Egbebi, A.O., 2011. Antibiotic susceptibility of *Salmonella* Typhi and *Klebsiella pneumoniae* from poultry and local birds in ado-Ekiti, Ekiti-State, Nigeria. *Ann. Biol. Res.* 2, 431–437.
- Akam, A., Khelef, D., Kaidi, R., Lafri, M., Rahal, K., Chirila, F., Cozma, V., 2004. Frequency of *Cryptosporidium parvum*, *Escherichia coli* K99 and *Salmonella* spp. isolated from calves in six breeding farms from Mitidja, Algeria. *Bulletin UASVM Animal Science and Biotechnologies* 61, 287–288.
- Akoachere, J.-F.T.K., Tanih, N.F., Ndip, L.M., Ndip, R.N., 2009. Phenotypic characterization of *Salmonella* Typhimurium isolates from food-animals and abattoir drains in Buea, Cameroon. *J. Health Popul. Nutr.* 27, 612–618.
- Akwuobu, C.A., Oboegbulem, S.I., Ofukwu, R.A., 2010. Characterization and antibiogram of local isolates of *Campylobacter* species from chicken in Nsukka area, Southeast Nigeria. *Am.-Eurasian J. Sustain. Agric.* 4, 117–121.
- Alao, F.O., Kester, C.T., Gbagba, B.K., Fakilede, F.K., 2012. Comparison of prevalence and antimicrobial sensitivity of *Salmonella* Typhimurium in apparently healthy cattle and goat in Sango-Ota, Nigeria. *Internet J. Microbiol.* 10.
- Alemayehu, D., Molla, B., Muckle, A., 2003. Prevalence and antimicrobial resistance pattern of *Salmonella* isolates from apparently healthy slaughtered cattle in Ethiopia. *Trop. Anim. Health Prod.* 35, 309–319.
- Alemu, S., Zewde, B.M., 2012. Prevalence and antimicrobial resistance profiles of *Salmonella enterica* serovars isolated from slaughtered cattle in Bahir Dar, Ethiopia. *Trop. Anim. Health Prod.* 44, 595–600.
- Al-Hazmi, M., Al-Arfaj, A., Mostafa, A., Ihab, M., 2013. Molecular detection of *Salmonella enterica* serovar Enteritidis in chicken-related samples collected from Egypt. *Life Sci.* 10, 2645–2649.
- Ali, F.H.M., Ouf, J.M., 2005. Evaluation of the hygienic status of broiler parts with and without skin in retail markets in Egypt. *Vet. Med. J. Giza* 53, 611–623.
- Aliaa, S.O., Ibrahim, A.M., Tolba, K., Atalla, O.A., 2014. Bacterial evaluation of fresh and frozen beef and buffalo meat. *Glob. J. Agric. Food Safety Sci.* 1, 371–381.
- Amal, A.A.S., Nassif, M.R.M., Dalia, Y.Y.M., 2014. Follow up of some foodborne bacterial pathogens on hides and meat of bovine carcasses. *Glob. J. Agric. Food Safety Sci.* 1, 199–213.
- Amara, A., Badou, M., Faid, M., Bouzoubaa, K., 1994. Microbial contamination of poultry slaughtered in traditional shops in Morocco. *Microbiologie, Aliments, Nutrition* 12, 323–327.
- Amin, H.S., El-Rahman, A.E.A.A., 2015. Molecular characterization of *Salmonella enterica* isolated from chicken meat and its products by multiplex PCR. *Alex. J. Vet. Sci.* 46, 155–160.
- Ammar, A.M.A., Ahmed, Y.A.E., Asawy, A.M.I., Ibrahim, A.A., 2009. Bacteriological studies on *Salmonella* Enteritidis isolated from different sources in Dakhlia Governorate. *Assiut Vet. Med. J.* 56, 125–135.
- Ammar, A., Alloui, N., Bennoune, O., Kassah-Laouar, A., 2010. Survey of *Salmonella* serovars in broilers and laying breeding reproducers in East of Algeria. *J. Infect. Dev. Ctries* 4, 103–106.
- Animal and Plant Health Agency (APHA), 2014. *Salmonella* in livestock production in Great Britain, 2014. In: Chapter 4: Reports of *Salmonella* in Pigs.
- Aragaw, K., Molla, B., Muckle, A., Cole, L., Wilkie, E., Poppe, C., Kleer, J., Hildebrandt, G., 2007. The characterization of *Salmonella* serovars isolated from apparently healthy slaughtered pigs at Addis Ababa abattoir, Ethiopia. *Prev. Vet. Med.* 82, 252–261.
- Aragaw, K., Terefe, L., Abera, M., 2010. Prevalence of *Salmonella* infection in intensive poultry farms in Hawassa and isolation of *Salmonella* species from sick and dead chickens. *Ethiopian Veterinary Journal* 14, 115–124.
- Ashenafi, M., 1994. Microbial flora and incidence of some food-borne pathogens on fresh raw beef from butcher's shops in Awassa, Ethiopia. *Bull. Anim. Health Prod. Afr.* 42, 273–277.
- Awadallah, M.A.I., Ahmed, H.A., El-Gedawy, A.A., Saad, A.M., 2014. Molecular identification of *C. jejuni* and *C. coli* in chicken and humans, at Zagazig, Egypt, with reference to the survival of *C. jejuni* in chicken meat at refrigeration and freezing temperatures. *Food Res. Int.* 21, 1801–1812.
- Bada-Alamedji, R., Fofana, A., Seydi, M., Akakpo, A.J., 2006. Antimicrobial resistance of *Salmonella* isolated from poultry carcasses in Dakar (Senegal). *Braz. J. Microbiol.* 37, 510–515.
- Barendregt, J.J., Doi, S.A., Lee, Y.Y., 2013. Meta-analysis of prevalence. *Epidemiol. Community Health* 67, 974–978.
- Barrow, P.A., Simpson, J.M., Lovell, M.A., 1988. Intestinal colonisation in the chicken by food-poisoning *Salmonella* serotypes; microbial characteristics associated with faecal excretion. *Avian Pathol* 17, 571–588.
- Bata, S.I., Karshima, N.S., Yohanna, J., Dashe, M., Pam, V.A., Ogbu, K.I., 2016. Isolation and antibiotic sensitivity patterns of *Salmonella* species from raw beef and quail eggs from farms and retail outlets in Jos, Plateau State, Nigeria. *J. Vet. Med. Anim. Health* 8, 29–34.
- Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67.
- Bawa, I.H., Bsadjo, T.G., Bagré, T.S., Bouda, S.C., Konaté, A., Bako, E., Kagambèga, A., Zongo, C., Somda, M., Savadogo, A., Traoré, A.S., Barro, N., 2015. Antimicrobial susceptibility of *Salmonella enterica* strains isolated from raw beef, mutton and intestines sold in Ouagadougou, Burkina Faso. *J. Appl. Biosci.* 95, 8966–8972.
- Bekele, B., Ashenafi, M., 2010. Distribution of drug resistance among enterococci and *Salmonella* from poultry and cattle in Ethiopia. *Trop. Anim. Health Prod.* 42, 857–864.
- Beshatu, F., Fanta, D., Aklilu, F., Getachew, T., Nebyu, M., 2015. Prevalence and antimicrobial susceptibility of *Salmonella* isolates from apparently healthy slaughtered goats at Dire Dawa municipal abattoir, eastern Ethiopia. *J. Microbiol. Antimicrob.* 7, 1–5.
- Bessell, P.R., Rotariu, O., Innocent, G.T., Smith-Palmer, A., Strachan, N.J., Forbes, K.J., Cowden, J.M., Reid, S.W., Matthews, L., 2012. Using sequence data to identify alternative routes and risk of infection: a case-study of *Campylobacter* in Scotland. *BMC Infect. Dis.* 12, 80.
- Bester, L.A., Essack, S.Y., 2012. Observational study of the prevalence and antibiotic resistance of *Campylobacter* spp. from different poultry production systems in KwaZulu-Natal, South Africa. *J. Food Prot.* 75, 154–159.
- Boes, J., Nersting, L., Nielsen, E.M., Kranker, S., Enoe, C., Wachmann, H.C., Baggesen, D.L., 2005. Prevalence and diversity of *Campylobacter jejuni* in pig herds on farms with and without cattle or poultry. *J. Food Prot.* 68, 722–727.
- Boko, C.K., Kpodekon, T.M., Duprez, J.N., Imberechts, H., Taminiau, B., Bertrand, S., Mainil, J.G., 2013. Identification and typing of *Salmonella enterica* serotypes isolated from guinea fowl (*Numida meleagris*) farms in Benin during four laying seasons (2007 to 2010). *Avian Pathol.* 42, 1–8.
- Bouchrif, B., Paglietti, B., Murgia, M., Piana, A., Cohen, N., Ennaji, M.M., Rubino, S., Timinouni, M., 2009. Prevalence and antibiotic-resistance of *Salmonella* isolated from food in Morocco. *J. Infect. Dev. Ctries* (1), 3.
- Boysen, L., Vigre, H., Rosenquist, H., 2011. Seasonal influence on the prevalence of thermotolerant *Campylobacter* in retail broiler meat in Denmark. *Food Microbiol.* 28, 1028–1032.
- Cardinale, E., Dromigny, J.A., Tall, F., Ndiaye, M., Konte, M., Perrier-Gros-Claude, J.D., 2003a. Fluoroquinolone susceptibility of *Campylobacter* strains, Senegal. *Emerg. Infect. Dis.* 9, 1479–1481.
- Cardinale, E., Gros-Claude, J.D.P., Tall, F., Cissé, M., Guèye, E.F., Salvat, G., 2003b. Prevalence of *Salmonella* and *Campylobacter* in retail chicken carcasses in Senegal. *Rev. Elev. Med. Vet. Pays Trop.* 56, 13–16.

- Cardinale, E., Rose, V., Perrier Gros-Claude, J.D., Tall, F., Rivoal, K., Mead, G., Salvat, G., 2006. Genetic characterization and antibiotic resistance of *Campylobacter* spp. isolated from poultry and humans in Senegal. *J. Appl. Microbiol.* 100, 209–217.
- Carrique-Mas, J.J., Bryant, J.E., Cuong, N.V., Hoang, N.V., Campbell, J., Hoang, N.V., Dung, T.T., Duy, D.T., Hoa, N.T., Thompson, C., Hien, V.V., Phat, V.V., Farrar, J., Baker, S., 2014. An epidemiological investigation of *Campylobacter* in pig and poultry farms in the Mekong delta of Vietnam. *Epidemiol. Infect.* 142, 1425–1436.
- Carron, M., Chang, Y.-M., Momanyi, K., Akoko, J., Kiiru, J., Bettridge, J., Chaloner, G., Rushton, J., O'Brien, S., Williams, N., Fèvre, E.M., Häslar, B., 2018. *Campylobacter*, a zoonotic pathogen of global importance: prevalence and risk factors in the fast-evolving chicken meat system of Nairobi, Kenya. *PLoS Negl. Trop. Dis.* 12, e0006658.
- Carter, J.D., Hudson, A.P., 2009. Reactive arthritis: clinical aspects and medical management. *Rheum. Dis. Clin. N. Am.* 35, 21–44.
- Centers for Disease Control and Prevention (CDC), 2017. Infectious diseases related to travel. In: Chapter 3: Typhoid & Paratyphoid Fever. *Travelers' Health*.
- Chambers, P.G., 1977. Salmonellae in Rhodesia: sources and serotypes of some isolates from abattoirs, domestic animals, birds and man. *J. S. Afr. Vet. Assoc.* 48, 241–244.
- Chanyalew, Y., Asrat, D., Amavisit, P., Loongyai, W., 2013. Prevalence and antimicrobial susceptibility of thermophilic *Campylobacter* isolated from sheep at Debre Birhan, North-Shoa, Ethiopia. *Kasetsart J. Nat. Sci.* 47, 551–560.
- Cohen, N., Ennaji, H., Hassar, M., Karib, H., 2006. The bacterial quality of red meat and offal in Casablanca (Morocco). *Mol. Nutr. Food Res.* 50, 557–562.
- Cohen, N., Ennaji, H., Bouchrif, B., Hassar, M., Karib, H., 2007. Comparative study of microbiological quality of raw poultry meat at various seasons and for different slaughtering processes in Casablanca (Morocco). *J. Appl. Poult. Res.* 16, 502–508.
- Collard, P., Sen, R., 1956. Isolation of salmonellae from cattle in Ibadan. *West Afr. Med. J.* 5, 118–120.
- Cools, I., Uyttendaele, M., Cerpentier, J., D'Haese, E., Nelis, H.J., Debevere, J., 2005. Persistence of *Campylobacter jejuni* on surfaces in a processing environment and on cutting boards. *Lett. Appl. Microbiol.* 40, 418–423.
- Cooper, R., Shires, K., Lastovica, A.J., Elisha, B.G., 2001. Molecular epidemiology of fluoroquinolone-resistant and susceptible *Campylobacter jejuni* isolates. *South Afr. J. Epidemiol. Infect.* 16, 57–61.
- Cressey, P., Lake, R.J., 2011. Estimated incidence of foodborne illness in New Zealand: Application of overseas models and multipliers. In: MPI Technical Paper no: 2012/11.
- Cummings, K.J., Warnick, L.D., Davis, M.A., Eckmann, K., Grohn, Y.T., Hoelzer, K., MacDonald, K., Root, T.P., Siler, J.D., McGuire, S.M., Wiedmann, M., Wright, E.M., Zansky, S.M., Besser, T.E., 2012. Farm animal contact as risk factor for transmission of bovine-associated *Salmonella* subtypes. *Emerg. Infect. Dis.* 18, 1929–1936.
- Cummings, K.J., Rodriguez-Rivera, L.D., McNeely, I., Suchodolski, J.S., Mesenbrink, B.T., Leland, B.R., Bodenchuk, M.J., 2018. Fecal shedding of *Campylobacter jejuni* and *Campylobacter coli* among feral pigs in Texas. *Zoonoses Public Health* 65, 215–217.
- Dabassa, A., 2013. Evaluation of home slaughtered meat quality used for human consumption at household and food seller house in Jimma. *J. Med. Sci.* 13, 779–784.
- Dabassa, A., Bacha, K., 2012. The prevalence and antibiogram of *Salmonella* and *Shigella* isolated from abattoir, Jimmarjruth West Ethiopia. *IJPBR* 3, 143–148.
- Dadi, L., Asrat, D., 2008. Prevalence and antimicrobial susceptibility profiles of thermotolerant *Campylobacter* strains in retail raw meat products in Ethiopia. *Ethiop. J. Health Dev.* 22 (2), 195–200.
- Daniyan, S.Y., 2011. Microbiological quality of pork meat from local mammy market in Niger State, Nigeria. *AU J. Tech.* 14, 229–231.
- Dione, M.M., Ieven, M., Garin, B., Marcotty, T., Geerts, S., 2009. Prevalence and antimicrobial resistance of *Salmonella* isolated from broiler farms, chicken carcasses, and street-vended restaurants in Casamance, Senegal. *J. Food Prot.* 72, 2423–2427.
- Dione, M.M., Ikumapayi, U.N., Saha, D., Mohammed, N.I., Geerts, S., Ieven, M., Adegbola, R.A., Antonio, M., 2011. Clonal differences between non-Typhoidal *Salmonella* (NTS) recovered from children and animals living in close contact in The Gambia. *PLoS Negl. Trop. Dis.* 5.
- Eguale, T., Engidawork, E., Gebreyes, W.A., Asrat, D., Alemayehu, H., Medhin, G., Johnson, R.P., Gunn, J.S., 2016. Fecal prevalence, serotype distribution and antimicrobial resistance of Salmonellae in dairy cattle in central Ethiopia. *BMC Microbiol.* 16.
- Eisa, M.I., Mohamed, A.A., 2004. Role of enteric pathogens in enteritis in lambs, goat kids and children and their zoonotic importance. *Vet. Med. J. Giza* 52, 41–59.
- Eissa, W.M.M., Moussa, M.M., Ahmed, M.I., 2014. Bacteriological status of chicken carcasses from poultry abattoirs as compared with private shops. *Glob. J. Agric. Food Safety Sci.* 1, 307–316.
- Ejeta, G., Molla, B., Alemayehu, D., Muckle, A., 2004. *Salmonella* serotypes isolated from minced meat beef, mutton and pork in Addis Ababa, Ethiopia. *Rev. Med. Vet.* 155, 547–551.
- Elegbe, I.A., 1983. *Campylobacter* infections: domestic cows as a possible source of infection in Nigeria. *Med. Lab. Sci.* 40, 145–147.
- Elegbe, I.A., Juba, A., Adebayo, J.O., 1987. Species and serotypes of *Campylobacter* from domestic animals in Nigeria. *J. Diarrhoeal Dis. Res.* 5, 97–101.
- El-Gamal, A.M., El-Bahi, E.F., 2016. Molecular characterization of rectal carriage of *E. coli* O157: H7 and *Salmonella* spp. in feedlot animals and its effects on carcasses contamination. *Alex. J. Vet. Sci.* 48, 42–49.
- El-Gamal Galal, B., Refaie, R.S., El-Ailla, A.A.A., 1992. Occurrence of *Campylobacter* in poultry carcasses. *Assiut Vet. Med. J.* 26, 110–113.
- El-Jakee, J., Ata, N.S., Hakim, A.S., Syame, S.M., Omara, S.T., 2015. Prevalence of virulence genes and antimicrobial resistance patterns of *Campylobacter* species isolated from chicken in Egypt. *Asian J. Poultry Sci.* 9, 250–261.
- Ellis, E.M., 1969. *Salmonella* reservoirs in animals and feeds. *J. Am. Oil Chem. Soc.* 46, 227–229.
- Elmossalami, E., Yassein, N.A., 1994. Salmonellae in slaughtered camels. *Arch. Leb.* 45, 118–120.
- El-Naker, Y.F.I., El-Sawalhy, A.A., Youssef, M.A.A., Zeidan, S.M., 2008. Some studies on neonatal calf diarrhea in Egypt. Part 1: causative agents and some epidemiological aspects. *Bull. Anim. Health Prod. Afr.* 56, 161–190.
- El-Shibiny, A.A., Shaha, A.N., Ghoneim, S.I., 2012. Occurrence and enumeration of *Campylobacter* before and after processing of conventional chickens in Egypt. *World J. Dairy Food Sci.* 7, 222–228.
- El-Tras, W.F., Tayel, A.A., Samir, A., 2010. Potential zoonotic pathways of *Salmonella* Enteritidis in laying farms. *Vector Borne Zoonotic Dis* 10, 739–742.
- El-Tras, W.F., Holt, H.R., Tayel, A.A., El-Kady, N.N., 2015. *Campylobacter* infections in children exposed to infected backyard poultry in Egypt. *Epidemiol. Infect.* 143, 308–315.
- Esan, O.B., Pearce, M., van Hecke, O., Roberts, N., Collins, D.R.J., Violato, M., McCarthy, N., Perera, R., Fanshawe, T.R., 2017. Factors associated with dequellae of *Campylobacter* and non-typhoidal *Salmonella* infections: a systematic review. *EBioMedicine* 15, 100–111.
- European Food Safety Authority (EFSA), European Centre for Disease Prevention Control, 2012. The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2010. *EFSA J.* 10.
- Ewnetu, D., Mihret, A., 2010. Prevalence and antimicrobial resistance of *Campylobacter* isolates from humans and chickens in Bahir Dar, Ethiopia. *Foodborne Pathog. Dis.* 7, 667–670.
- Falade, S., Ehizokhale, M.U., 1981. *Salmonella* and *Escherichia coli* strains isolated from poultry in Ibadan, Nigeria. *Bull. Anim. Health Prod. Afr.* 29, 99–101.
- Farrag, H., El-Affify, A., 1956. *Salmonella* in apparently normal camels. *J. Egypt Med. Assoc.* 39, 698–699.
- Farrag, H., El-Affify, A., Zaki, O., 1954. *Salmonella* in apparently normal pigs. *J. Egypt Med. Assoc.* 37, 1110–1113.
- Farrag, H.F., El-Garhy, M.T., Fahmy, A.N., 1962. Bacteriological and histological studies of the gall bladder of pigs slaughtered in Cairo and used for human consumption with special reference to *Salmonella* food poisoning. *J. Egypt Med. Assoc.* 45, 310–316.
- Fashae, K., Ogunsoola, F., Aarestrup, F.M., Hendriksen, R.S., 2010. Antimicrobial susceptibility and serovars of *Salmonella* from chickens and humans in Ibadan, Nigeria. *J. Infect. Dev. Ctries* 4, 484–494.
- Feasey, N.A., Dougan, G., Kingsley, R.A., Heyderman, R.S., Gordon, M.A., 2012. Invasive non-typhoidal *Salmonella* disease: an emerging and neglected tropical disease in Africa. *Lancet* 379, 2489–2499.
- Floyd, T.M., Baranski, J.R., El-Gannani, M., 1953. Recovery of human enteric pathogens on meat from butcher shops in Cairo, Egypt. *J. Infect. Dis.* 92, 224–227.
- Food and Agriculture Organization of the United Nations (FAO), World Health Organization (WHO), 2005. FAO/WHO Regional Conference of Food Safety for Africa. Final Report.
- Food and Drug Administration (FDA), 2012. Bad Bug Book, Foodborne Pathogenic Microorganisms and Natural Toxins, Second edition.
- FSANZ and the South Australian Research and Development Institute, 2010. Baseline Survey on the Prevalence and Concentration of *Salmonella* and *Campylobacter* in Chicken Meat On-farm and at Primary Processing.
- Funk, J.A., Davies, P.R., Nichols, M.A., 2000. The effect of fecal sample weight on detection of *Salmonella enterica* in swine feces. *J. Vet. Diagn. Investig.* 12, 412–418.
- Gaedirelwe, O.G., Sebunya, T.K., 2008. The prevalence and antibiotic susceptibility of *Salmonella* spp. in poultry and ostrich samples from slaughter houses in Gaborone, Botswana. *J. Anim. Vet. Adv.* 7, 1151–1154.
- Galanis, E., Lo Fo Wong, D.M., Patrick, M.E., Binsztein, N., Cieslik, A., Chalermchikit, T., Aidara-Kane, A., Ellis, A., Angulo, F.J., Wegener, H.C., 2006. Web-based surveillance and global *Salmonella* distribution, 2000–2002. *Emerg. Infect. Dis.* 12, 381–388.
- Garedew, L., Hagos, Z., Addis, Z., Tesfaye, R., Zegeye, B., 2015. Prevalence and antimicrobial susceptibility patterns of *Salmonella* isolates in association with hygienic status from butcher shops in Gondar town, Ethiopia. *Antimicrob. Resist. Infect. Control* 4.
- Garin, B., Gouali, M., Wouafo, M., Perche, A.M., Thu, P.M., Ravaonindrina, N., Urbès, F., Gay, M., Diawara, A., Leclercq, A., Rocourt, J., Pouillot, R., 2012. Prevalence, quantification and antimicrobial resistance of *Campylobacter* spp. on chicken neckskins at points of slaughter in 5 major cities located on 4 continents. *Int. J. Food Microbiol.* 157, 102–107.
- Gashe, B.A., Mpuchane, S., 2000. Prevalence of salmonellae on beef products at butcheries and their antibiotic resistance profiles. *J. Food Sci.* 65, 880–883.
- Gay, J.M., Rice, D.H., Steiger, J.H., 1994. Prevalence of Fecal *Salmonella* Shedding by Cull Dairy Cattle Marketed in Washington State. 57. pp. 195–197.
- Gblossi Bernadette, G., Eric Essoh, A., Elise Solange, K.N., Natalie, G., Souleymane, B., Lamine Sébastien, N., Mireille, D., 2012. Prevalence and antimicrobial resistance of the thermophilic *Campylobacter* isolated from chicken in Côte d'Ivoire. *Int. J. Microbiol.* e150642.
- Gebeye, A., Yousef, M., Sebsibe, A., 2013. Evaluation of microbial load of beef of arsi cattle in Adama town, Oromia, Ethiopia. *J. Food Process. Technol.* 4, 234.
- Gharieb, R.M., Tartor, Y.H., Khedr, M.H., 2015. Non-Typhoidal *Salmonella* in poultry meat and diarrhoeic patients: prevalence, antibiogram, virulotyping, molecular detection and sequencing of class I integrons in multidrug resistant strains. *Gut Pathog.* 7, 34.
- Ghoneim, N.H., Mohamed, W.W., Hussein, M.K., 2015. Public health importance of enterotoxigenic and multi-drug resistant *Salmonella* serotypes from poultry meat in Egypt. *Glob. Vet.* 14, 813–818.
- Gitter, M., Brand, T.F., 1970. *Salmonella* survey in Kenya abattoirs. *Trop. Anim. Health Prod.* 2, 18–22.
- Gopo, J.M., Banda, G.N., 1997. Occurrence of *Salmonella* on meat and products in an ostrich abattoir as determined with a DNA probe. *S. Afr. J. Anim. Sci.* 27, 1–6.
- Goualie, G., Karou, A.G.T., Bakayoko, S., Dosso, M., Diopoh, J.K., 2007. Prevalence of *Campylobacter* in raw chicken products in Abidjan, cote d'Ivoire. *Zoonoses Public Health*

- Health 54, 74.
- Grace, D., 2017. Food Safety in Developing Countries: Research Gaps and Opportunities. White Paper. ILRI, Nairobi, Kenya.
- Grimont, P.A.D., Weill, F.X., 2007. Antigenic formulae of the *Salmonella* serovars. In: WHO Collaborating Centre for Reference and Research on *Salmonella*.
- Guergueb, N., Alloui, N., Ayachi, A., Bennoune, O., 2014. Effect of slaughterhouse hygienic practices on the bacterial contamination of chicken meat. *Sci. J. Vet. Adv.* 3, 71–76.
- Guo, C., Hoekstra, R.M., Schroeder, C.M., Pires, S.M., Ong, K.L., Hartnett, E., Naugle, A., Harman, J., Bennett, P., Cieslak, P., Scallan, E., Rose, B., Holt, K.G., Kissler, B., Mbandi, E., Roodsari, R., Angulo, F.J., Cole, D., 2011. Application of Bayesian techniques to model the burden of human salmonellosis attributable to U.S. food commodities at the point of processing: adaptation of a Danish model. *Foodborne Pathog. Dis.* 8, 509–516.
- Hag Elsafi, H.E., Nor Elmadiena, M.M., El Hussein, A.A., M Siddiq, M.A., A Muckle, C., Cole, L., Wilkie, E., Mistry, K., 2009. *Salmonella* Umdadah: A new *Salmonella* serovar isolated from cattle in Sudan. *Trop. Anim. Health Prod.* 41, 1605–1606.
- Hald, T., Wingstrand, A., Swanenburg, M., von Altrock, A., Thorberg, B.M., 2003. The occurrence and epidemiology of *Salmonella* in European pig slaughterhouses. *Epidemiol. Infect.* 131, 1187–1203.
- Hamada, S., El-Sawah, H., Sherif, I., Yousef, M., Hikik, M., 1963. *Salmonella* of the mesenteric lymph nodes of slaughtered cattle, buffaloes and camels. *J. Arab Vet. Met. Assoc.* 23, 272–277.
- Hang'ombe, B.M., Sharma, N.R., Skjerve, E., Tuchili, L.M., 1999. Isolation of bacteria during processing of chicken carcasses for the market in Lusaka, Zambia. *Vet. Arh.* 69, 191–197.
- Haruna, M., Sasaki, Y., Murakami, M., Mori, T., Asai, T., Ito, K., Yamada, Y., 2013. Prevalence and antimicrobial resistance of *Campylobacter* isolates from beef cattle and pigs in Japan. *J. Vet. Med. Sci.* 75, 625–628.
- Hassanain, N.A., 2011. Antimicrobial resistant *Campylobacter jejuni* isolated from humans and animals in Egypt. *Glob. Vet.* 6, 195–200.
- Hassanien, A.S., Adiarose, H., Talaat, M.M., Nouman, T.M., 2006. Contamination of Beef Carcasses During Slaughter in Two Egyptian Slaughterhouses.
- Hassb-Elnaby, G.R., Abdelaziz, A.H.B., Sobhy, E.E., 2011. Serological and electrophoretic characterization of *Salmonella* species isolated from beef meat. *Alex. J. Vet. Sci.* 32, 1–11.
- Havelaar, A.H., Kirk, M.D., Torgerson, P.R., Gibb, H.J., Hald, T., Lake, R.J., Praet, N., Bellinger, D.C., de Silva, N.R., Gargouri, N., Speybroeck, N., Cawthorne, A., Mathers, C., Stein, C., Angulo, F.J., Devleeschauwer, B., World Health Organization Foodborne Disease Burden Epidemiology Reference, G., 2015. World health organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Med.* 12, e1001923.
- Higgins, J.P.T., Thompson, S.G., Deeks, J.J., Altman, D.G., 2003. Measuring Inconsistency in Meta-analyses. 327. pp. 557–560.
- Hughes, F.A., Adu-Gyamfi, A., Appiah, V., 2015. Microbiological and parasitological quality of local beef retained in Accra and radiation sensitivity of *Salmonella* sp. *Int. J. Curr. Microbiol. Appl. Sci.* 4, 86–96.
- Hummel, P.H., 1974. Isolation of salmonellae from cattle at Dar es Salaam. *Bull. Epizoot. Dis. Afr.* 22, 109–113.
- Ibrahim, A.E., 1974. Isolation of *Salmonella* from the bile of meat animals. *Bull. Epizoot. Dis. Afr.* 22, 234–237.
- Ibrahim, M.A., 2016. Prevalence of *Salmonella* species in minced beef and meat handlers and their drug resistance. *Alex. J. Vet. Sci.* 49, 122–128.
- Ikwap, K., Erume, J., Owiny, D.O., Nasinyama, G.W., Melin, L., Bengtsson, B., Lundeheim, N., Fellström, C., Jacobson, M., 2014. *Salmonella* species in piglets and weaners from Uganda: prevalence, antimicrobial resistance and herd-level risk factors. *Prev. Vet. Med.* 115, 39–47.
- Int'Hout, J., Ioannidis, J.P.A., Rovers, M.M., Goeman, J.J., 2016. Plea for Routinely Presenting Prediction Intervals in Meta-analysis. 6. pp. e010247.
- Iroha, I.R., Ugbo, E.C., Ilang, D.C., Oji, A.E., Ayogu, T.E., 2011. Bacteria contamination of raw meat sold in Abakaliki, Ebonyi State Nigeria. *J. Public Health Epidemiol.* 3, 49–53.
- Isogai, E., Silungwe, M., Sinkala, P., Chisenga, C., Mubita, C., Syakalima, M., Hang'ombe, B.M., Makungu, C., Yabe, J., Simuunzab, M., Nambota, A., Isogai, H., Fukushi, H., Yasuda, J., 2005. Rapid detection of *Salmonella* on commercial carcasses by using isothermal and chimeric primer-initiated amplification of nucleic acids (ICAN)-enzyme-linked immunosorbent assay (ELISA) in Zambia. *Int. J. Appl. Res. Vet.* 3, 367–371.
- Iwu, C.J., Iweriebor, B.C., Obi, L.C., Basson, A.K., Okoh, A.I., 2016. Multidrug-resistant *Salmonella* isolates from swine in the Eastern Cape Province, South Africa. *J. Food Prot.* 79, 1234–1239.
- Jacob, P., Mdegela, R.H., Nonga, H.E., 2011. Comparison of Cape Town and Skirrow's *Campylobacter* isolation protocols in humans and broilers in Morogoro, Tanzania. *Trop. Anim. Health Prod.* 43, 1007–1013.
- Jajere, S.M., Adamu, N.B., Atsanda, N.N., Onyilokwu, S.A., Gashua, M.M., Hambali, I.U., Mustapha, F.B., 2015. Prevalence and antimicrobial resistance profiles of *Salmonella* isolates in apparently healthy slaughtered food animals at Maiduguri central abattoir, Nigeria. *Asian Pac. J. Trop. Dis.* 5, 996–1000.
- Jiwa, S.F.H., Kazwala, R.R., Namahungu, E., 1994. Prevalence of *Campylobacter* spp. in clinically normal goats kept under various management systems in urban Tanzania. *Small Rumin. Res.* 15, 97–100.
- Joint United Nations (UN) Programme on HIV/AIDS, 2017. UNAIDS Data 2017.
- Jones, B.A., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M.Y., McKeever, D., Mutua, F., Young, J., McDermott, J., Pfeiffer, D.U., 2013. Zoonosis emergence linked to agricultural intensification and environmental change. *Proc. Natl. Acad. Sci. U. S. A.* 110, 8399–8404.
- Jonker, A., Picard, J.A., 2010. Antimicrobial susceptibility in thermophilic *Campylobacter* species isolated from pigs and chickens in South Africa. *J. S. Afr. Vet. Assoc.* 81, 228–236.
- Kagambèga, A., Haukka, K., Siitonen, A., Traore, A.S., Barro, N., 2011. Prevalence of *Salmonella enterica* and the hygienic indicator *Escherichia coli* in raw meat at markets in Ouagadougou, Burkina Faso. *J. Food Prot.* 74, 1547–1551.
- Kagambèga, A., Barro, N., Traore, A.S., Siitonen, A., Haukka, K., 2012. Characterization of *Salmonella enterica* and detection of the virulence genes specific to diarrheagenic *Escherichia coli* from poultry carcasses in Ouagadougou, Burkina Faso. *Foodborne Pathog. Dis.* 9, 589–593.
- Kagambèga, A., Lienemann, T., Aulu, L., Traoré, A.S., Barro, N., Siitonen, A., Haukka, K., 2013. Prevalence and characterization of *Salmonella enterica* from the feces of cattle, poultry, swine and hedgehogs in Burkina Faso and their comparison to human *Salmonella* isolates. *BMC Microbiol.* 13 (11 November 2013).
- Kapondorah, T.L., Sebunya, T.K., 2007. Occurrence of *Salmonella* species in raw chicken livers purchased from retail shops in Gaborone, Botswana. *J. Anim. Vet. Adv.* 6, 87–89.
- Kashoma, I.P., Kassem, I., Kumar, A., Kessy, B.M., Gebreyes, W., Kazwala, R.R., Rajashekara, G., 2015. Antimicrobial resistance and genotypic diversity of *Campylobacter* isolated from pigs, dairy, and beef cattle in Tanzania. *Front. Microbiol.* 6.
- Kashoma, I.P., Kassem, I., John, J., Kessy, B.M., Gebreyes, W., Kazwala, R.R., Rajashekara, G., 2016. Prevalence and antimicrobial resistance of *Campylobacter* isolated from dressed beef carcasses and raw milk in Tanzania. *Microb. Drug Resist.* 22, 40–52.
- Kassa, T., Gebre-Selassie, S., Asrat, D., 2007. Antimicrobial susceptibility patterns of thermotolerant *Campylobacter* strains isolated from food animals in Ethiopia. *Vet. Microbiol.* 119, 82–87.
- Kempf, I., Kerouanton, A., Bougeard, S., Nagard, B., Rose, V., Mourand, G., Osterberg, J., Denis, M., Bengtsson, B.O., 2017. *Campylobacter coli* in organic and conventional pig production in France and Sweden: prevalence and antimicrobial resistance. *Front. Microbiol.* 8, 955.
- Khadr, A.M., Haggag, Y.N., Khaleil, S.A., 2006. Prevalence of *Campylobacter jejuni* and *Campylobacter coli* in calves and lambs with and without diarrhea and their public health importance. *Assiut Vet. Med. J.* 52, 179–190.
- Khalafalla, F.A., 1990. *Campylobacter jejuni* in poultry giblets. *Zentralbl. Veterinarmed. B* 37, 31–34.
- Khalafalla, F.A., Abdel-Atty, N.S., Abdel-Wanis, S.A., Hanafy, A.S., 2015. Food poisoning microorganisms in chicken broiler meat. *Glob. Vet.* 14, 211–218.
- Khalifa, N.O., Afify, J.S.A., Rabie, N.S., 2013. Zoonotic and molecular characterizations of *Campylobacter jejuni* and *Campylobacter coli* isolated from beef cattle and children. *Glob. Vet.* 11, 585–591.
- Khallaf, M., Ameur, N., Terta, M., Lakranbi, M., Senouci, S., Ennaji, M.M., 2014. Prevalence and antibiotic-resistance of *Salmonella* isolated from chicken meat marketed in Rabat, Morocco. *IJIAS* 6, 1123–1128.
- Khan, A.Q., 1970a. *Salmonella* infections in birds in the Sudan. *Bull. Epizoot. Dis. Afr.* 18, 207–212.
- Khan, A.Q., 1970b. *Salmonella* infections in cattle in the Sudan. *Bull. Epizoot. Dis. Afr.* 18, 13–18.
- Khan, A.Q., 1970c. *Salmonella* infections in healthy sheep and goats in the Sudan. *Bull. Epizoot. Dis. Afr.* 18, 117–122.
- Kich, J.D., Coldebella, A., Mores, N., Nogueira, M.G., Cardoso, M., Fratamico, P.M., Call, J.E., Fedorka-Cray, P., Luchansky, J.B., 2011. Prevalence, distribution, and molecular characterization of *Salmonella* recovered from swine finishing herds and a slaughter facility in Santa Catarina, Brazil. *Int. J. Food Microbiol.* 151, 307–313.
- Kikuyi, G.M., Ombui, J.N., Mitema, E.S., Schwarz, S., 2007. Antimicrobial resistance in *Salmonella* serotypes isolated from slaughter animals in Kenya. *East Afr. Med. J.* 84, 233–239.
- Kittel, S., Heckel, G., Korczak, B.M., Kuhnert, P., 2013. Source attribution of human *Campylobacter* isolates by MLST and *Fla*-typing and association of genotypes with quinolone resistance. *PLoS One* 8, e81796.
- Komba, E.V.G., Mdegela, R.H., Msoffe, P.L.M., Matowo, D.E., Maro, M.J., 2014. Occurrence, species distribution and antimicrobial resistance of thermophilic *Campylobacter* isolates from farm and laboratory animals in Morogoro, Tanzania. *Vet. World* 7, 559–565.
- Kpodekon, M.T., Goussanou, J.S.E., Attakpa, E.Y., Boko, C.K., Ahounou, S.G., Salifou, C.F., Tougan, U.P., Youssao, I.A.K., 2013. Evaluation of macroscopic and microbiological hazards of indigenous pork consumption in south of Benin. *Int. J. Curr. Microbiol. Appl. Sci.* 2, 98–109.
- Kuroda, K., Suzuki, R., Ihara, K., Miyagi, H., Watanabe, H., Sato, K., Hang'ombe, B.M., Mubita, C., Isogai, N., Mulenga, E., Moonga, L., Isogai, H., Fukuda, T., Yoneyama, H., Isogai, E., 2013. Detection of virulence genes of *Escherichia coli* and *Salmonella* spp. from fecal samples of Kafue lechwe (*Kobus lechwe kaffuensis*) and pastoral cattle in the interface areas of Zambia. *Afr. J. Microbiol. Res.* 7, 504–508.
- Kusiluka, L.J.M., Karimuribo, E.D., Mdegela, R.H., Luoga, E.J., Munishi, P.K.T., Mlozi, M.R.S., 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. *Phys. Chem. Earth* 30, 818–825.
- Kwaga, J.K., 1985. Prevalence of salmonellae in camels in Nigeria. *Vet. Rec.* 117, 291.
- Larsen, K., Merlo, J., 2005. Appropriate assessment of neighborhood effects on individual health: integrating random and fixed effects in multilevel logistic regression. *Am. J. Epidemiol.* 161, 81–88.
- Lastovica, A.J., le Roux, E., 2000. Efficient isolation of campylobacteria from stools. *J. Clin. Microbiol.* 38, 2798–2799.
- Le Minor, L., 1988. Typing of *Salmonella* species. *Eur. J. Clin. Microbiol. Infect. Dis.* 7, 214–218.

- Letellier, A., Messier, S., Paré, J., Ménard, J., Quessy, S., 1999. Distribution of *Salmonella* in swine herds in Québec. *Vet. Microbiol.* 67, 299–306.
- Levesque, S., Fournier, E., Carrier, N., Frost, E., Arbeit, R.D., Michaud, S., 2013. Campylobacteriosis in urban versus rural areas: a case-case study integrated with molecular typing to validate risk factors and to attribute sources of infection. *PLoS One* 8, e83731.
- Lotfi, Z.S., Kamel, H.M., 1964a. Salmonellae from abattoir slaughtered buffaloes. *J. Arab Vet. Met. Assoc.* 24, 145–150.
- Lotfi, Z.S., Kamel, H.M., 1964b. Salmonellae from apparently healthy sheep slaughtered at Cairo abattoir. *J. Arab Vet. Met. Assoc.* 24, 89–94.
- Mabote, K.I., Mbewe, M., Ateba, C.N., 2011. Prevalence of *Campylobacter* contamination in fresh chicken meat and milk obtained from markets in the North-west Province, South Africa. *J. Hum. Ecol.* 36, 23–28.
- Madoroba, E., Kapeta, D., Gelaw, A.K., 2016. *Salmonella* contamination, serovars and antimicrobial resistance profiles of cattle slaughtered in South Africa. *Onderstepoort J. Vet. Res.* 83.
- Mahangaiko, M., Mabi, N., Bakana, M., Nyongombe, U., 2015. Food contamination with *Salmonella* and human health in Kinshasa City, Democratic Republic of Congo (DRC). *J. Appl. Biosci.* 94, 8809–8814.
- Mahmoud, Y.E., Hamouda, S.N., 2006. Quality evaluation of poultry meat carcass in El-Gharbia governorate markets. *Assiut Vet. Med. J.* 52, 31–43.
- Marín-Martínez, F., Sánchez-Meca, J., 2010. Weighting by Inverse Variance or by Sample Size in Random-effects Meta-analysis. 70. pp. 56–73.
- Mather, A.E., Vaughan, T.G., French, N.P., 2015. Molecular approaches to understanding transmission and source attribution in nontyphoidal *Salmonella* and their application in Africa. *Clin. Infect. Dis.* 61, S259–S265.
- Mathole, M.A., Muchadeyi, F.C., Mdladla, K., Malatji, D.P., Dzomba, E.F., Madoroba, E., 2017. Presence, distribution, serotypes and antimicrobial resistance profiles of *Salmonella* among pigs, chickens and goats in South Africa. *Food Control* 72, 219–224.
- Mdegela, R.H., Yongolo, M.G.S., Minga, U.M., Olsen, J.E., 2000. Molecular epidemiology of *Salmonella* Gallinarum in chickens in Tanzania. *Avian Pathol* 29, 457–463.
- Mdegela, R.H., Nonga, H.E., Ngowi, H.A., Kazwala, R.R., 2006. Prevalence of thermophilic *Campylobacter* infections in humans, chickens and crows in Morogoro, Tanzania. *J. Vet. Med. B Infect. Dis. Vet. Public Health* 53, 116–121.
- Mdegela, R.H., Nonga, H.E., Chuma, I., 2007. Prevalence of thermophilic campylobacters in humans, cattle and poultry and definitive identification of *Campylobacter jejuni* by PCR in Morogoro, Tanzania. *Zoonoses Public Health* 54, 46–47.
- Mdegela, R.H., Laurence, K., Jacob, P., Nonga, H.E., 2011. Occurrences of thermophilic *Campylobacter* in pigs slaughtered at Morogoro slaughter slabs, Tanzania. *Trop. Anim. Health Prod.* 43, 83–87.
- Meara, P.J., Melmed, L.N., Cook, R.C., 1977. Microbiological investigation of meat wholesales premises and beef carcasses in Johannesburg. *J. S. Afr. Vet. Assoc.* 48, 255–260.
- Messad, S., Hamdi, T.M., Bouhamed, R., Ramdani-Bouguessa, N., Tazir, M., 2014. Frequency of contamination and antimicrobial resistance of thermotolerant *Campylobacter* isolated from some broiler farms and slaughterhouses in the region of Algiers. *Food Control* 40, 324–328.
- Mezali, L., Hamdi, T.M., 2012. Prevalence and antimicrobial resistance of *Salmonella* isolated from meat and meat products in Algiers (Algeria). *Foodborne Pathog. Dis.* 9, 522–529.
- Miller, A.S., 1971. Salmonellosis in Botswana. I. Incidence in cattle. *J. Hyg.* 69, 491–496.
- Mira, E.K.I., Eskandar, A.A., 2007. Bacteriological assessment of freshly slaughtered chicken and a trial for improvement. *Assiut Vet. Med. J.* 53, 88–101.
- Missohou, A., Mbodj, M., Zanga, D., Niang, S., Sylla, K.S.B., Seydi, M., Cissé, O., Seck, W.S., 2009. Analysis of Microbiological and Chemical Quality of Poultry Meat in the Vicinity of the Mbeubeuss Landfill in Malika (Senegal), Beekbergen.
- Moawad, R.K., Mohamed, G.F., Ashour, M.M.S., El-Hamzy, E.M.A., 2013. Chemical composition, quality characteristics and nutritive value of goat kids meat from Egyptian Baladi breed. *J. Appl. Sci. Res.* 9, 5048–5060.
- Modolo, J.R., Margato, G.F., Gottschalk, A.F., Lopes, C.A., 1999. Incidence of *Campylobacter* in pigs with and without diarrhea. *Rev. Microbiol.* 30, 19–21.
- Mohamed, S.R., Dapgh, A.N., 2007. Bacteriological studies on *Salmonella* Typhimurium isolated from different sources. *Vet. Med. J. Giza* 55, 329–340.
- Mohamed, I.A.H., Hessain, A.M., Al-Arfaj, A.A., Moussa, I.M., 2014. Molecular detection of *Salmonella enterica* serovars Typhimurium and Enteritidis in diarrheic calves. *J. Food Agric. Environ.* 12, 192–194.
- Mohammed, M.E.H., Hart, C.A., Kadden, O.R., 2003. Viruses and bacteria associated with neonatal camel calf diarrhea in Eastern Sudan. *Emir. J. Food Agric.* 15, 56–62.
- Mohammed, H.O., Stipetic, K., Salem, A., McDonough, P., Chang, Y.F., Sultan, A., 2015. Risk of *Escherichia coli* O157:H7, non-O157 shiga toxin-producing *Escherichia coli*, and *Campylobacter* spp. in food animals and their products in Qatar. *J. Food Prot.* 78, 1812–1818.
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 6, e1000097.
- Molla, B., Mesfin, A., 2003. A survey of *Salmonella* contamination in chicken carcass and giblets in Central Ethiopia. *Rev. Med. Vet.* 154, 267–270.
- Molla, B., Kleer, J., Sinell, H.J., 1999. Antibiotic resistance pattern of foodborne *Salmonella* isolates in Addis Ababa (Ethiopia). *Berl. Munch. Tierarztl. Wochenschr.* 112, 41–43.
- Molla, B., Alemayehu, D., Salah, W., 2003. Sources and distribution of *Salmonella* serotypes isolated from food animals, slaughterhouse personnel and retail meat products in Ethiopia: 1997–2002. *Ethiop. J. Health Dev.* 17, 63–70.
- Molla, B., Mohammed, A., Salah, W., 2004. *Salmonella* prevalence and distribution of serotypes in apparently healthy slaughtered camels (*Camelus dromedarius*) in Eastern Ethiopia. *Trop. Anim. Health Prod.* 36, 451–458.
- Molla, B., Berhanu, A., Muckle, A., Cole, L., Wilkie, E., Kleer, J., Hildebrandt, G., 2006a. Multidrug resistance and distribution of *Salmonella* serovars in slaughtered pigs. *J. Vet. Med. B Infect. Dis. Vet. Public Health* 53, 28–33.
- Molla, W., Molla, B., Alemayehu, D., Muckle, A., Cole, L., Wilkie, E., 2006b. Occurrence and antimicrobial resistance of *Salmonella* serovars in apparently healthy slaughtered sheep and goats of central Ethiopia. *Trop. Anim. Health Prod.* 38, 455–462.
- Montwedi, M., Ateba, C.N., 2012. Use of the *cdt* gene specific PCR in determining virulence properties of *Campylobacter jejuni* isolated from chicken meat samples obtained in some supermarkets in Mafikeng, NWP. *South Africa. Life Sci. J.* 9, 2696–2701.
- Motsola, C., Collison, E.K., Gashe, B.A., 2002. Prevalence of *Salmonella* in two Botswana abattoir environments. *J. Food Prot.* 65, 1869–1872.
- Moussa, M.M., Awad, H.A., Yassien, N.M., Gouda, H.I., 1993. Microbial quality of some meat-products. *Vet. Med. J. Giza* 41, 59–62.
- Moussa, I.M., Aleslamboly, Y.S., Al-Arfaj, A.A., Hessain, A.M., Gouda, A.S., Kamal, R.M., 2013. Molecular characterization of *Salmonella* virulence genes isolated from different sources relevant to human health. *J. Food Agric. Environ.* 11, 197–201.
- Moussa, I.M., Hessain, A.M., Gassem, M.A., Al-Arfaj, A.A., Mohamed, I.A., 2014. Genotyping of *Salmonella enterica* collected from poultry farms located in Cairo, Egypt by multiplex-PCR. *J. Food Agric. Environ.* 12, 195–198.
- Mughini Gras, L., Smid, J.H., Wagenaar, J.A., de Boer, A.G., Havelaar, A.H., Friesema, I.H., French, N.P., Busani, L., van Pelt, W., 2012. Risk factors for campylobacteriosis of chicken, ruminant, and environmental origin: a combined case-control and source attribution analysis. *PLoS One* 7, e42599.
- Mullner, P., Spencer, S.E., Wilson, D.J., Jones, G., Noble, A.D., Midwinter, A.C., Collins-Emerison, J.M., Carter, P., Hathaway, S., French, N.P., 2009. Assigning the source of human campylobacteriosis in New Zealand: a comparative genetic and epidemiological approach. *Infect. Genet. Evol.* 9, 1311–1319.
- Mulneh, G., Kibret, M., 2015. *Salmonella* spp. and risk factors for the contamination of slaughtered cattle carcass from a slaughterhouse of Bahir Dar town, Ethiopia. *Asian Pac. J. Trop. Dis.* 5, 130–135.
- Nabawy, E.E., Gharieb, R.M.A., Tharwat, A.E., 2016. Occurrence, phenotypic and genotypic characterization of multidrug resistant zoonotic bacteria isolated from poultry slaughterhouses. *Jpn J. Vet. Res.* 64, S173–S180.
- Nassar, A.M., El-Ela, A.A., 2000. Prevalence of some food poisoning pathogens in squabs and wooden pigeons carcasses in Assiut governorate. *Assiut Vet. Med. J.* 43, 209–218.
- Nawar, E.M., Khedr, A.M., 2014. Molecular studies on *Salmonella* species isolated from chicken. *Alex. J. Vet. Sci.* 43, 58–64.
- Ngoma, M., Pandey, G.S., Suzuki, A., Sato, G., Chimana, H., 1996. Prevalence of *Salmonella* in apparently healthy slaughtered cattle and pigs in Zambia. *Indian J. Anim. Sci.* 35, 197–200.
- Ngulukun, S.S., Oboegbulem, S.I., Fagbamila, I.O., Emenna, P.E., Ankele, P.I., Ardard, S.S., Okeke, L.A., Ajayi, O.T., Usman, M., Muhammed, M.J., Odugbo, M.O., Okewole, P.A., 2010. Isolation of thermophilic *Campylobacter* species from Japanese quails (*Coturnix coturnix*) in Vom, Nigeria. *Vet. Rec.* 166, 147–148.
- Ngulukun, S.S., Oboegbulem, S.I., Fagbamila, I.O., Bertu, W., Odugbo, M.O., 2011. Prevalence and molecular characterization of thermophilic *Campylobacter* species isolated from cattle in Plateau State, Nigeria. *Niger. Vet. J.* 32, 349–356.
- van Nierop, W., Duse, A.G., Marais, E., Aithma, N., Thothobolo, N., Kassel, M., Stewart, R., Potgieter, A., Fernandes, B., Galpin, J.S., Bloomfield, S.F., 2005. Contamination of chicken carcasses in Gauteng, South Africa, by *Salmonella*, *Listeria monocytogenes* and *Campylobacter*. *Int. J. Food Microbiol.* 99, 1–6.
- Nigatu, S., Abebe, M., Tesfaye, R., Garew, L., 2015. Prevalence and drug sensitivity pattern of *Campylobacter jejuni* isolated from cattle and poultry in and around Gondar town, Ethiopia. *Glob. Vet.* 14, 43–47.
- Niyonzima, E., Ongol, M.P., Brostaux, Y., Koulagenko, N.K., Daube, G., Kimonyo, A., Sindic, M., 2016. Daily intake and bacteriological quality of meat consumed in the households of Kigali, Rwanda. *Food Control* 69, 108–114.
- Nonga, H.E., Muhairwa, A.P., 2010. Prevalence and antibiotic susceptibility of thermophilic *Campylobacter* isolates from free range domestic duck (*Cairina moschata*) in Morogoro municipality, Tanzania. *Trop. Anim. Health Prod.* 42, 165–172.
- Nonga, H.E., Sells, P., Karimuribo, E.D., 2010. Occurrences of thermophilic *Campylobacter* in cattle slaughtered at Morogoro municipal abattoir, Tanzania. *Trop. Anim. Health Prod.* 42, 73–78.
- Nossair, M.A., Khedr, K., El-Shabasy, N.A., Samaha, I.A., 2015. Detection of some enteric pathogens in retail meat. *Alex. J. Vet. Sci.* 44, 67–73.
- Nouichi, S., Hamdi, T.M., 2009. Superficial bacterial contamination of ovine and bovine carcasses at El-Harrach slaughterhouse (Algeria). *Eur. J. Sci. Res.* 38, 474–485.
- Nwachukwu, N.C., Orji, F.A., Madu, C.N., 2010. Antibiotic-resistant *Salmonella* species in pork on display for sale in Umuahia, Abia state, Nigeria. *Res. J. Agric. & Biol. Sci.* 6, 750–753.
- Nyamakwere, F., Muchenje, V., Mushonga, B., Makepe, M., Mutero, G., 2016. Assessment of *Salmonella*, *Escherichia coli*, Enterobacteriaceae and aerobic colony counts contamination levels during the beef slaughter process. *J. Food Safety* 36 (4), 548–556.
- Nyeleti, C., Hildebrandt, G., Kleer, J., Molla, B., 2000. Prevalence of *Salmonella* in Ethiopian cattle and minced beef. *Berl. Munch. Tierarztl. Wochenschr.* 113, 431–434.
- Nzouankeu, A., Ngandjio, A., Ejenguele, G., Njine, T., Wouafo, M.N., 2010. Multiple contaminations of chickens with *Campylobacter*, *Escherichia coli* and *Salmonella* in Yaounde (Cameroon). *J. Infect. Dev. Ctries* 4, 583–586.
- Oboegbulem, S.I., Muogbo, E.N., 1981. A survey of salmonellae in trade cattle slaughtered at Nsukka abattoir. *Int. J. Zoonoses* 8, 107–110.
- OECD/FAO, 2016. Agriculture in sub-Saharan Africa: prospects and challenges for the next decade. In: Publishing, O. (Ed.), OECD-FAO Agricultural Outlook 2016–2025, (Paris).
- Ofukwu, R.A., Okoh, A.E.J., Akwuobu, C.A., 2008. Prevalence of *Campylobacter jejuni* in duck faeces around drinking water sources in Makurdi, north-central Nigeria. *Sokoto*

- J. Vet. Sci. 7, 26–30.
- Okunlade, A.O., Ogunleye, A.O., Jeminlehin, F.O., Ajuwape, A.T.P., 2015. Occurrence of *Campylobacter* species in beef cattle and local chickens and their antibiotic profiling in Ibadan, Oyo State, Nigeria. *Afr. J. Microbiol. Res.* 9, 1473–1479.
- Ola Ojo, M., 1974. A survey of Salmonellae in goats and dogs in Nigeria. *Bull. Epizoot. Dis. Afr.* 22, 33–34.
- Olatoye, O.I., 2011. Antibiotics use and resistance patterns of *Salmonella* species in poultry from Ibadan, Nigeria. *Trop. Vet.* 29, 28–35.
- Olayemi, A.B., Gaultney, J.B., Belino, E.D., 1979. Isolation of *Salmonella* from cattle slaughtered at the Zaria abattoir. *Niger. Med. J.* 9, 707–710.
- Olubunmi, P.A., Adeniran, M.O.A., 1986. Isolation of *Campylobacter* species from man and domestic animals in the western part of Nigeria. *Bull. Anim. Health Prod. Afr.* 34, 224–228.
- Oluyeye, A.O., Ojo-Bola, O., 2015. Prevalence of non-typhoidal *Salmonella* among HIV/AIDS patients and poultry chicken in Ekiti State. *Br. Microbiol. Res. J.* 6, 113–118.
- Omara, S.T., El-Fadaly, H.A., Barakat, A.M.A., 2015. Public health hazard of zoonotic *Campylobacter jejuni* reference to Egyptian regional and seasonal variations. *Res. J. Microbiol.* 10, 343–354.
- Onyekaba, C.O., Njoku, H.O., 1986. Bacteria and helminth isolates from bile and faeces of zebu cattle slaughtered for human consumption in the Niger Delta areas of Nigeria. *Ann. Trop. Med. Parasitol.* 80, 421–424.
- Orji, M.U., Onuigbo, H.C., Mbata, T.I., 2005. Isolation of *Salmonella* from poultry droppings and other environmental sources in Awka, Nigeria. *Int. J. Infect. Dis.* 9, 86–89.
- Osano, O., Arimi, S.M., 1999. Retail poultry and beef as sources of *Campylobacter jejuni*. *East Afr. Med. J.* 76, 141–143.
- Osman, K.M., Yousef, A.M.M., Aly, M.M., Radwan, M.I., 2010. *Salmonella* spp. infection in imported 1-day-old chicks, ducklings, and turkey poults: a public health risk. *Foodborne Pathog. Dis.* 7, 383–390.
- Osman, K.M., Marouf, S.H., Erfan, A.M., AlAtfeehy, N., 2014a. *Salmonella enterica* in imported and domestic day-old turkey poults in Egypt: repertoire of virulence genes and their antimicrobial resistance profiles. *Rev. Sci. Tech.* 33, 1017–1026.
- Osman, K.M., Marouf, S.H., Mehana, O.A., AlAtfeehy, N., 2014b. *Salmonella enterica* serotypes isolated from squabs reveal multidrug resistance and a distinct pathogenicity gene repertoire. *Rev. Sci. Tech.* 33, 997–1006.
- Osman, K.M., Marouf, S.H., Zolnikov, T.R., AlAtfeehy, N., 2014c. Isolation and characterization of *Salmonella enterica* in day-old ducklings in Egypt. *Pathog. Glob. Health* 108, 37–48.
- Otaru, M.M.M., Nsengwa, G.R.M., Wagstaff, L., 1990. Animal salmonellosis in southern Tanzania. *Bull. Anim. Health Prod. Afr.* 38, 199–201.
- Oueslati, W., Rjeibi, M.R., Mhadhbi, M., Jbeli, M., Zrelli, S., Ettriqui, A., 2016. Prevalence, virulence and antibiotic susceptibility of *Salmonella* spp. strains, isolated from beef in Greater Tunis (Tunisia). *Meat Sci.* 119, 154–159.
- Ouf, J.M., 2004. Microbiological evaluation and mycotoxin residues in some frozen camel's meat products. *Vet. Med. J. Giza* 52, 213–230.
- Phagoo, L., Neetoo, H., 2015. Antibiotic resistance of *Salmonella* in poultry farms of Mauritius. *JWPR* 5, 42–47.
- Pires, S.M., Kneigt, L., Hald, T., 2011. Estimation of the Relative Contribution of Different Food and Animal Sources to Human *Salmonella* Infections in the European Union. 8. pp. 184E.
- Pires, S.M., Vieira, A.R., Hald, T., Cole, D., 2014. Source attribution of human salmonellosis: an overview of methods and estimates. *Foodborne Pathog. Dis.* 11, 667–676.
- Prior, B.A., Badenhorst, L., 1974. Incidence of salmonellae in some meat products. *S. Afr. Med. J.* 48, 2532–2537.
- Rady, E.M., Ibrahim, H.A., Samaha, I.A., 2011. Enteropathogenic bacteria in some poultry meat products. *Alex. J. Vet. Sci.* 33, 175–180.
- Rahimi, E., Ameri, M., Kazemini, H.R., 2010. Prevalence and antimicrobial resistance of *Campylobacter* species isolated from raw camel, beef, lamb, and goat meat in Iran. *Foodborne Pathog. Dis.* 7, 443–447.
- Raji, M.A., Adekeye, J.O., Kwaga, J.K.P., Bale, J.O.O., 2000. Bioserogroups of *Campylobacter* species isolated from sheep in Kaduna State, Nigeria. *Small Rumin. Res.* 37, 215–221.
- Ramadan, H., Jackson, C. and Hinton, A., Jr., 2015: Screening and rapid identification of *Campylobacter* spp. DNA by *flaA* PCR based method on chicken and human fecal samples in Egypt. *Int. J. Poultry Sci.* 14, 252–256.
- Randa, G.A.S., Eman, S.E., Tolba, K., 2014. Bacteriological status of chicken skeleton and legs sold in local markets. *Glob. J. Agric. Food Safety Sci.* 1, 237–250.
- Raufu, I., Hendriksen, R.S., Ameh, J.A., Aarestrup, F.M., 2009. Occurrence and characterization of *Salmonella* Hiduiffy from chickens and poultry meat in Nigeria. *Foodborne Pathog. Dis.* 6, 425–430.
- Raufu, I., Bortolaia, V., Svendsen, C.A., Ameh, J.A., Ambali, A.G., Aarestrup, F.M., Hendriksen, R.S., 2013. The first attempt of an active integrated laboratory-based *Salmonella* surveillance programme in the north-eastern region of Nigeria. *J. Appl. Microbiol.* 115, 1059–1067.
- Ravel, A., Hurst, M., Petrica, N., David, J., Mutschall, S.K., Pintar, K., Taboada, E.N., Pollari, F., 2017. Source attribution of human campylobacteriosis at the point of exposure by combining comparative exposure assessment and subtype comparison based on comparative genomic fingerprinting. *PLoS One* 12, e0183790.
- Refai, M., Gad El-Said, W., Osman, K., Lotfi, Z.S., Safwat, E., Elias, S., 1984. *Salmonella* in slaughtered camels in Egypt. *Zagazig Vet. J.* 9, 266–276.
- Rene, K.A., Adjehi, D., Timothee, O., Tago, K., Marcelin, D.K., Ignace-Herve, M.E., 2014. Serotypes and antibiotic resistance of *Salmonella* spp. isolated from poultry carcass and raw gizzard sold in markets and catering in Abidjan, Côte d'Ivoire. *Int. J. Curr. Microbiol. Appl. Sci.* 3, 764–772.
- Richardson, N.J., Koornhof, H.J., 1979. *Campylobacter* infections in Soweto. *S. Afr. Med. J.* 55, 73–74.
- Richardson, N.J., Burnett, G.M., Koornhof, H.J., 1968. A bacteriological assessment of meat, offal and other possible sources of human enteric infections in a bantu township. *J. Hyg.* 66, 365–375.
- Rosner, B.M., Schielke, A., Didelot, X., Kops, F., Breidenbach, J., Willrich, N., Golz, G., Alter, T., Stingl, K., Josenhans, C., Suerbaum, S., Stark, K., 2017. A combined case-control and molecular source attribution study of human *Campylobacter* infections in Germany, 2011–2014. *Sci. Rep.* 7, 5139.
- Sackey, B.A., Mensah, P., Collison, E., Sakyi-Dawson, E., 2001. *Campylobacter, Salmonella, Shigella* and *Escherichia coli* in live and dressed poultry from metropolitan Accra. *Int. J. Food Microbiol.* 71, 21–28.
- Sahin, O., Morishita, T.Y., Zhang, Q., 2002. *Campylobacter* colonization in poultry: sources of infection and modes of transmission. *Anim. Health Res. Rev.* 3, 95–105.
- Salihu, M.D., Abdulkadir, J.U., Oboegbulem, S.I., Egwu, G.O., Magaji, A.A., Lawal, M., Hassan, Y., 2009a. Isolation and prevalence of *Campylobacter* species in cattle from Sokoto State, Nigeria. *Vet. Ital.* 45, 501–505.
- Salihu, M.D., Junaidu, A.U., Oboegbulem, S.I., Egwu, G.O., Tambuwal, F.M., Yakubu, Y., 2009b. Prevalence of *Campylobacter* species in apparently healthy goats in Sokoto state (Northwestern) Nigeria. *Afr. J. Microbiol. Res.* 3, 572–574.
- Salihu, M.D., Junaidu, A.U., Magaji, A.A., Yakubu, Y., 2012. Prevalence and antimicrobial resistance of thermophilic *Campylobacter* isolates from commercial broiler flocks in Sokoto, Nigeria. *Res. J. Vet. Sci.* 5, 51–58.
- Sallam, K.I., Mohammed, M.A., Hassan, M.A., Tamura, T., 2014. Prevalence, molecular identification and antimicrobial resistance profile of *Salmonella* serovars isolated from retail beef products in Mansoura, Egypt. *Food Control* 38, 209–214.
- Samaha, H.A., Draz, A.A., Hagg, Y.N., Abdou, E.M., 2002. Small ruminants as a reservoir of certain bacterial and mycotic pathogens to man. *Assiut Vet. Med. J.* 46, 22–35.
- Samaha, I.A., Ibrahim, H.A., Aboukaf, H.A., 2011. Enterobacteriaceae in retail meat. *Alex. J. Vet. Sci.* 34, 1–9.
- Samaha, I.A., Ibrahim, H.A.A., Hamada, M.O., 2012. Isolation of some enteropathogens from retail poultry meat in Alexandria province. *Alex. J. Vet. Sci.* 37, 17–22.
- Sandhu, B.K., Paul, S.P., 2014. Irritable bowel syndrome in children: pathogenesis, diagnosis and evidence-based treatment. *World J. Gastroenterol.* 20, 6013–6023.
- Scharaw, H.I., Ibrahim, H.M., Safwat, E., 2009. Studies on some *Salmonella* serovars isolated from slaughtered imported camels. *Vet. Med. J. Giza* 57, 23–33.
- Schwarzer, G., 2007. meta: an R package for meta-analysis. *R News* 7, 40–45.
- Sen, R., Collard, P., 1957a. Isolation of Salmonellae from fowls in Ibadan. *West Afr. Med. J.* 6, 15–17.
- Sen, R., Collard, P., 1957b. Isolation of Salmonellae from healthy pigs in Ibadan. *West Afr. Med. J.* 6, 64–67.
- Shaltout, F.A., Abdel-Aziz, A.M., 2004. *Salmonella enterica* serovar Enteritidis in poultry meat and their epidemiology. *Vet. Med. J. Giza* 52, 429–436.
- Shilangale, R.P., Kaaya, G.P., Chimwamurombe, P.M., 2015. Prevalence and characterization of *Salmonella* isolated from beef in Namibia. *European J. Nutr. Food Saf.* 5, 267–274.
- Sibhat, B., Zewde, B.M., Zerihun, A., Muckle, A., Cole, L., Boerlin, P., Wilkie, E., Perets, A., Mistry, K., Gebreyes, W.A., 2011. *Salmonella* serovars and antimicrobial resistance profiles in beef cattle, slaughterhouse personnel and slaughterhouse environment in Ethiopia. *Zoonoses Public Health* 58, 102–109.
- Skarp, C.P., Hanninen, M.L., Rautelin, H.I., 2016. Campylobacteriosis: the role of poultry meat. *Clinical microbiology and infection: the official publication of the European Society of Clinical Microbiology and Infectious Diseases* 22, 103–109.
- Smid, J.H., Mughini Gras, L., de Boer, A.G., French, N.P., Havelaar, A.H., Wagenaar, J.A., van Pelt, W., 2013. Practicalities of using non-local or non-recent multilocus sequence typing data for source attribution in space and time of human campylobacteriosis. *PLoS One* 8, e55029.
- Smith, S.I., Bamidele, M., Goodluck, H.A., Fowora, M.N., Omonigbehin, E.A., Opere, B.O., Aboaba, O.O., 2009. Antimicrobial susceptibilities of Salmonellae isolated from food handlers and cattle in Lagos, Nigeria. *Int. J. Health Res.* 2, 189–193.
- Smith, S., Braun, S., Akintimehin, F., Fosobi, T., Bamidele, M., Coker, A., Monecke, S., Ehrlich, R., 2016. Serogenotyping and antimicrobial susceptibility testing of *Salmonella* spp. isolated from retail meat samples in Lagos, Nigeria. *Mol. Cell. Probes* 30 (4), 189–194.
- Stevens, A., Kaboré, Y., Perrier-Gros-Claude, J.D., Millemann, Y., Brisabois, A., Catteau, M., Cavin, J.F., Dufour, B., 2006. Prevalence and antibiotic-resistance of *Salmonella* isolated from beef sampled from the slaughterhouse and from retailers in Dakar (Senegal). *Int. J. Food Microbiol.* 110, 178–186.
- Tafida, S.Y., Kabir, J., Kwaga, J.K.P., Bello, M., Umoh, V.J., Yakubu, S.E., Nok, A.J., Hendriksen, R., 2013. Occurrence of *Salmonella* in retail beef and related meat products in Zaria, Nigeria. *Food Control* 32, 119–124.
- Tanih, N.F., Sekwadi, E., Ndip, R.N., Bessong, P.O., 2015. Detection of pathogenic *Escherichia coli* and *Staphylococcus aureus* from cattle and pigs slaughtered in abattoirs in Vhembe District, South Africa. *Sci. World J.* 195972.
- Teklu, A., Negussie, H., 2011. Assessment of risk factors and prevalence of *Salmonella* in slaughtered small ruminants and environment in an export abattoir, Modjo, Ethiopia. *Am. Eurasian J. Agric. Environ. Sci.* 10, 992–999.
- Thai, T.H., Hirai, T., Lan, N.T., Yamaguchi, R., 2012. Antibiotic resistance profiles of *Salmonella* serovars isolated from retail pork and chicken meat in North Vietnam. *Int. J. Food Microbiol.* 156, 147–151.
- Tibajjuka, B., Molla, B., Hildebrandt, G., Kleier, J., Salah, W., 2002. Antimicrobial resistance to salmonellae isolated from retail raw chicken meat and giblets in Ethiopia. *Bull. Anim. Health Prod. Afr.* 50, 86–95.
- Toyofuku, H., Hald, T., 2011. *Salmonella* source attribution in Japan by a microbiological subtyping approach. *Ecohealth* 7.
- Turkson, P.K., Lindqvist, K.J., Kapperud, G., 1988. Isolation of *Campylobacter* spp. and *Yersinia enterocolitica* from domestic animals and human patients in Kenya. *APMIS* 96, 141–146.
- Uaboi-Egbenni, P.O., Okolie, P.N., Adesanya, O.D., Omonigbehin, E., Sobande, A.O.,

2008. Epidemiological studies of the incidence of pathogenic *Campylobacter* spp. amongst animals in Lagos metropolis. *Afr. J. Biotechnol.* 7, 2952–2956.
- Uaboi-Egbenni, P.O., Bessong, P.O., Samie, A., Obi, C.L., 2010. Campylobacteriosis in sheep in farm settlements in the Vhembe District of South Africa. *Afr. J. Microbiol. Res.* 4, 2109–2117.
- Uaboi-Egbenni, P.O., Bessong, P.O., Samie, A., Obi, C.L., 2011a. Prevalence and antimicrobial susceptibility profiles of *Campylobacter jejuni* and *coli* isolated from diarrheic and non-diarrheic goat faeces in Venda region, South Africa. *Afr. J. Biotechnol.* 10, 14116–14124.
- Uaboi-Egbenni, P.O., Bessong, P.O., Samie, A., Obi, C.L., 2011b. Prevalence, haemolysis and antibiograms of campylobacters isolated from pigs from three farm settlements in Venda region, Limpopo province, south. *Afr. J. Biotechnol.* 10, 703–711.
- Uaboi-Egbenni, P.O., Bessong, P.O., Samie, A., Obi, C.L., 2012. Potentially pathogenic *Campylobacter* species among farm animals in rural areas of Limpopo province, South Africa: A case study of chickens and cattle. *Afr. J. Microbiol. Res.* 6, 2835–2843.
- United Nations (UN) Statistics Division, 2016. Standard Country or Area Codes for Statistical Use (M49): Geographic Regions.
- Varela, N.P., Friendship, R.M., Dewey, C.E., 2007. Prevalence of *Campylobacter* spp. isolated from grower-finisher pigs in Ontario. *Can Vet J* 48, 515–517.
- Wesonga, S.M., Muluvi, G.M., Okemo, P.O., Kariuki, S., 2010. Antibiotic resistant *Salmonella* and *Escherichia coli* isolated from indigenous *Gallus domesticus* in Nairobi, Kenya. *East Afr. Med. J.* 87, 205–210.
- Woldemariam, E., Molla, B., Alemayehu, D., Muckle, A., 2005. Prevalence and distribution of *Salmonella* in apparently healthy slaughtered sheep and goats in Debre Zeit, Ethiopia. *Small Rumin. Res.* 58, 19–24.
- Woldemariam, T., Asrat, D., Zewde, G., 2009. Prevalence of thermophilic *Campylobacter* species in carcasses from sheep and goats in an abattoir in Debre Zeit area, Ethiopia. *J. Health Dev.* 23, 229–233.
- World Health Organisation (WHO), 2017. Foodborne Zoonoses. In: Zoonoses and Veterinary Public Health, (accessed 28 June 2017).
- World Health Organisation (WHO) Regional Office for Africa, 2017. Food Safety and Nutrition Food Law Guidelines.
- World Health Organization (WHO), 2012. The Global View of Campylobacteriosis: Report of an Expert Consultation.
- Yagoub, I.A., Mohamed, T.E., 1987. Isolation and identification of *Salmonella* from chickens in Khartoum province of Sudan. *Br. Vet. Rec.* 143, 537–540.
- Yizengaw, H.A., 2015. Isolation, identification and antimicrobial susceptibility testing of *Salmonella* from selected poultry farms in Debre Zeit. *Value Health* 18, A542.
- Zahran, R., El-Behiry, A., 2014. Prevalence, molecular identification and virulence attributes of *Salmonella* serovars isolated from feces of diarrheic cow and buffalo-calves. *Int. J. Curr. Microbiol. Appl. Sci.* 3, 9–27.
- Zishiri, O.T., Mkhize, N., Mukaratirwa, S., 2016. Prevalence of virulence and antimicrobial resistance genes in *Salmonella* spp. isolated from commercial chickens and human clinical isolates from South Africa and Brazil. *Onderstepoort J. Vet. Res.* 83, e1–e11.