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REVIEW

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The prevalence and antimicrobial resistance profiles of bacterial isolates from meat and meat products in Ethiopia: a systematic review and meta-analysis

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Abstract

Background: Foodborne diseases associated with the consumption of meat and its products are of public health significance worldwide. The study is, therefore, aimed to estimate the prevalence and the antimicrobial resistance profile of some bacterial pathogens isolated from meats and its products in Ethiopia.

Methods: Literature search was conducted from major electronic databases and indexing services including PubMed/MEDLINE, Google Scholar, Science Direct and WorldCat. Both published and unpublished studies addressing the prevalence and antimicrobial resistance profiles of some bacterial pathogens in meat and its products in Ethiopia were included for the study. Data were extracted with structured format prepared in Microsoft Excel and exported to STATA 15.0 software for the analyses. Pooled estimation of outcome measures was performed with DerSimonian-Laird random-effects model at 95% confidence level. Degree of heterogeneity of studies was presented with I^2 statistics. Publication bias was conducted with comprehensive meta-analysis version 3.0 software and presented with funnel plots supplemented by Begg's and Egger's tests. The study protocol is registered on PROSPERO with reference number ID: **CRD42018106361.**

Results: A total of 27 original studies with 7828 meat samples were included for systematic review and meta-analysis. The pooled prevalence of *Salmonella* spp., *E. coli* O157:H7, *Staphylococcus* spp. and *L. monocytogenes* was 9, 5, 21 and 4%, respectively. Based on animal species, the prevalence of *Salmonella* in goat, mutton, beef, pork, chicken, and fish meat was 18, 6, 10, 11, 14 and 2%, respectively. The prevalence of *E. coli* O157:H7 in beef, mutton, goat and other animal meats was 6, 6, 3 and 21%, respectively. The prevalence of *Staphylococcus* spp. in beef and other animal meats was 21 and 22%, respectively. Based on the sample source, *Salmonella* prevalence in abattoir, butcher and market was 6, 36, and 11%, respectively. The *E. coli* O157:H7 prevalence in abattoir, butcher and market was 5, 6 and 8%, respectively. The bacterial isolates showed different antimicrobial resistance profiles against selected drugs. About 25% of the *Salmonella* spp. was resistant to ampicillin. Besides, 9% of *Salmonella* spp. and 2% of *E. coli* O157:H7 were found to be resistant to ceftriaxone. The pooled estimates showed that 10% of *E. coli* O157:H7 isolates were resistant to ciprofloxacin. Moreover, *Salmonella* spp. (6%), *L. monocytogenes* (5%) and *E. coli* O157:H7 (2%) were resistant to gentamicin.

Conclusion: This study revealed that pooled prevalence of bacterial pathogens is relatively high as compared to other countries and hence, there is a need to design intervention to ensure meat safety in the sector.

Keywords: Meat, Bacterial isolates, Antimicrobial resistance, Ethiopia

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Introduction

Meat is a nutrient-rich food which provides vital amount of proteins, vitamins and minerals with greater bioavailability than other food sources (McAfee et al., 2010). However, it has been recognized as the main vehicle for the transmission of foodborne pathogens to humans (EFSA, 2013). The water activity of fresh meat and its optimum pH play the major role for the growth of microorganisms. As a result, meat is considered as highly perishable foodstuff. Cross contamination of carcasses and meat products occur during subsequent handling, processing, preparation and distribution (Dave & Ghaly, 2011).

The safety of meat may be affected by many biological, chemical and physical hazards; although the biological hazards pose the highest foodborne risk for meat consumers (Norrung & Buncic, 2008). The pathogenic microorganisms possess greater socioeconomic impact due to their potential to contaminate meat and meat based products (Buzby et al., 2001). From the biological hazards, bacterial pathogens are the most serious concern regarding the issues of meat safety to consumers (Sofos, 2008).

Contamination of meat with foodborne pathogens is a major public health issue. Hence, the quantitative synthesis of studies is important to estimate the level of contamination of meat. In this meta-analysis, the population is defined as meat and meat-based products surveyed at abattoirs and retail establishments/markets in Ethiopia. The primary outcome of interest is the prevalence of pathogens, while the antibiotic resistance status of the pathogen is considered as a secondary outcome.

In Ethiopia, studies have been conducted on the prevalence of bacterial pathogens on meats in different parts of the meat chain and settings. These individual studies alone would not, however, show the nationwide burden of bacterial pathogens in meat unless evidence is generated from pooled estimation of the results of primary studies to provide a common national figure. Therefore, this systematic review and meta-analysis was aimed to estimate the overall prevalence of bacterial pathogens and their antimicrobial resistance profile in meat and meat products in Ethiopian abattoirs and retail establishments.

Methods

Study protocol

The identification of records, screening of titles and abstracts as well as evaluation of eligibility of full texts for final inclusion was conducted in accordance with the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) flow diagram (Moher et al., 2009a). PRISMA checklist (Moher et al., 2009b) was also strictly followed while conducting this systematic review and meta-analysis. The study protocol is registered on PROSPERO with reference number ID: **CRD42018106361** and Available from: http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42018106361

Data sources and search strategies

The literature search was carried out through visiting electronic databases and indexing services. The PubMed/MEDLINE, Google Scholar, and WorldCat were used as main sources of data. Besides, other supplementary sources including Research Gate, Science Direct and University repositories were searched to retrieve relevant data. Excluding the non-explanatory terms, the search strategies included important key words and indexing terms: Meat (MeSH), "meat products", meat*, bacteria (MeSH), bacterial* "antimicrobial resistance", "antibacterial resistance", "antimicrobial susceptibility", and "Ethiopia". The Boolean logical connectors (AND and OR), and truncation were applied for appropriate search and identification of records for the research question.

Inclusion and exclusion criteria

The papers with original article written in English language, possessed approved microbiological methods for pathogen detection and contain sufficient and extractable data were included in the meta-analysis. Having assessed all the information from the recovered publications, online records available from 2008 to June, 2018 were considered as appropriate for eligibility assessment. Furthermore, only studies focusing on meat and meat-based products were included. All review articles and original articles conducted outside Ethiopia, articles with irretrievable full texts (after requesting full texts from the corresponding authors via email and/or Research Gate) and records with unrelated outcomes of interest were excluded during screening and eligibility assessment.

Screening and eligibility of studies

Records identified from various electronic databases, indexing services and directories were exported to ENDNOTE reference software version 8.2 (Thomson Reuters, Stamford, CT, USA) with compatible formats. Duplicate records were identified, documented and removed with ENDNOTE. Some duplicates were addressed manually due to variation in reference styles across sources. Thereafter, two authors (AZ and MS) independently screened the title and abstracts with predefined inclusion criteria. Two authors (AZ and MS) also independently collected full-texts and evaluated the eligibility of them for final inclusion. In each case, the rest authors played a critical role in solving discrepancies arose between two authors to come up to consensus.

Data extraction

With the help of standardized data abstraction format prepared in Microsoft Excel, authors independently extracted

important data related to study characteristics (study area, first author, year of publication, study design, slaughtered animals, sample source, sample type, sample size) and outcome of interests (number of positive samples (prevalence) per bacterium and number of resistant isolates (if any) per bacterium in each positive sample).

Quality assessment of studies

The quality of studies was evaluated according to Newcastle-Ottawa scale adapted for cross-sectional studies (Newcastle- Ottawa, 2016) and graded out of 10 points (stars). For ease of assessment, the tool included important indicators categorized into three major sections: (1) the first section assesses the methodological quality of each study and weighs a maximum of five stars (2) the second section considers comparability of the study and takes 2 stars (3) the remaining section assess outcomes with related statistical analysis. This critical appraisal was conducted to assess the internal (systematic error) and external validity of studies and reduce the risk of biases. The mean score of two authors were taken for final decision and studies with score greater than or equal to five were included.

Outcome measurements

The primary outcome measure is the prevalence of clinically relevant bacterial isolates in meat and meat products sampled in abattoir and retail establishments in Ethiopia. The pooled prevalence was calculated per bacterium. The calculation was conducted for both gram positive and gram negative bacterial isolates including *Staphylococcus* spp., *L. monocytogenes*, *E. coli* O157:H7, and *Salmonella* spp. The secondary outcome measure is the antimicrobial resistance status of the above-mentioned bacteria against selected antimicrobials from different categories (ceftriaxone, gentamicin, ciprofloxacin and ampicillin). Subgroup analyses were also conducted based on the spatial source of meat and slaughtered animal type.

Data processing and analysis

The relevant data were extracted from selected studies using format prepared in Microsoft Excel and exported to STATA 15.0 software for analyses of pooled estimate of outcome measures and subgroup analyses. Subgroup analysis for the primary outcome (prevalence of selected pathogens) was done by sample source (abattoirs, butcher and market), and slaughtered animal types. Considering variation in true effect sizes across population, Der-Simonian-Laird's random effects model was applied for the analysis at 95% confidence level.

The significance of heterogeneity of the studies was assessed using I^2 statistics (based on Cochran's Q test, I^2 returns the percent variation across studies. The formula is: $I^2 = 100\% * (Q - df)/Q$, Where: Q = Cochran's Q and df = degrees of freedom. Comprehensive Meta-analysis version-3 software (Biostat, Englewood, New Jersey, USA) was used for publication bias assessment. The presence of publication bias was evaluated by using the Begg's and Egger's tests and presented with funnel plots of standard error of Logit event rate (proportion) (Begg & Mazumdar, 1994; Egger et al., 1997). A statistical test with a *p*-value less than 0.05 (one tailed) was considered significant.

Results

Search results

A total of 189 potentially relevant studies were identified from several sources including PubMed/MEDLINE, Google Scholar and WorldCat. From these, 18 duplicated articles were removed with the help of ENDNOTE and manual tracing. The remaining 171 records were screened using their titles and abstracts and 113 of them were excluded. Full texts of 58 records were then evaluated for eligibility. From these, 31 articles were excluded due to the outcome of interest was found missing, insufficient and/or ambiguous. Finally, a total of 27 articles fulfilled the eligibility criteria and quality assessment and thus included for systematic review and meta-analysis (Fig. 1).

Study characteristics

Table 1 summarizes the characteristics of 27 eligible studies with 7828 samples which were considered for determining the prevalence of bacterial pathogens and their antimicrobial resistance status. The studies were published in the year between 2008 and 2018. All the selected studies were cross-sectional study design in nature. The majority of meat samples were investigated from beef only (Abdissa et al., 2017; Alemu & Zewde, 2012; Atnafie et al., 2017; Bedasa et al., 2018; Beyi et al., 2017; Dagnachew, 2017; Garedew et al., 2015a; Garedew et al., 2015b; Gebretsadik et al., 2011; Abunna et al., 2016; Kore et al., 2017; Mengistu et al., 2017; Muluneh & Kibret, 2015; Wabeto et al., 2017; Adugna et al., 2018). The rest animal species were goat (Dulo, 2014; Dulo et al., 2015; Ferede, 2014), sheep (Mulu & Pal, 2016), and others (Ejo et al., 2016; Kebede et al., 2014; Senait & Moorty, 2016; Azage & Kibret, 2017). Samples of meat from two or more animals were also taken in four studies (Bekele et al., 2014; Hiko et al., 2008; Kebede et al., 2016; Zewdu & Cornelius, 2009). The foodborne pathogens such as *Staphylococcus* spp. and *L. monocytogenes* were the outcomes/pathogens with the fewest observations retrieved: *Staphylococcus* spp. (with only four published studies) and *L. monocytogenes* (with only three published studies) as their presence in meats have not been widely surveyed. The average quality score of included studies ranges from 6.5 to 9 as per the Newcastle-Ottawa scale adapted for cross sectional studies (Table 1).

The antimicrobial resistance profile of common bacterial isolates against four major antimicrobial agents (ampicillin, gentamicin, ciprofloxacin and ceftriaxone) is

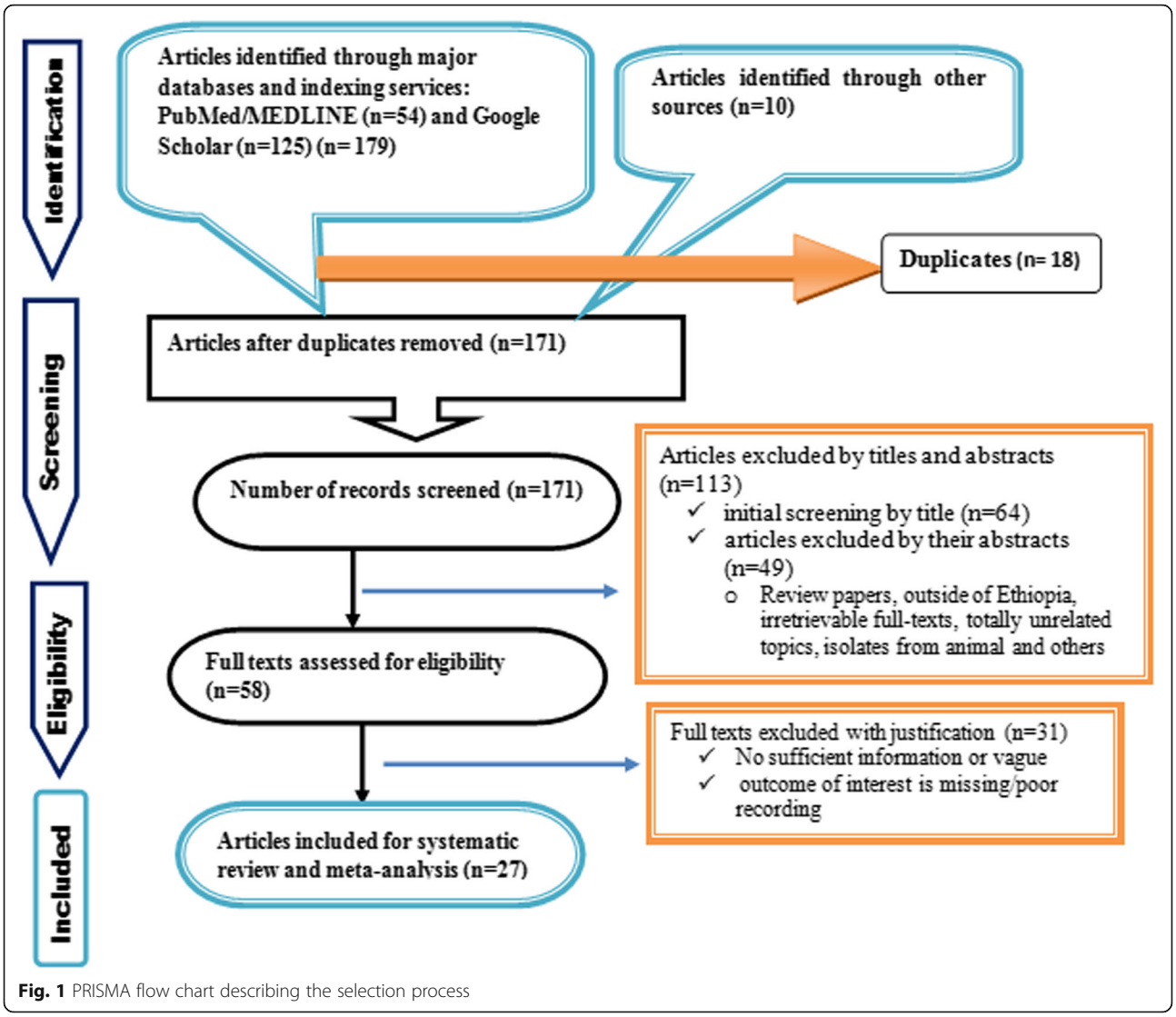

Fig. 1 PRISMA flow chart describing the selection process

summarized in Table 2. Out of 722 positive samples, 475 of them were tested for susceptibility. Regardless of the nature of bacterial pathogens, 73, 25, 17 and 15 bacteria were found resistant to ampicillin, ceftriaxone, gentamicin and ciprofloxacin, respectively.

Study outcomes

Primary outcomes: Prevalence of bacterial isolates

The study showed that different bacterial pathogens have been detected in meat and meat products in Ethiopia at different level of occurrence (Table 1). The forest plot indicated that the pooled prevalence of *Salmonella* in meat and meat products was found to be 9% (95% CI: 6.0, 12.0) (Fig. 2).

The highest prevalence was observed in goat meat 18% (95% CI: 13.0, 22.0) followed by chicken meat, 14% (95% CI: 10.0, 19.0), whereas the least prevalence was observed in fish meat 2% (95% CI: 0.00, 5.00) (Table 3). The prevalence of *Salmonella* in butcher, market and abattoirs was 36% (95% CI: 26.0, 44.0), 11% (95% CI: 6.0, 16.0) and 6% (95% CI: 3.0, 9.0), respectively (Table 4).

The pooled estimate of *E. coli* O157:H7 was found to be 5% (95% CI: 4.0, 7.0) (Fig. 3) and subgroup analysis indicated that the highest prevalence was recorded in beef and sheep meat with value of 6% in each (Table 3). The prevalence of *E. coli* O157:H7 in meats collected from market, abattoir and butcher was 8% (95% CI: 4.0, 12.0), 5% (95% CI: 3.0, 7.0) and 6% (95% CI: 2.0, 9.0), respectively (Table 4).

The pooled estimate of *Staphylococcus* spp. isolated from meat samples was 21% (95% CI: 12, 30) (Fig. 4). Comparable pooled estimates were observed across spatial sources of meat (21%, 20% and 22% from abattoir, butcher and market, respectively) (Table 4). The overall prevalence of *L. monocytogenes* in meat samples was 4% (95% CI: 2.0, 6.0) (Fig. 5). Beef and sheep meat were the

Table 1 Characteristics of the studies describing the prevalence of selected bacterial pathogens in meat and meat products in Ethiopia

Studies	Quality score	Publication year	Study Area	Study Design	Slaughtered Animal	Spatial Source	Sample Type	Bacteria isolates	Sample size	# positive samples
Study 1 (Abdissa et al., 2017)	8.5	2017	AA/Debre Berhan	CS	Beef	Market	Carcass swab	*E. coli* O157:H7	125	1
						Abattoir	Carcass swab	*E. coli* O157:H7	370	2
Study 2 (Adugna et al., 2018)	8	2018	AA	CS	Beef	Abattoir	Carcass swab	*S. aureus*	384	36
						Butcher	Carcass swab	*S. aureus*	384	76
Study 3 (Alemu & Zewde, 2012)	8	2012	Bahir Dar	CS	Beef	Abattoir	Carcass swab	*Salmonella* spp.	186	9
Study 4 (Atnafie et al., 2017)	8.5	2017	Hawassa	CS	Beef	Abattoir	Carcass swab	*E. coli* O157:H7	150	4
						Butcher	Meat	*E. coli* O157:H7	150	3
Study 5 (Ejo et al., 2016)	8.5	2016	Gondar town	CS	Other	Market	Minced meat	*Salmonella* spp.	25	2
							Meat	*Salmonella* spp.	50	6
Study 6 (Azage & Kibret, 2017)	9	2017	Bahir Dar	CS	Other	Butcher	Meat	*Salmonella* spp.	30	21
Study 7 (Bekele et al., 2014)	8	2014	AA	CS	Beef	Abattoir	Carcass swab	*E. coli* O157:H7	64	3
					Sheep	Abattoir	Carcass swab	*E. coli* O157:H7	64	4
					Goat	Abattoir	Carcass swab	*E. coli* O157:H7	64	4
					Beef	Market	Meat	*E. coli* O157:H7	64	14
					Sheep	Market	Meat	*E. coli* O157:H7	64	8
					Goat	Market	Meat	*E. coli* O157:H7	64	6
Study 8 (Bedasa et al., 2018)	9	2018	Bishoftu town	CS	Beef	Market	Meat	*E. coli* O157:H7	65	11
Study 9 (Beyi et al., 2017)	8	2017	AA, Bishoftu, Batu and Holeta	CS	Beef	Butcher	Carcass swab	*E. coli* O157:H7	110	5
					Beef	Butcher	Minced meat	*E. coli* O157:H7	85	0
Study 10 (Dagnachew, 2017)	7.5	2017	Bishoftu/AA	CS	Beef	Market	Minced beef	*Salmonella* spp.	102	10
Study 11 (Dulo, 2014)	8	2014	DD	CS	Goat	Abattoir	Carcass swab	*E. coli* O157:H7	93	3
Study 12 (Dulo et al., 2015)	9	2015	Somali Region	CS	Goat	Abattoir	Carcass swab	*E. coli* O157:H7	93	3
Study 13 (Ferede, 2014)	7.5	2014	DD	CS	Goat	Abattoir	Carcass swab	*Salmonella* spp.	249	44
Study 14 (Garedew et al., 2015a)	7.5	2015	Gondar town	CS	Beef	Butcher	Meat	*Salmonella* spp.	90	32
Study 15 (Garedew et al., 2015b)	7.5	2015	Gondar town	CS	Beef	Market	Minced meat	*L. monocytogenes*	25	3
							Meat	*L. monocytogenes*	60	4
							Meat	*L. monocytogenes*	50	3
Study 16 (Gebretsadik et al., 2011)	8	2011	AA	CS	Beef	Market	Meat	*L. monocytogenes*	76	2
Study 17 (Hiko et al., 2008)	7	2008	Modjo and Bishoftu towns	CS	Beef	Abattoir	Meat	*E. coli* O157:H7	164	12
					Goat	Abattoir	Meat	*E. coli* O157:H7	223	4

Table 1 Characteristics of the studies describing the prevalence of selected bacterial pathogens in meat and meat products in Ethiopia *(Continued)*

Studies	Quality score	Publication year	Study Area	Study Design	Slaughtered Animal	Spatial Source	Sample Type	Bacteria isolates	Sample size	# positive samples
					Sheep	Abattoir	Meat	*E. coli* O157:H7	223	5
					Beef	Butcher	Meat	*E. coli* O157:H7	86	8
					Goat	Butcher	Meat	*E. coli* O157:H7	22	1
					Sheep	Butcher	Meat	*E. coli* O157:H7	20	1
Study 18 (Kebede et al., 2016)	8.5	2016	AA	CS	Beef	Abattoir	Carcass swab	*Salmonella* spp.	70	4
					Sheep	Abattoir	Carcass swab	*Salmonella* spp.	70	1
Study 19 (Kebede et al., 2014)	7	2014	Adigrat	CS	Other	Abattoir	Meat	*E. coli* O157:H7	20	3
								S. aureus	20	0
						Butcher shop	Minced meat	*E. coli* O157:H7	20	6
								S. aureus	20	6
Study 20 (Abunna et al., 2016)	7	2016	Asella	CS	Beef	Abattoir	Meat swab	*S. aureus*	66	35
Study 21 (Kore et al., 2017)	8	2017	Hawassa	CS	Beef	Abattoir	Carcass swab	*Salmonella* spp.	150	2
						Abattoir	Meat	*Salmonella* spp.	100	4
Study 22 (Mengistu et al., 2017)	7	2017	DD/ HU	CS	Beef	Abattoir	Meat	*E. coli* O157:H7	45	17
								Salmonella spp.	45	3
						Abattoir	Meat	*E. coli* O157:H7	100	13
								Salmonella spp.	100	1
						market	Meat	*E. coli* O157:H7	45	5
								Salmonella spp.	45	3
						Market	Meat	*E. coli* O157:H7	100	7
								Salmonella spp.	100	1
Study 23 (Mulu & Pal, 2016)	6.5	2016	AA	CS	Sheep	Abattoir	Meat swab	*L. monocytogenes*	384	8
						Butcher	Meat swab	*L. monocytogenes*	384	21
Study 24 (Muluneh & Kibret, 2015)	8.5	2015	Bahir Dar	CS	Beef	Abattoir	Carcass swab	*Salmonella* spp.	300	23
Study 25 (Senait & Moorty, 2016)	7	2016	Bishoftu	CS	Other	Market	Cooked ground meat	*Staphylococcus* spp.	103	31
							Roasted meat	*Staphylococcus* spp.	116	34
							Roasted chicken meat	*Staphylococcus* spp.	19	1
Study 26 (Wabeto et al., 2017)	7	2017	Wolaita Sodo	CS	Beef	Abattoir	Carcass	*Salmonella* spp.	448	56
Study 27 (Zewdu & Cornelius, 2009)	8.5	2009	AA	CS	Chicken	Market	Chicken carcass	*Salmonella* spp.	208	29

Table 1 Characteristics of the studies describing the prevalence of selected bacterial pathogens in meat and meat products in Ethiopia *(Continued)*

Studies	Quality score	Publication year	Study Area	Study Design	Slaughtered Animal	Spatial Source	Sample Type	Bacteria isolates	Sample size	# positive samples
					Pig	Market	Pork	*Salmonella* spp.	194	22
					Sheep	Market	Mutton	*Salmonella* spp	212	21
					Beef	Market	Minced meat	*Salmonella* spp.	142	12
					Fish	Market	Fish	*Salmonella* spp.	128	3
									7828	722

Key: *CS* cross-sectional, *AA* Addis Ababa, *DD* Dire Dawa, *HU* Haramaya University

Table 2 The antimicrobial resistance profile of bacterial isolates obtained from meat and its products in Ethiopia

Author	Year of publications	Bacteria isolates	# positive samples	Antimicrobial Resistance Profile			
				CIP	GEN	CRO	AMP
Adugna et al	2018	*S. aureus*	112	–	–	–	0
Alemu and Zewde	2012	*Salmonella* spp.	9	–	0	–	–
Atnafie et al	2017	*E. coli* O157:H7	7	–	0	0	–
Amenu and Ejo	2016	*Salmonella* spp.	8	–	1	0	0
Bekele et al.	2014	*E. coli* O157:H7	39	7	–	0	–
Bedasa et al.	2018	*E. coli* O157:H7	11	0	–	0	–
Beyi et al.	2017	*E. coli* O157:H7	5	0	–	–	–
Dagnachew	2017	*Salmonella* spp.	10	1	–	0	3
Ferede	2014	*Salmonella* spp.	44	0	8	10	24
Garedew et al.	2015	*Salmonella* spp.	32	–	0	0	–
Garedew et al.	2015	*L. monocytogenes*	10	–	0	–	–
Hiko et al.	2008	*E. coli* O157:H7	31	–	0	–	2
Kebede et al.	2016	*Salmonella* spp.	5	–	0	0	0
Kebede et al.	2014	*E. coli* O157:H7	9	–	0	–	–
Wabeto et al.	2017	*Salmonella* spp.	56	4	7	13	26
Zewdu and Cornelius	2009	*Salmonella* spp.	87	3	1	2	18
Total			475	15	17	25	73

Key: ---- not determined, *CIP* Ciprofloxacin, *GEN* Gentamicin, *CRO* Ceftriaxone, *AMP* Ampicillin

only sources of this bacterium with 4.1% prevalence in each (Table 3). The highest prevalence (6%; 95% CI: 3.0, 7.0) of *L. monocytogenes* was reported from meat samples collected from butcher (Table 4).

Secondary outcomes: Antimicrobial resistance profiles of bacterial isolates

The bacterial isolates showed different antimicrobial resistance profile against selected agents. About 25% (95% CI: 10.0, 40.0) of the *Salmonella* spp. were found resistant to ampicillin. Besides, 9% (95% CI: 2.0, 15.0) of *Salmonella* spp. and 2% (95% CI: 0.0, 5.0) of *E. coli* O157:H7 isolates were found to be resistant to ceftriaxone. The pooled estimate indicated that 10% of *E. coli* O157:H7 isolates were resistant to ciprofloxacin. *Salmonella* spp. (6%), *L. monocytogenes* (5%) and *E. coli* O157:H7 (2%) were resistant to gentamicin (Table 5).

Publication bias

Funnel plots of standard error with Logit event rate (prevalence of bacterial isolates) supplemented by statistical tests confirmed that there is some evidence of publication bias on studies reporting the prevalence of bacterial isolates from meat and meat products in Ethiopia (Begg's test, $p = 0.003$; Egger's test, $p = 0.000$) (Fig. 6).

Discussion

Out of 27 original studies with 7828 meat samples included in this study, the pooled prevalence of *Salmonella* in meat and meat products was 9%. This result is in concordance with the meta-analysis conducted in Portugal where the prevalence of *Salmonella* spp. in meats was 6% (95% CI: 4, 9%) (Xavier et al., 2014). The finding is much higher than the report made by United States Department of Agriculture, Food Safety and Inspection Service (USDA-FSIS: United States Department of Agriculture, Food Safety and Inspection Service, 2014) which showed that the *Salmonella* prevalence in ground beef was 1.9% in United States. This difference might be due to the fact that the presence of poor food handling practice, lack of slaughtering facility and poor animal health management at primary production and substandard transport of animal meat contributing to high prevalence bacterial pathogen in Ethiopia. Furthermore, reduced prevalence of *Salmonella* spp. might be attributed to effective management strategies of pathogens at different stages of production in developed countries.

In a meta-analysis conducted in Portugal, the prevalence of *Salmonella* in raw and minced beef were 1.9% (95% CI: 0.5, 7.2%) and 1.5% (95% CI: 0.3, 7.8%), respectively (Xavier et al., 2014). Compared to studies conducted in developed countries, the subgroup analysis indicated that the pooled estimate of *Salmonella* in beef meat is much higher in Ethiopia, 10.0% (95% CI: 6.0, 12.0). The highest *Salmonella* prevalence was observed in goat meat 18% (95% CI: 13.0, 22.0). The prevalence of *Salmonella* on chicken meat (14%) is also higher than the European surveys which indicated that the overall pooled estimate of *Salmonella* spp. in poultry meat was 7.10% (95% CI: 4.60,

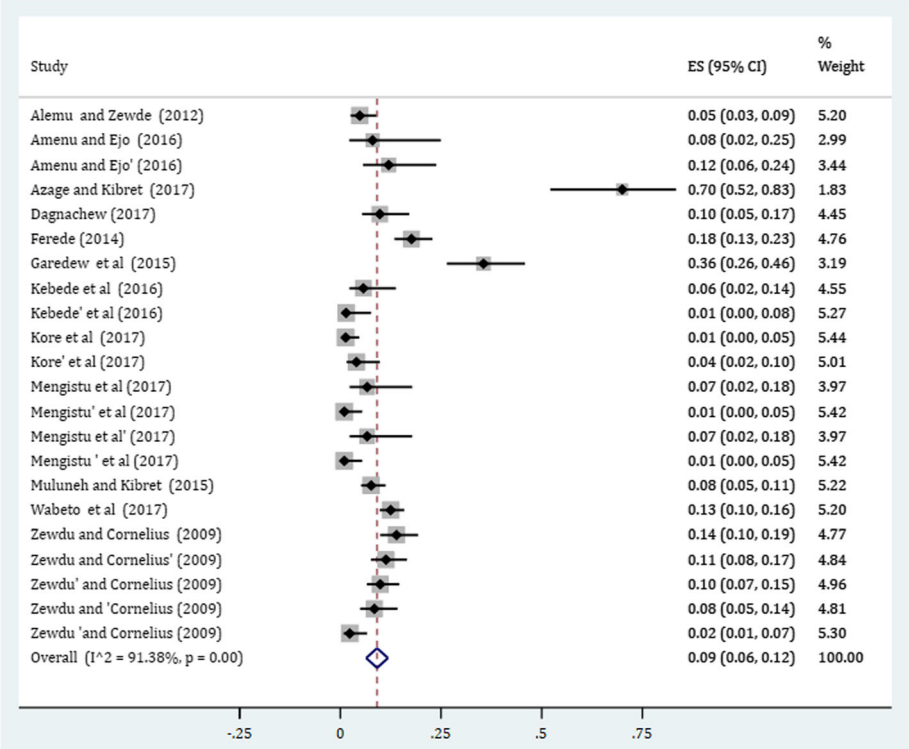

Fig. 2 Forest plot depicting the prevalence of *Salmonella* spp. obtained from meat and meat products in Ethiopia

10.8%) (Gonçalves-Tenório et al., 2018). Generally, this finding supports the conclusion made by Islam et al. (Islam et al., 2014) who identified slaughtered animal species as one of the sources of variation when estimating the prevalence of bacterial pathogens.

The least prevalence of *Salmonella* was observed in fish meat, 2.0% (95% CI: 0.0, 5.0). In line with this result, in United States, the prevalence of *Salmonella* in domestic fish and its products as well as imported fish and its products was 1.3% and 7.2%, respectively (Olgunoğlu, 2012). Animal waste can be introduced directly through bird droppings in ponds or indirectly through runoff. Fish and fish products may carry *Salmonella* spp., particularly if they are caught in areas contaminated with fecal pollution. Moreover, unsafe handling and packaging may contribute to its contamination.

Our study indicated that the pooled prevalence of *E. coli* O157:H7 isolated from meat and meat products was 5% which is much higher than a study conducted by Hill et al. (Hill et al., 2011) who reported that *E. coli* O157:H7 was detected on 0.25% of ground beef and 0.82% of trimmed beef meats in USA. Similarly, very low (1.7%) *E. coli* O157:H7 prevalence was detected on manufactured beef collected at the processing facility in Australia (Kiermeier et al., 2011).

The highest prevalence was recorded in beef and sheep meats with estimates of 6% in each, whereas the lowest prevalence (3%) was recorded in goat meat. Similarly, Jacob et al. (Jacob et al., 2013) reported that the prevalence of *E. coli* O157:H7 on goat carcasses was 2.7% (95% CI: 0.8, 4.5%) in United States. In this regard, ruminants, particularly cattle, are considered as the primary

Table 3 Subgroup analysis of bacterial prevalence in meat samples based on the slaughtered animals

Bacteria	Bacterial prevalence, proportion (95% CI)						
	Animals						
	Beef	Sheep	Goat	Pig	Fish	Chicken	Other
E. coli O157:H7	0.06 (0.04, 0.08)	0.06 (0.01, 0.01)	0.03 (0.02, 0.05)	–	–	–	0.21 (0.04, 0.07)
Salmonella spp.	0.10 (0.06, 0.12)	0.06 (−0.03, 0.14)	0.18 (0.13, 0.22	0.11 (0.07, 0.16)	0.02 (0.00, 0.05	0.14 (0.10, 0.19)	–
Staphylococcus spp.	0.21 (0.10, 0.32)	–	–	–	–	–	0.22 (0.07, 0.37)
L. monocytogenes	0.04 (0.02, 0.07	0.04 (0.00, 0.07)	–	–	–	–	–

Key: ---- not determined

Table 4 Subgroup analysis of the prevalence of bacterial isolates in meat by sample source

Bacteria	Bacterial prevalence, proportion (95% CI)		
	Sample Source		
	Abattoir	Butcher	Market
E. coli O157:H7	0.05 (0.03, 0.07)	0.06 (0.02, 0.09)	0.08 (0.04, 0.12)
Salmonella spp.	0.06 (0.03, 0.09)	0.36 (0.26, 0.44)	0.11 (0.06, 0.16)
Staphylococcus spp.	0.21 (0.01, 0.40)	0.20 (0.16, 0.24)	0.22 (0.07, 0.37)
L. monocytogenes	0.02 (0.00, 0.04)	0.06 (0.03, 0.07)	0.04 (0.02, 0.07)

reservoirs for *E. coli* O157:H7, where the organism typically colonizes the lower gastrointestinal tract (Low et al., 2005). In Ethiopia beef is most commonly consumed foods, however, the risk of acquiring *E. coli* O157:H7 from beef meat appears higher than the risk from meats of other animal species. Many outbreaks of *E. coli* O157:H7 are usually associated with foods from cattle or their fecal contamination (CDC, 1991).

The pooled estimate of *Staphylococcus* spp. was found to be 21% in meat and meat products which is in trajectory with the prevalence of *S. aureus* in Portuguese meat product samples, 22.6% (95% CI: 15.4, 31.8%) (Xavier et al., 2014). The high occurrence of *Staphylococcus* spp. in meat and meat products is an indicator of hygiene deficiency during processing of meat (Rajkovic, 2012).

In this study, the overall prevalence of *L. monocytogenes* isolated from beef and mutton meat was 4%. Comparable estimate was reported in Ireland where the prevalence of *L. monocytogenes* in meat products was 4.2% (Leong et al., 2014). However, much higher prevalence of *L. monocytogenes* (18.7%) was reported in raw meat and raw meat products in Estonia (Kramarenko et al., 2013). The live animals may contribute little to the total contamination of the abattoir. Nevertheless, the *L. monocytogenes* may be introduced from potential environment and dirty transport crates into the meat production chain at different level. The contamination of carcass by *L. monocytogenes* is likely to occur due to poor handling by retailers and abattoir workers.

Most of bacterial pathogens were more prevalent in meats samples collected from retails as compared to meat samples collected from abattoirs. Correspondingly, the bacterial pathogen prevalence was globally lower in carcasses at the slaughter house level and higher in meat cuts and minced beef at retail (ECDC, 2013; Stevens et al., 2006). The temperature fluctuation during distribution, meat contamination by handlers, lack of hygiene

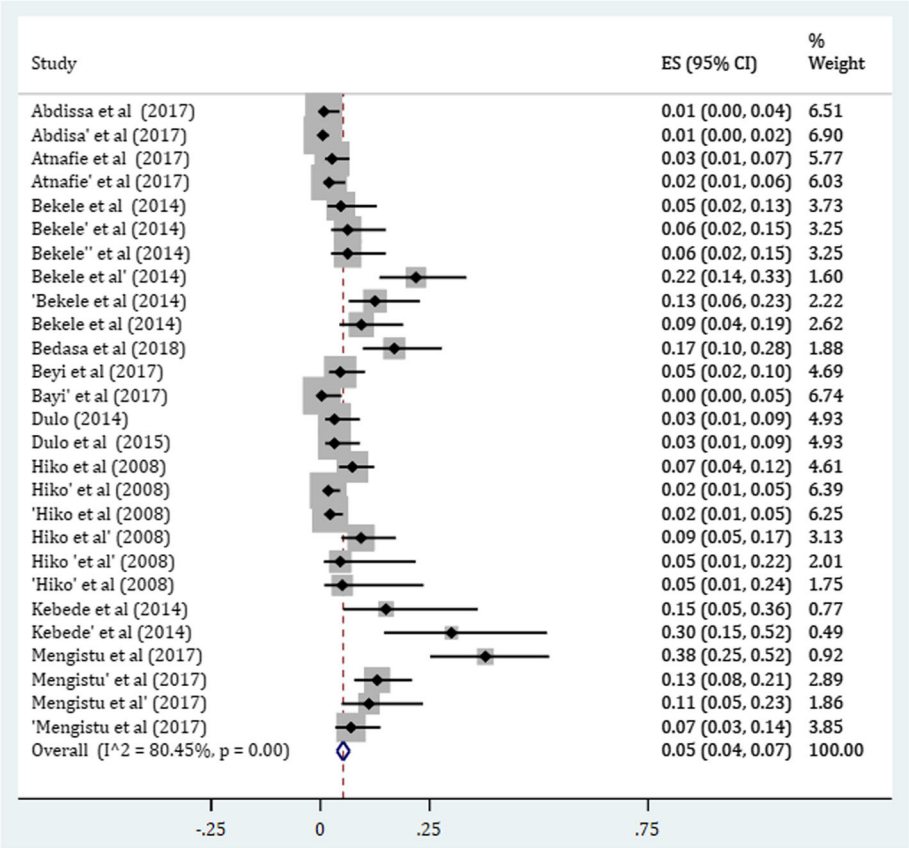

Fig. 3 Forest plot of *E. coli* O157:H7 prevalence in meat and meat products

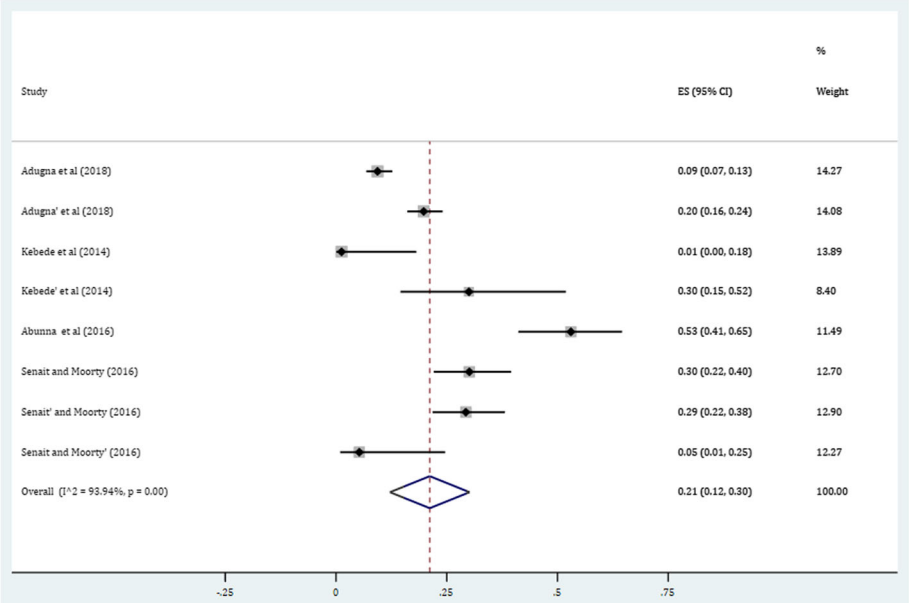

Fig. 4 Forest plot depicting the prevalence of *Staphylococcus* spp. in meat and meat products

and unsafe loading and unloading practices might have contributed for slight increment of meat contamination in retail outlets (Rajkovic, 2012). The high cost of cold storage equipment can also be key factors impeding the transportation of meat under refrigeration conditions in developing countries. Likewise, Gill et al. *(Gill & McGinnis,* 2000*)* reported that raw beef sold at retail outlets is subjected to a long chain of slaughtering and transportation where each step poses a potential risk of microbial contamination. Whereas, in abattoirs, a variety of decontamination measures might be employed during carcass processing in order to reduce the microbial load and contamination of carcass with pathogens.

Meta-analysis was conducted for antimicrobial susceptibility profile of bacterial isolates from subset of studies to which the secondary outcome measures were considered. The antimicrobial resistance profile of bacterial isolates from meat and meat products was found less than 10% in majority of estimates. However, slightly higher resistance profile (25% of *Salmonella* isolates*)*

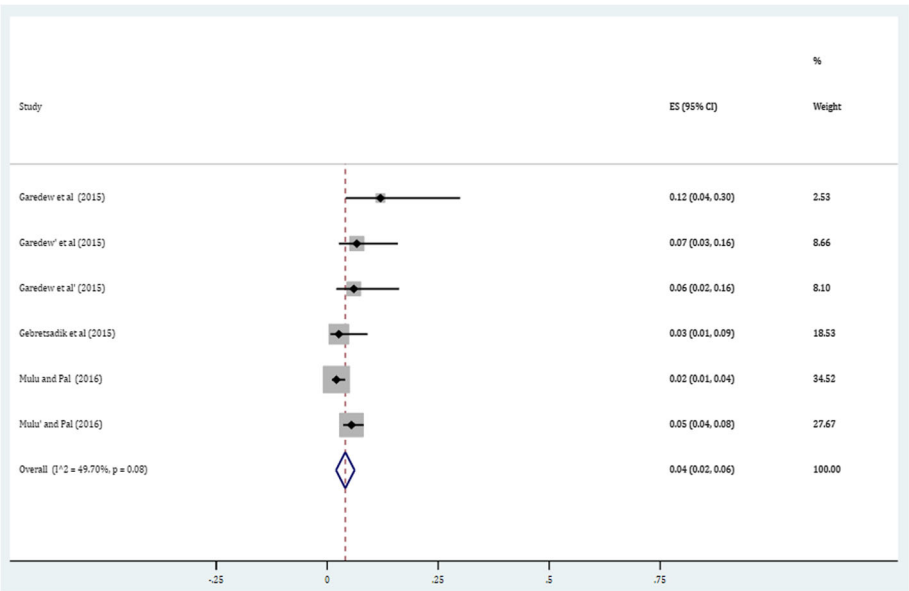

Fig. 5 Forest plot showing the prevalence of *L. monocytogenes* in meat and meat products

Table 5 Subgroup analysis of bacterial pathogens resistance profile against selected antibiotics

	Pooled estimate of resistance profile, proportion (95% CI)		
Antibiotics	*E. coli* O157:H7	*Salmonella* spp.	*L. monocytogenes*
Ampicillin	–	0.25 (0.10, 0.40)	–
Ceftriaxone	0.02(−0.02, 0.05)	0.09 (0.02, 0.15)	–
Ciprofloxacin	0.10 (0.01, 0.20)	0.03 (0.00, 0.06)	–
Gentamicin	0.02 (−0.02, 0.06)	0.06 (0.01, 0.10)	0.05 (−0.08, 0.17)

Key: ---- not determined

was recorded against ampicillin. To this end, higher prevalence (38%) of antimicrobial resistance *Salmonella* isolates against ampicillin was reported from chicken meat and their processing environment in Brazil (Medeiros et al., 2011). In the present study, 10% of *E. coli* O157:H7 isolates were resistant against ciprofloxacin. Despite a temporal variation, a study conducted in China in 2010 noted 4.1% antimicrobial resistance *E. coli* isolates against ciprofloxacin (Jiang et al., 2012). Antimicrobial resistance profile of meat borne pathogens might vary spatially and temporally due to sample type, environmental contamination and exposure, farm management system and antimicrobial use.

Implication and limitation of the study

According to the evidence generated from the meta-analysis, the contamination of meat and meat products requires stringent management on the area of food safety in meat sector in Ethiopia. The national food, medicine and health care administration and control authority and policy makers could make use of the estimates as inputs to enforce food safety measures. In this study, sufficient data was not found to assess the seasonal effect on the prevalence of bacterial pathogens in meat. Likewise, the risk factors of meat and meat products contamination along the production chain were not addressed. In most of the studies, there was lack of enumeration or bacterial load determination which indicates the actual safety status of food/ meat. Besides, very few reports were available for some pathogens from meat and meat products.

Most of the retrieved studies were carried out in slaughterhouses and markets in urban area of the country where most abattoirs are located therefore, the pooled prevalence estimates of contaminated meat items should not be generalized for rural and smaller settings of the country. All these limitations are clear gaps for further research in the area of meat safety in Ethiopia.

Conclusion

Relatively high prevalence of bacterial pathogens observed in meat and its products in Ethiopia, as highlighted in this review, may possibly be considered as potential sources of human foodborne illnesses. The results justify the need for strict measures to reduce contamination of carcasses in meat throughout the entire supply chain. The antibiotic resistance profiles of bacterial isolates in meat and its product was found lower. Relatively, *Salmonella* spp. showed high resistance against ampicillin.

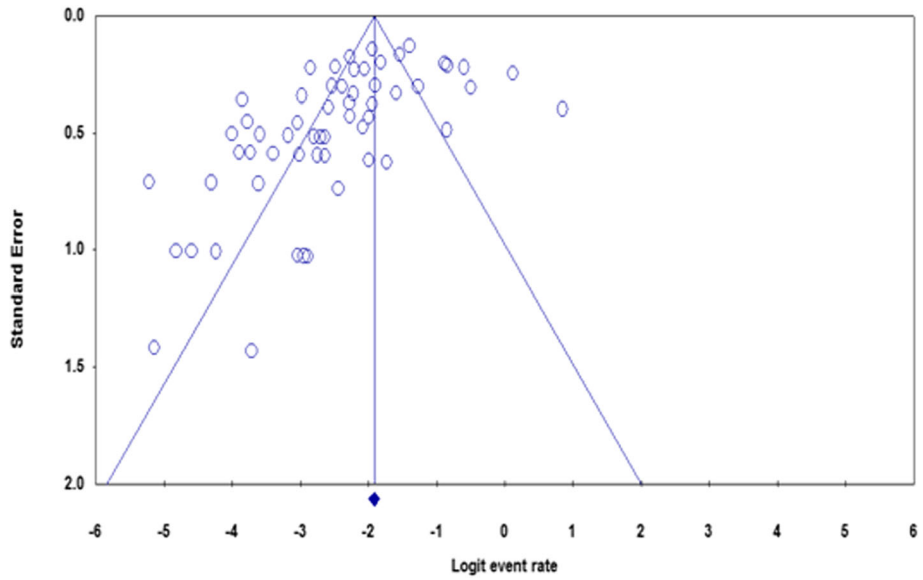

Fig. 6 Funnel plot depicting publication bias of studies reporting the prevalence of bacterial isolates obtaied from meat and meat products in Ethiopia

Abbreviations
CS: Cross sectional; MeSH: Medical Subject Headings; PRISMA: Preferred Reporting Items for Systematic Review and Meta-analysis

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Availability of data and materials
All data used for the study are contained within the manuscript.

Authors' contributions
AZ and MS performed the bibliographic searches, extracted, organized and analyzed the data; KA, JV, AK and YT, supervised the work, performed writing, and editing. AZ and MS also drafted the manuscript and prepared the final version for publication. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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