Bacteriological Quality and Public Health Risk of Ready-to-Eat Foods in Developing Countries: Systematic Review and Meta Analysis

Microbiology Insights
Volume 15: 1–11

DOI: 10.1177/11786361221113916

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ABSTRACT

BACKGROUND: Ready-to-eat foods are foods that are consumed at the point of sale or later, without any further processing or treatment. Foodborne diseases are on the rise worldwide, involving a wide range of diseases caused by pathogenic bacteria, and are becoming a public health problem. Therefore, this study sought to identify and determine the bacteriological quality and public health risks in ready-to-eat foods in developing countries.

METHODS: The studies published from 2012 to 2020 were identified through systematic searches of various electronic databases such as Google Scholar, PubMed and MEDLINE, MedNar, EMBASE, CINAHL, Scopus, and Science Direct. The articles were searched using a Boolean logic operator ("AND," "OR," "NOT") combination with Medical Subject Headings (MeSH) terms and keywords. All identified keywords and an index term were checked in all included databases. In addition, a quality assessment is performed to determine the relevance of the article, and then the data are extracted and analyzed.

RESULTS: The current study found that the pooled prevalence of *Staphylococcus aureus, Enterobacter* species, *Klebsiella, Escherichia coli, Salmonella, Bacillus cereus, Pseudomonas* species, and *Shigella in* ready-to-eat foods was 30.24% (95% CI: 18.8, 44.65), 11.3% (95% CI: 6.6, 18.7), 9.1% (95% CI: 7.0, 11.8), 23.8% (95% CI: 17.5, 31.5), 17.4% (95% CI: 11.6, 25.31)], 26.8% (95% CI: 13.7, 45.9), 6.1% (95% CI: 2.8, 12.6), 34.4% (95% CI: 18.1-55.4), respectively.

CONCLUSIONS: Most of the reviewed articles reported on various pathogenic bacterial species that are potentially harmful to human health, such as *Staphylococcus aureus*, *Salmonella*, *Shigella*, and *Escherichia coli* in ready-to-eat food above the maximum allowable limit. Therefore, relevant national and international organizations must take corrective measures to prevent foodborne diseases and protect human health.

KEYWORDS: Ready-to-eat foods, microbiological quality, street-vended foods, microbiological contamination, and public health

RECEIVED: December 28, 2021. **ACCEPTED:** June 27, 2022.

TYPE: Review

FUNDING: The author(s) received no financial support for the research, authorship, and/or publication of this article.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Introduction

Ready-to-eat (RTE) foods are foods and beverages consumed at the point of sale or at a later time without any further processing or treatment in such a way that may significantly reduce the microbial load and could be raw or cooked, hot or chilled.[1,2] RTE foods can be fruits and fruit products,[3] meat and its products, eggs and the like.[4-6]

RTE foods provide an important source of readily available and nutritious meals for consumers. Today, the increasing demand for RTE foods has led to an increase in the amount of food and different types of food that consumers can easily obtain.[7] RTE foods are convenient meals for today's lifestyle because they do not require cooking or further preparation. In addition to its benefits, the incidence of foodborne diseases is increasing globally, involving a wide range of diseases caused by pathogenic organisms, and becoming a public health problem that requires urgent response.[8]

Due to the negligence of regulatory agencies and weak law enforcement, which has affected food quality and led to the provision of unsafe food to consumers, the hygiene and safety practices of most food suppliers have not been supervised or monitored.[9] According to estimates by the World Health Organization,[10] eating contaminated food can cause/spread more than 200 different types of disease, and sometimes they can cause long-term health problems, especially for vulnerable groups such as the elderly, pregnant women, and babies.

Even in developed countries, it is estimated that one-third of the population is affected by microbial foodborne diseases every year.[11] According to Scallan et al,[12] from 2000 to 2010, there were approximately 47.8 million foodborne illnesses in the United States each year, of which 9.4 million were caused by 31 known and identified pathogens. In United States alone, food-borne diseases caused an estimated of 76 million illnesses, 325 000 hospitalizations, and 5000 deaths annually.[13]

In developing countries, food-borne or water-borne microbial pathogens are the main cause of disease.[11] Feglo and Sakyi[14] identified various types of microorganisms in RTE foods, such as *Staphylococcus aureus*, *Bacillus*, *Klebsiella pneumoniae*, and *Escherichia coli (E.coli)* in different types of RTE foods. Furthermore, Gizaw, also identified various bacterial species that cause food poisoning and foodborne diseases such as *Salmonella, Shigella, E. coli, Clostridium, Staphylococcus, Campylobacter*, and *Vibrio* from RTE foods, some of which are common bacteria that cause food-related illness.[15] Similarly, according to the study conducted in china using national food-borne disease outbreak surveillance system data (2003-2017), 19 517 food borne outbreaks were reported, which resulted in 235 754 illnesses, 107 470 hospitalizations, and 1457 deaths. Of 13 307 outbreaks with known etiology, about 6.8%, 4.2%, and 3.0% of outbreaks were caused by *Salmonella, Staphylococcus aureus*, and *Bacillus cereus*, respectively.[16]

In general, illness and death from diseases caused by contaminated food are a threat to public health and a significant impediment to socio-economic development. Foodborne disease outbreaks are common and cause considerable morbidity and mortality.[17]

This indicates the need to determine the microbial load or status of RTE foods to prevent foodborne diseases and promote health and well-being. Therefore, this study sought to determine the microbiological quality and public health risks of RTE foods in developing countries.

Methods

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[18]

Eligibility criteria

This review included articles that met the following predetermined inclusion criteria.

i. ***Population***: Any type of RTE foods carried out in developing countries based on the World Bank.
ii. ***Outcome***: Articles reported the quantitative outcome (prevalence or magnitude) of selected bacterial species (*Salmonella, Shigella, Staphylococcus aurous, Bacillus cereus*, *Pseudomonas*, *Entrobacter* species, *E. coli*, and *Klebsiella*).
iii. ***Study design***: A cross-sectional study that provides quantitative results.
iv. ***Study location***: Full-text articles conducted in developing countries
v. ***Publication issue***: Articles published in peer-reviewed journals from 2012 to 2020
vi. ***Language***: Full-text articles written in English.

Information sources and search strategy

This review takes into account articles published in 2012 to 2020 that provide quantitative results and written in English. The search was done based on keywords and Medical Subject Headings (MeSH) terms in combination with "AND" or "OR" (Boolean logic operators) or individually from various electronic databases such as Google Scholar, PubMed/MEDLINE, Med Nar, EMBASE, CINAHL, Web of Science, Scopus, and Science direct. The authors then checked the identified keywords and an index term in the included databases.

The following is a search term the authors (DAM, DDB, AAT and YAA) used in the initial search: ((((((“microbiological quality” [MeSH Terms] OR (“microbiological” [All Fields] AND “quality” [All Fields]) OR “microbiological quality” [All Fields]) AND (((“Public health” [MeSH Terms] OR (“public” [All Fields] AND “health” [All Fields]) OR “public health” [All Fields])) AND ((((“risk” [MeSH Terms] OR “risk” [All Fields] OR “risks” [All Fields])) OR ((“implication” [MeSH Terms] OR “implication” [All Fields] OR “implications” [All Fields]) OR (((“hazard” [MeSH Terms] OR “hazard” [All Fields] OR “hazards” [All Fields])) AND (((((((“ready-to-eat food” [MeSH Terms] OR (“Ready-to-eat” [All Fields] AND “foods” [All Fields]) OR “ready-to-eat food” [All Fields]))) AND (((((“developing countries” [MeSH Terms] OR (“developing” [All Fields] AND “countries” Fields]) OR “low-and middle-income countries” [MeSH Terms] OR (“low-and middle-income” [All Fields] AND “countries” [All Fields])))))).

Finally, the keywords and index terms were checked by authors (DAM, DDB, AAT, and YAA) across the included electronic databases. Furthermore, a manual search was done for further studies to cover other published articles not included in the selected electronic databases. The last literature search was conducted in December 2020.

Study selection

The authors used ENDNOTE software version X5 (Thomson Reuters, USA) to remove duplicate articles. Then the authors (DAM, DDB, AAT, and YAA) independently screened the studies by using the inclusion criteria based on their abstract and titles. A disagreement between the authors was resolved by taking the mean score of the 2 reviewers after repeating the procedure and discussing the rationale for the differences. Finally, the review included 23 articles that met the inclusion criteria to determine the microbiological quality and public health risk of RTE foods sold in developing countries.

Data extraction and quality assessment

The authors (DAM, DDB, AAT, and YAA) used a predetermined data extraction form under the following key points/headings: author, publication year, country where the study was conducted, study design, and primary outcome. For articles

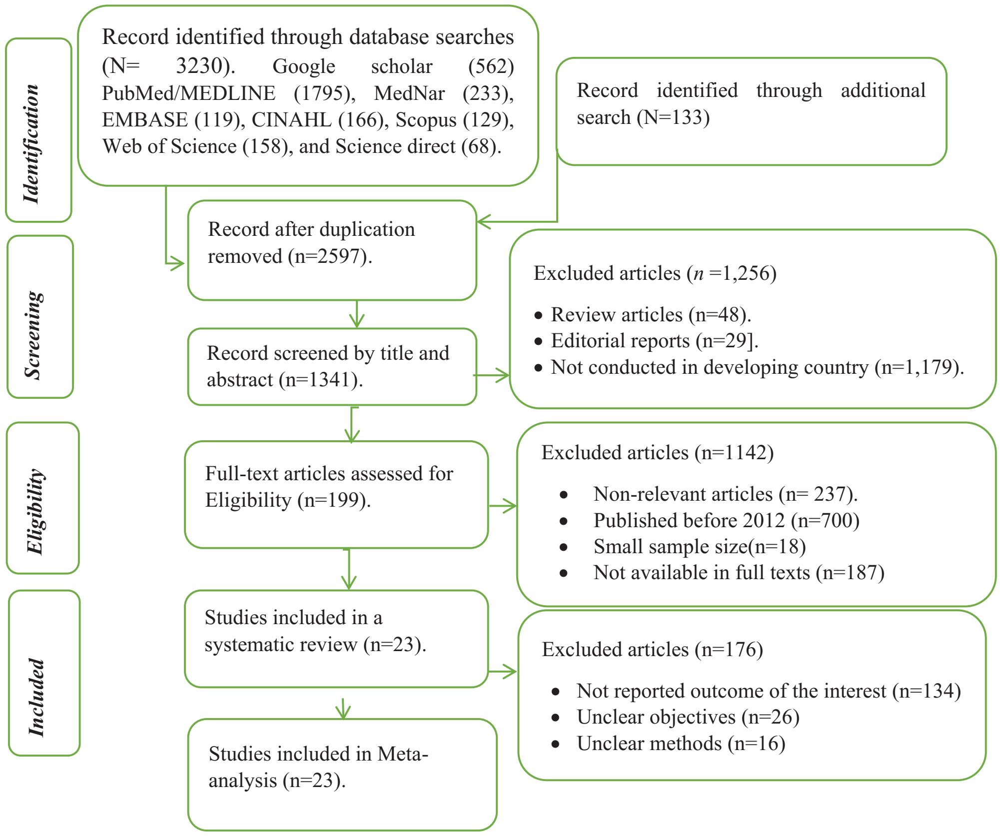


Figure 1. Flow diagram that shows the selection process of studies for a systematic review and meta-analysis.

that met the inclusion criteria, the abstracts and methodology were read and evaluated to establish their relevance and to assess the quality of the included articles.

Furthermore, to assess and determine the quality of each article, the authors performed a rigorous and independent evaluation using standardized critical evaluation tools, Joanna Briggs Institute (JBI) Critical Appraisal tools.[19] Then the mean score was taken for each included article and classified as high (80% and above), moderate (65%-80%), and low (less than 65%) quality. Disagreements made among the authors (DAM, DDB, AAT, and YAA) on what to be extracted and on quality assessment were resolved by discussion after repeating the same procedure and by taking a mean score of reviewers.

Data analysis and statistical procedures

The pooled prevalence of selected bacterial species in RTE foods was performed using Comprehensive Meta-Analysis (CMA) version 3.0 statistical software. Furthermore, the forest plot and random effects models were used to determine the pooled prevalence of selected bacterial species in RTE foods. Cochran's Q test, (Q) and (*I* squared test) I^2 statistics were used to evaluate heterogeneity among included articles. The publication bias of the included studies was evaluated using funnel plots and a *P*-value of $<.05$ was considered evidence of publication bias. Finally, the results were presented using text, tables, and graphs/figures.

Results

Study selection

A total of 3363 articles published between 2012 and 2020 were searched from various electronic databases such as Google Scholar, PubMed/MEDLINE, MedNar, EMBASE, CINAHL, and Science direct. Following the search for articles, 766 duplicate articles were excluded. Furthermore, 1256 articles were excluded after initial screening and 176 articles were excluded after full-text articles were assessed for eligibility, of which 23 articles were included in the systematic review and meta-analysis (Figure 1).

Characteristics of the included studies

In this study, a total of 1959 RTE food samples were included in 23 articles conducted in developing countries and published between 2012 and 2020. Regarding the included articles, 7 (30.43%) articles[5,6,20-24] conducted in Nigeria, 4 (17.39%) articles[25-28] in Ethiopia, 2 (8.7%) articles[29,30] in Bangladesh, 2 (8.7%) in India[31,32], 2 (8.7%) articles in Ghana,[14,33] and 1 article in Egypt,[34] 1 in Sudan,[35] 1 in South Africa,[36] 1 in Benin,[37] 1 in Pakistan,[38] and 1 in Saudi Arabia.[39] The included studies were cross-sectional studies with a sample size ranging from 12[23] to 252[36] RTE foods samples. Based on the JBI Critical Appraisal tool,[19] all included articles had a low risk of bias. The prevalence of *Entrobacter*, *Klebsiella*, *B. cereus*, *S. aureus*, *E. coli*, *Salmonella, Shigella*, *and Pseudomonas* in RTE foods was ranged from 5.36%[22] to 41.6%,[37] 5.6%[28] to 18.0%,[14] 5.0%[25] to 93.3%,[33] not detected[37] to 89.8%,[28] not-detected[36] 96.7%,[33] not detected[36-38] to 100%,[35] 2%[20] to 76.7%[33] and 2.2%[14] to 25.0%,[23] respectively (Table 1).

Microbiological status of ready-to-eat foods

Prevalence of Staphylococcus aureus *in ready-to-eat foods.* The pooled prevalence of *Staphylococcus aureus* in RTE foods was 30.24% [95% CI 18.8-44.65 and a *P*-value of .008] and $I^2 = 95.26\%$ with a *P*-value < .001 (Figure 2).

Prevalence of Entrobacter *species in ready-to-eat foods.* The overall prevalence of *Entrobacter* species in RTE food was 11.3% [95% CI: 6.6-18.7 and a *P*-value < .001]; $I^2 = 87.37\%$ with a *P*-value < .001 (Figure 3).

Prevalence of Klebsiella *in ready-to-eat foods.* The total mean prevalence of *Klebsiella* in RTE food was 9.1% [95% CI: 7.0-11.8 and *P*-value < .001]; $I^2 = 31.73\%$ with a *P*-value = .16 (Figure 4).

Prevalence of Escherichia coli *in ready-to-eat foods.* The pooled prevalence of *E. coli* in RTE food was 23.8% [95% CI: 17.5-31.5 and a *P*-value < .001]; $I^2 = 88.34\%$ with a *P*-value < .001 (Figure 5).

Prevalence of Salmonella *in ready-to-eat foods.* The pooled prevalence of *Salmonella* in RTE food was 17.4% [95% CI: 11.6-25.3 and *P*-value < .001]; $I^2 = 84.59\%$ with a *P*-value < .001 (Figure 6).

Prevalence of Bacillus cereus *in ready-to-eat foods.* The pooled prevalence of *Bacillus cereus* in RTE food was 26.8% [95% CI: 13.7-45.9 and a *P*-value = .019]; $I^2 = 93.5\%$ with a *P*-value < .001 (Figure 7).

Prevalence of Pseudomonas *species in ready-to-eat foods.* The pooled prevalence of *Pseudomonas* species in RTE food was 6.1% [95% CI: 2.8-12.6 and a *P*-value < .001]; $I^2 = 84.24\%$ with a *P*-value < .001 (Figure 8).

Prevalence of Shigella *in ready-to-eat foods.* The pooled prevalence of *Shigella* in RTE food was 34.4% [95% CI: 18.1-55.4]; $I^2 = 87.47\%$ with a *P*-value < .001 (Figure 9).

Subgroup analysis of the pooled prevalence of selected bacteria species ready-to-eat foods

The subgroup analysis of the pooled prevalence of *E. coli, S. aureus, B. cereus, Salmonella* spp., *Shigella* spp., *Entrobacter* spp., *Klebsiella*, *and Pseudomonas* species is presented in Table 2 below with 95% CI and *P*-value (Table 2).

Discussion

This study reviewed studies conducted in developing countries to determine the microbiological quality and public health risk of RTE foods. A total of 23 articles conducted on the bacteriological quality or contamination of RTE foods were included in the systematic review and meta-analysis. The included articles reported various pathogenic bacterial species higher than the recommended standard set for RTE foods.[40]

Currently, food-borne diseases represent a significant health problem for individuals, communities, and food industries[41] and remain a global public health challenge.[42] *Salmonella, E. coli, Shigella, Clostridium, Staphylococcus*, and *Vibrio* are among the most common bacteria species that cause food-related illness.[43-45]

However, the current study found the pooled prevalence of selected pathogenic bacterial species in RTE foods such as *Staphylococcus aureus* (30.24%), *E. coli* (23.8%), and *Shigella* (34.4%). This indicates that at least 1 in 4 RTE food samples were contaminated with at least one pathogenic bacterial species and potential risk to consumer health. There is high risk of to be effected by food borne disease as the result of consuming contaminated RTE foods, which can be highly complex, reaching far beyond acute gastroenteritis and lead to a variety of health outcomes.[46]

Furthermore, the current study found the pooled prevalence of bacterial species in RTE foods such as *Entrobacter* species (11.3%), *Klebsiella* (9.1%), *Bacillus cereus* (26.8%) and *Pseudomonas* species (6.1%). Contamination of food with these microorganisms is beyond the standard limit and poses a risk to human health. This was in line with various studies reporting various foodborne pathogenic bacterial species in foods such as *B. cereus, C. perfringens, S. aureus*, and *Salmonella* species.[47,48]

Gizaw also reported that different disease-causing bacteria species were identified, mainly *Salmonella* species, *E. coli*, *Klebsiella* species, *Shigella* species, *Enterobacter* species, *Staphylococcus aureus*, *Bacillus cereus*, and *Pseudomonas* species[15] that was in line with the current study.

In general, foodborne illness is a major public health concern and a common cause of illness and death worldwide.[49] Foodborne diseases can occur as single cases or outbreaks and sometimes as in the case of cholera spread around the world to cause pandemics.[50]

This study indicated that the consumption of RTE foods contaminated with pathogenic bacterial species continues to be a major risk to consumer health in developing countries. Particularly, old, very young, immune-compromised, and healthy people exposed to a very high dose of pathogenic microorganisms, including bacterial species are at high risk of to be effected by food borne disease.[51]

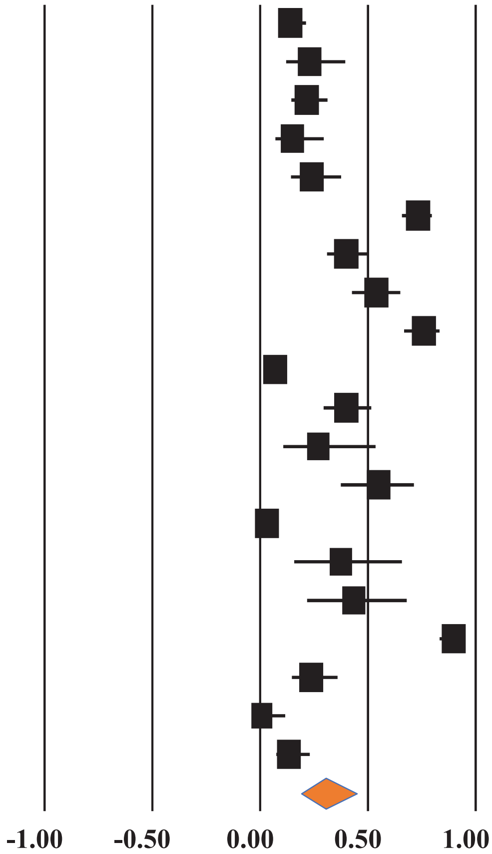
Therefore, to prevent foodborne diseases and protect public health, it is crucial to apply food hygiene and safety measures that include, but are not limited to, good practices, proper

Table 1. Overall characteristics of the articles included in the systematic review and meta-analysis.

AUTHORS	PUBLICATION YEAR	N	*ENTROBACTER* (%)	*KLEBSIELLA* (%)	*B. CEREUS* (%)	*S.AUREUS* (%)	*E. COLI* (%)	*SALMONELLA* (%)	*SHIGELLA* (%)	*PSEUDOMONAS* (%)	SAMPLES	COUNTRY
Bello Olorunjuwon et al[6]	2014	120	0.06	0.08	0.08	0.14	0.06	0.06	NA	0.03	Juice	Nigeria
Oje et al[20]	2018	35	NA	0.17	0.2	0.23	0.09	0.18	0.02	0.06	Meat pie, egg roll, roasted groundnut, and fried fish	Nigeria
Iqbal et al[38]	2016	90	NA	NA	0.6637	0.2168	0.1194	ND	NA	NA	Juice	Pakistan
Geta et al[25]	2019	40	0.1	0.075	0.05	0.15	0.1	NA	NA	NA	Juice	Ethiopia
Mahfuza et al[29]	2016	50	NA	0.09	0.25	0.24	0.36	NA	NA	NA	Fresh-cut fruits, salad vegetables and juices	Bangladesh
Reddi et al[31]	2015	150	NA	NA	NA	0.733	0.426	NA	0.486	NA	Juice	India
Abd-El-Malek[34]	2014	100	NA	NA	0.2	0.4	NA	0.07	0.23	NA	Liver sandwiches (kibda)	Egypt
Amare et al[26]	2019	72	0.1587	NA	NA	0.5396	0.238	NA	NA	NA	Sanbusa, donat, bombolino and bread	Ethiopia
Dashen et al[21]	2020	100	NA	NA	NA	0.76	0.36	0.15	NA	0.08	Meat	Nigeria
Alharbi et al[39]	2019	155	NA	NA	NA	0.07	0.18	0.15	NA	NA	Vegetable salad, falafel, kibtha and shawarma	Saudi Arabia
Igbinosa et al[22]	2020	210	0.0536	0.089	NA	NA	0.411	0.214	NA	0.1786	Fried rice, jollof rice, moi-moi, salad, oil beans, non-oil beans, and African salad	Nigeria
Sabuj et al[30]	2018	72	NA	NA	NA	0.4	0.333	0.267	NA	NA	Shingara, samosa, piazu, puri, potato chop and beguni	Bangladesh
Singh[32]	2015	15	NA	NA	0.27	NA	0.4	0.13	NA	NA	Juice	India
Elhag et al[35]	2017	30	NA	NA	NA	0.55	0.733	1.0	NA	NA	Juice	Sudan
Nyenje et al[36]	2012	252	0.18	0.08	NA	0.032	ND	ND	NA	0.024	Vegetables, potatoes, rice, pies, beef and chicken stew	South Africa
Bristone et al[23]	2018	12	NA	NA	NA	0.375	0.5	0.375	0.375	0.25	Awara (soybean cheese)	Nigeria
El-Hassan et al[24]	2018	15	NA	NA	NA	0.435	0.13	0.217	0.217	NA	Meat Product (Tsire)	Nigeria
Abakari et al[33]	2018	30	NA	NA	0.933	NA	0.967	0.733	0.767	NA	Vegetable salads	Ghana
Leul and Kibret[27]	2012	90	0.114	0.057	NA	NA	0.143	0.2	NA	0.029	Juice	Ethiopia
Abera et al[28]	2016	126	0.056	0.056	NA	0.898	0.315	0.176	NA	NA	Milk	Ethiopia
Feglo and Sakyi[14]	2012	60	0.067	0.18	0.215	0.237	0.022	NA	NA	0.022	Ice-kenkey, cocoa drink, ready-to-eat red pepper, salad and macaroni.	Ghana
Anihouvi et al[37]	2019	60	0.416	NA	0.542	ND	0.25	ND	NA	NA	Fresh pork and processed pork meat	Benin
Adesetan et al[5]	2013	75	NA	NA	0.053	0.134	0.067	NA	NA	NA	Street vended fruits	Nigeria

Abbreviations: N, sample size; ND, not detected; *S. aureus*, *Staphylococcus aureus; B. cereus*, *Bacillus cereus; E. coli*, *Escherichia coli*.

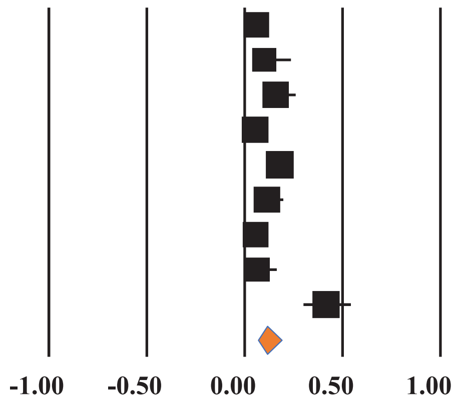
Study name	Statistics for each study					Event rate and 95% CI
	Event rate	Lower limit	Upper limit	Z-Value	p-Value	
Bello et al	0.140	0.089	0.214	-6.900	0.000	
Oje et al	0.230	0.120	0.396	-3.008	0.003	
Iqbal et al	0.217	0.144	0.314	-5.021	0.000	
Geta et al	0.150	0.069	0.296	-3.917	0.000	
Mahfuza et al	0.240	0.142	0.377	-3.481	0.000	
Reddi, et al	0.733	0.657	0.798	5.472	0.000	
Malek	0.400	0.309	0.499	-1.986	0.047	
Amare et al	0.540	0.424	0.651	0.671	0.502	
Dashen et al	0.760	0.667	0.834	4.923	0.000	
Alharbi et al	0.070	0.039	0.122	-8.217	0.000	
Sabuj et al	0.400	0.294	0.517	-1.685	0.092	
Singh et al	0.270	0.106	0.536	-1.710	0.087	
Elhag et al	0.550	0.373	0.715	0.547	0.585	
Nyenje et al	0.032	0.016	0.063	-9.526	0.000	
Bristone et al	0.375	0.157	0.659	-0.857	0.392	
EL-Hassan et al	0.435	0.217	0.681	-0.502	0.616	
Abera et al	0.898	0.832	0.940	7.390	0.000	
Feglo and Sakyi	0.237	0.146	0.360	-3.851	0.000	
Anihouvi et al	0.008	0.001	0.118	-3.377	0.001	
Adesetan et al	0.134	0.074	0.231	-5.505	0.000	
Overall	0.302	0.188	0.446	-2.641	0.008	



Heterogeneity (I^2) = 95.26 % with a *p* -value < 0.001
Random effect model

Figure 2. Forest plot shows the pooled prevalence of *Staphylococcus aureus* in ready-to-eat foods in developing countries.

Study name	Statistics for each study					Event rate and 95% CI
	Event rate	Lower limit	Upper limit	Z-Value	p-Value	
Bello et al	0.060	0.029	0.119	-7.158	0.000	
Geta et al	0.100	0.038	0.238	-4.169	0.000	
Amare et al	0.159	0.091	0.262	-5.171	0.000	
Igbinosa	0.054	0.030	0.094	-9.371	0.000	
Nyenje et al	0.180	0.137	0.232	-9.248	0.000	
Leul and kibret	0.114	0.063	0.198	-6.182	0.000	
Abera et al	0.056	0.027	0.113	-7.290	0.000	
Feglo and Sakyi	0.067	0.025	0.165	-5.101	0.000	
Anihouvi et al	0.416	0.299	0.543	-1.295	0.195	
Overall	0.113	0.066	0.187	-6.885	0.000	



Heterogeneity (I^2) = 87.37% with a *p* -value < 0.001
Random effect model

Figure 3. Forest plot shows the pooled prevalence of *Entrobacter* species in ready-to-eat foods in developing countries.

Study name	Event rate	Lower limit	Upper limit	Z-Value	*p*-Value
Bello et al	0.080	0.043	0.144	-7.258	0.000
Oje et al	0.170	0.078	0.331	-3.524	0.000
Geta et al	0.075	0.024	0.208	-4.185	0.000
Mahfuza et al	0.090	0.036	0.207	-4.682	0.000
Igbinosa,	0.089	0.058	0.136	-9.597	0.000
Nyenje et al	0.080	0.052	0.121	-10.518	0.000
Leul and Kibret	0.057	0.024	0.128	-6.172	0.000
Abera et al	0.056	0.027	0.113	-7.290	0.000
Feglo and Sakyi	0.180	0.102	0.298	-4.513	0.000
	0.091	0.070	0.118	-15.844	0.000

Statistics for each study

Heterogeneity (I^2) = 31.73% with a p -value = 0.16

Random effect model

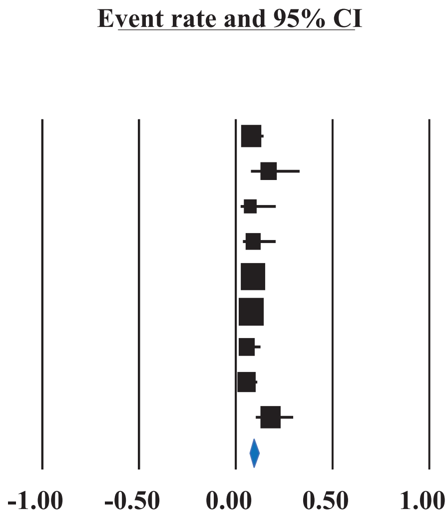


Figure 4. Forest plot shows the pooled prevalence of *Klebsiella* in ready-to-eat foods in developing countries.

Study name	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Bello et al	0.060	0.029	0.119	-7.158	0.000
Oje et al	0.090	0.030	0.239	-3.917	0.000
Iqbal et al	0.119	0.067	0.204	-6.147	0.000
Geta et al	0.100	0.038	0.238	-4.169	0.000
Mahfuza et al	0.360	0.240	0.501	-1.953	0.051
Reddi, et al	0.426	0.349	0.506	-1.806	0.071
Amare et al.	0.238	0.154	0.349	-4.205	0.000
Dashen et al	0.360	0.272	0.458	-2.762	0.006
Alharbi et al	0.180	0.127	0.249	-7.253	0.000
Igbinosa,	0.411	0.346	0.479	-2.566	0.010
Sabuj et al	0.333	0.234	0.449	-2.778	0.005
Singh et al	0.400	0.192	0.652	-0.769	0.442
Elhag et al	0.733	0.550	0.860	2.447	0.014
Nyenje et al	0.002	0.000	0.031	-4.397	0.000
Bristone et al	0.500	0.244	0.756	0.000	1.000
EL-Hassan et al	0.130	0.032	0.402	-2.476	0.013
Abakari et al	0.967	0.798	0.995	3.305	0.001
Leul and kibret	0.143	0.085	0.231	-5.947	0.000
Abera et al	0.315	0.240	0.401	-4.051	0.000
Feglo and Sakyi	0.022	0.004	0.112	-4.311	0.000
Anihouvi et al	0.250	0.157	0.374	-3.685	0.000
Adesetan et al	0.067	0.028	0.151	-5.703	0.000
Overall	0.238	0.175	0.315	-5.878	0.000

Statistics for each study

Heterogeneity (I^2) = 88.34% with a p -value < 0.001

Random effect model

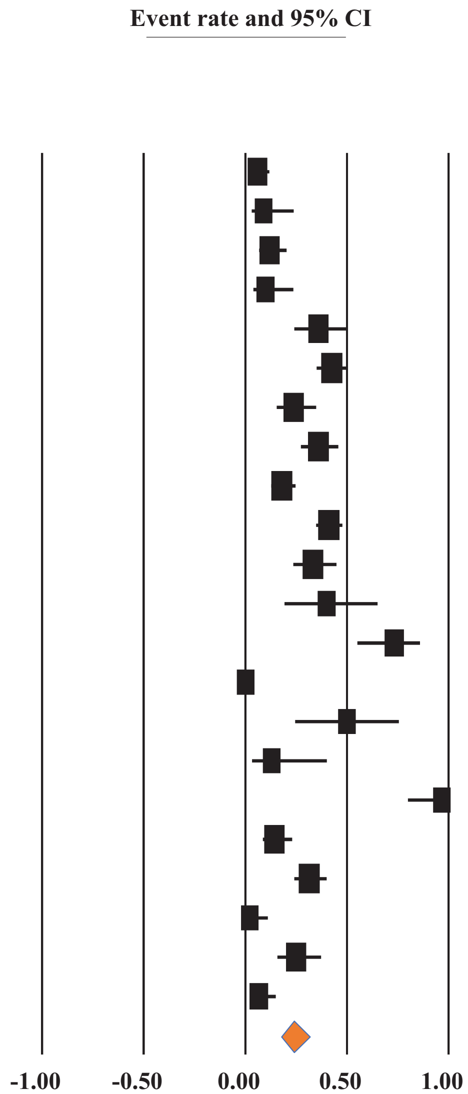
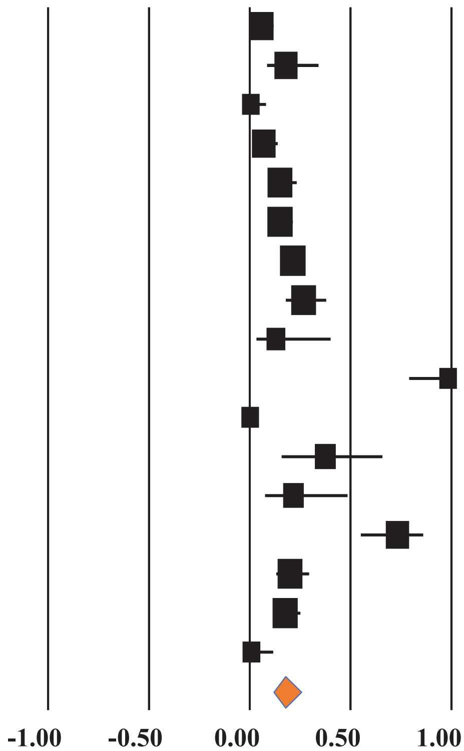


Figure 5. Forest plot shows the pooled prevalence of *Escherichia coli* in ready-to-eat foods in developing countries.

Study name	Statistics for each study				
	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Bello et al	0.060	0.029	0.119	-7.158	0.000
Oje et al	0.180	0.085	0.342	-3.446	0.001
Iqbal et al	0.005	0.000	0.082	-3.666	0.000
Malek	0.070	0.034	0.140	-6.600	0.000
Dashen et al	0.150	0.092	0.234	-6.194	0.000
Alharbi et al	0.150	0.102	0.215	-7.711	0.000
Igbinosa,	0.214	0.164	0.275	-7.732	0.000
Sabuj et al	0.267	0.178	0.380	-3.791	0.000
Singh et al	0.130	0.032	0.402	-2.476	0.013
Elhag et al	0.984	0.789	0.999	2.883	0.004
Nyenje et al	0.002	0.000	0.031	-4.397	0.000
Bristone et al	0.375	0.157	0.659	-0.857	0.392
EL-Hassan et al	0.217	0.075	0.486	-2.049	0.040
Abakari et al	0.733	0.550	0.860	2.447	0.014
Leul and kibret	0.200	0.130	0.295	-5.261	0.000
Abera et al	0.176	0.119	0.253	-6.599	0.000
Anihouvi et al	0.008	0.001	0.118	-3.377	0.001
Overall	0.174	0.116	0.253	-6.425	0.000

Event rate and 95% CI



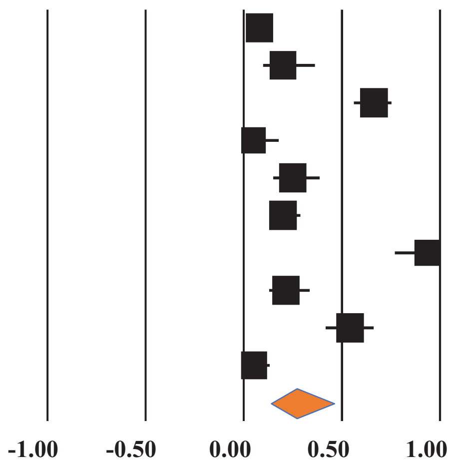
Heterogeneity (I^2) = 84.59% with a p -value < 0.001

Random effect model

Figure 6. Forest plot shows the pooled prevalence of *Salmonella* in ready-to-eat foods in developing countries.

Study name	Statistics for each study				
	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Bello et al	0.080	0.043	0.144	-7.258	0.000
Oje et al	0.200	0.098	0.364	-3.281	0.001
Iqbal et al	0.664	0.560	0.753	3.047	0.002
Geta et al	0.050	0.013	0.179	-4.059	0.000
Mahfuza et al	0.250	0.149	0.387	-3.364	0.001
Malek	0.200	0.133	0.290	-5.545	0.000
Abakari et al	0.933	0.769	0.983	3.607	0.000
Feglo and Sakyi	0.215	0.129	0.336	-4.121	0.000
Anihouvi et al	0.542	0.416	0.663	0.650	0.516
Adesetan et al	0.053	0.020	0.133	-5.594	0.000
Overall	0.268	0.137	0.459	-2.349	0.019

Event rate and 95% CI



Heterogeneity (I^2) = 95.3% with a p -value < 0.001

Random effect model

Figure 7. Forest plot shows the pooled prevalence of *Bacillus cereus* in ready-to-eat foods in developing countries.

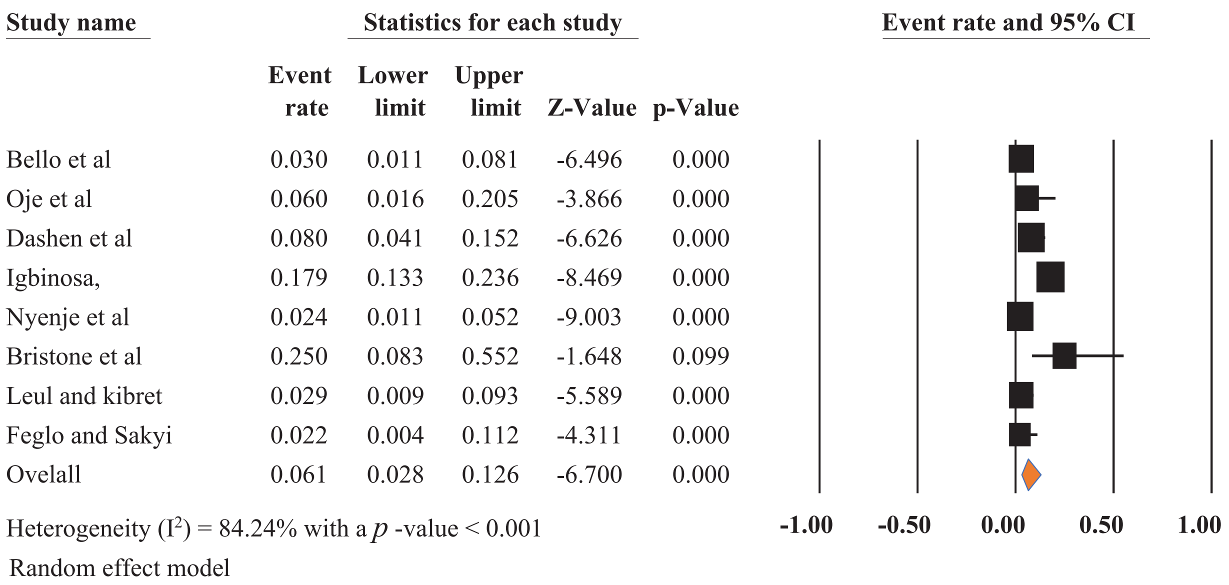


Figure 8. Forest plot shows the pooled prevalence of *Pseudomonas* species in ready-to-eat foods in developing countries.

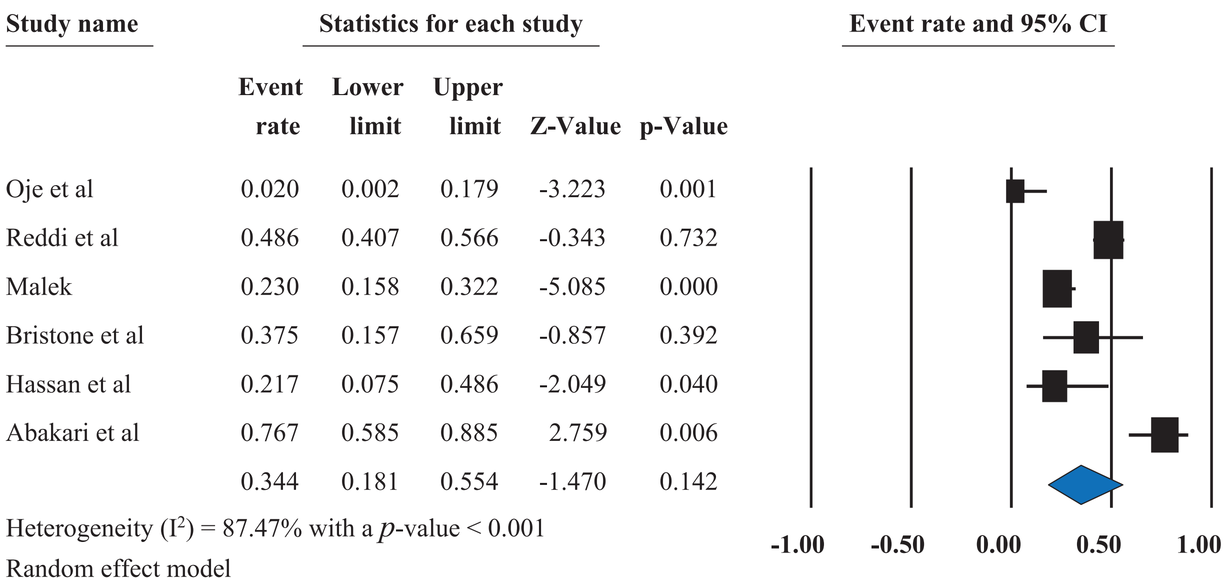


Figure 9. Forest plot shows the pooled prevalence of *Shigella* in ready-to-eat foods in developing countries.

Table 2. Subgroup analysis of the pooled prevalence of selected bacterial species in ready-to-eat foods in developing countries.

SELECTED BACTERIA SPECIES	BASED ON STUDY AREA (COUNTRY)					BASED ON PUBLICATION YEAR				
	POOLED PREVALENCE (%)	95% CI		*P*-VALUE	*I*²	POOLED PREVALENCE	95% CI		*P*-VALUE	*I*²
		LCI	UCL				LCI	UCL		
E. coli	29.5	26.2	33.2	<.001	88.34	29.2	25.8	32.8	<.001	88.34
Staphylococcus aureus	23.7	20.1	27.7	<.001	95.26	47.3	36.7	50	<.001	95.26
Bacillus cereus	36.2	31	41.8	<.001	93.5	16.5	11.3	23.6	<.001	93.5
Salmonella species	19.1	16.3	22.4	<.001	84.59	14.3	11	18.5	<.001	84.59
Shigella species	42.1	36.2	48.3	=.012	87.47	39.3	33.2	45.6	=.001	87.47
Entrobacter species	14.9	12.5	17.8	<.001	87.37	7.9	5.9	10.6	<.001	87.37
Klebsiella	9	7.3	11.2	<.001	31.75	8.8	6.9	11.3	<.001	31.75
Pseudomonas species	4.2	2.6	6.8	<.001	84.24	4.4	2.9	6.7	<.001	84.24

Abbreviations: CI, confidence interval; *E. coli*, *Escherichia coli*; LCI, lower confidence interval; UCI, upper confidence interval.

handling, regular monitoring, and effective surveillance, setting and enforcement of regulations, creating awareness, and working in collaboration.[52]

Conclusions

Most of the reviewed articles reported various pathogenic bacterial species such as *Staphylococcus aureus, Salmonella, Shigella, B. cereus, E. coli*, and other species of bacteria in RTE foods greater than the maximum allowed limits and potentially dangerous to human health. Thus, national or/and international organizations concerned must take the corrective measure on the application of food safety practices to prevent foodborne disease or illness and to protect human health.

Limitations

The review was based on previous studies that were conducted in different time periods. Therefore, the distribution may be incorrect. However, efforts were made to include all published articles on the microbial quality and public health of RTE foods. Some important findings such as conference proceedings and dissertations were not included due to the type of search strategy adopted in this systematic review.

Acknowledgements

We extend our deepest thanks to Haramaya University, Faculty of Health and Medical Sciences, Department of Environmental Health staff for their valuable and constructive supports.

Author Contributions

DAM conceived the idea and played an important role in data review, extraction, and analysis. DAM, DDB, AAT, and YAA also played a role in data extraction. All authors (DAM, DDB, AAT, and YAA) have contributed in analysis, writing, drafting, and editing. Finally, the authors (DAM, DDB, AAT, and YAA) read and approved the final version to be published and agreed on all aspects of this work.

Availability of Data and Materials

Almost all data are included in the systematic review and meta-analysis. However, additional data (particularly pooled prevalence of subgroup analysis results) are available from the corresponding author on a reasonable request. Furthermore, the 2015 PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis) Protocol checklists are the recommended items to address in a systematic review and meta-analysis.

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