BMC Infectious Diseases

RESEARCH

Open Access

Health risk assessment of *Staphylococcus aureus* and *Salmonella* from the consumption of street foods in Ethiopia

Mathewos Moges[1*], Ernst Kristian Rodland[3] and Argaw Ambelu[2]

Abstract

Introduction Due to inadequate hygienic practices and improper handling, street foods may become contaminated, posing a significant risk for various foodborne diseases. This study aimed to determine the health risks to consumers from consuming street foods contaminated with Staphylococcus aureus and Salmonella.

Method A cross-sectional study design was used from December 2022 to February 2023 on the street foods of Addis Ababa, Hawassa, Dire Dawa, and Jimma towns. A total of 525 street foods were taken from 175 street food vending stalls. A stratified sampling technique was used to select vending stalls. A questionnaire was used to collect the data which were analyzed via SPSS-25. Food samples were analyzed at the Ethiopian Public Health Institute food microbiology laboratory using the standard microbiological methods used for the isolation, enumeration, and identification of bacteria. A quantitative microbial risk assessment was used to assess and determine the risk of infection using a deterministic approach.

Result The frequent, average, and occasional consumers of street foods were 26.9%, 52.6%, and 20.5% respectively. The prevalence of Staphylococcus aureus was 43.4% whereas 25.7% for Salmonella species. The risk of infection from S. aureus was higher than Salmonella. The mean annual risk of S aureus infection of consumers was 100%, 99%, and 93% for frequent, average, and occasional consumers respectively. A total of 32.6% of the sampled foods had greater than 104 CFU/g a colony count of Staphylococcus aureus whereas in 25.7% of the samples Salmonella exceeded the safety standards and made the food unfit for consumption.

Conclusion The results highlighted the significant risk of infection with Staphylococcus aureus and Salmonella in Ethiopian street foods, and revealed that frequent consumption of street foods was associated with a high risk of infection. This urges improved hygiene practices to mitigate hazards and protect public health.

Keywords Street food, Microbial risk assessment, *Staphylococcus aureus*, *Salmonella*

*Correspondence:
Mathewos Moges
moges.mathewos@yahoo.com
[1]College of medicine and health sciences, Department of Environmental Health, Hawassa University, Hawassa, Ethiopia
[2]Division of Water and Health, Ethiopian Institute of Water Resources, Addis Ababa University, Addis Ababa, Ethiopia
[3]Norwegian Institute of Public Health, Oslo, Norway

Introduction

Street foods are ready-to-eat foods and beverages prepared and/or sold by vendors and hawkers, especially in streets and other similar public places [1]. As urbanization increases worldwide, the consumption of meals outside the home is becoming more common. Street foods play an important role in meeting the food needs of urban dwellers in many developing-country cities and towns [2]. It feeds millions of people every day with a diverse range of low-cost and easily accessible foods [3]. Food safety is a significant issue with street foods, as they are often prepared and sold in unsanitary environments [4, 5]. In addition, the traditional processing methods that are used in preparation, inappropriate holding temperatures, and poor personal hygiene of food handlers are some of the main causes of contamination of street foods [2, 3, 6].

Food safety is a critical public health concern within communities [7]. Studies on street food safety in developing countries have revealed the presence of different species of pathogens as well as favorable conditions to allow their proliferation. *Staphylococcus aureus* and *Salmonella* are the common foodborne pathogens associated with street foods in different parts of the world [3, 4, 8, 9]. This happens due to the use of nutritious ingredients in processing fast food [10], and is associated with contamination that has been directly introduced into the food by food handlers through coughing and sneezing [11].

Staphylococcus aureus, which is commonly present in the environment, coexists as a commensal organism within the human body and is a well-recognized zoonotic pathogen transmitted through food, often swiftly developing resistance to antimicrobial agents [7, 11]. It remains one of the primary bacteria implicated in human diseases [12]. As major bacterial culprits of food-borne illnesses globally [7]. *Staphylococcus aureus* is part of the normal skin microbiota in both animals and humans, with a carriage rate ranging from 20 to 30% in healthy individuals [13].

Risk analysis is used to estimate the risks to human health, identify and implement effective risk-control measures, and communicate with stakeholders about the risks and the implemented measures [10]. Microbiological risk assessment is a systematic method for determining and characterizing the risk of biological hazards in food [14]. It can be performed qualitatively, semi-quantitatively, or quantitatively [1]. Quantitative microbiological risk assessment (QMRA), which is one of the three components of the risk analysis process, is a scientific-based process consisting of four components; hazard identification, hazard characterization (dose-response), exposure assessment, and risk characterization which together provide numerical expressions of risk [12, 15, 16]. This holistic approach to food safety uses process risk models to simulate consumer exposure and response to pathogens that contaminate food produced by specific farm-to-table scenarios [17]. It is a relatively new scientific field that can approximate the impact of contaminated food on consumer health by connecting data on food-borne diseases and information on food production to consumption [15, 18].

There have been few studies on the safety and quality of Ethiopian street foods, with the majority of them focused on assessing hygienic practices and the isolation of pathogens and their susceptibility patterns to various antibiotic drugs [8, 19–24]. However, none of them have attempted to assess the risk of infection from the consumption of *Staphylococcus aureus* and *Salmonella* contaminated street foods. Hence, the purpose of this study was to assess the health risks to street food consumers from *S aureus* and *Salmonella* contaminated street food.

Materials and methods

Study design, study period, and settings

A Laboratory-based cross-sectional study design was used from December 2022 to February 2023 in four selected towns of Ethiopia, namely Addis Ababa, Dire Dawa, Hawassa, and Jimma.

Sample size determination and sampling procedure

The sample size was determined via the single population proportion formula by considering the 95% CI, corresponding to a standard score of 1.96, margin of error (d) 0.05, and 11.7% prevalence (P) of *Staphylococcus aureus* on street food [19] including a 10% non-response rate and the sample size was one hundred seventy five street food vending stalls. Proportional allocation of street food vendors to the number of population found in the selected cities was used, and stratified sampling was used to locate the vending stalls while a convenient sampling technique was used to select a person who consumes one of the street food items from the selected street food vending stall [25].

Bacteria culture and enumeration

Sample collection

The three selected food items from a single vending stall were collected aseptically, kept in labeled sterile polyethylene plastic bags on ice, and immediately transported to Hawassa, Jimma, Haramaya Universities, medical laboratory departments, and Ethiopian Public Health Institute Laboratories. On arrival, samples were registered, and given a unique code [25].

Media Preparation

Mannitol-salt agar (MSA), Nutrient agar, and Buffered Peptone water (BPW) all from Oxoid Ltd, England, were

prepared according to manufacturer's instructions, and sterilized by autoclaving at 121°C for 15 min.

Food sample processing

The food samples were prepared for analysis following the standard methods for isolation, and detection of bacteria from food samples as described by Moges et al. *(2024).*

Enumeration and Isolation of Staphylococcus aureus

Staphylococcus aureus was isolated and enumerated by the pour plate method via Mannitol-salt agar (MSA). After 24 h of incubation at 37°C, golden yellow colonies were counted and recorded as presumptive *Staphylococcus* species in CFU/g using the colony counter. Presumptive *Staphylococcus* species colonies on MSA were sub cultured onto freshly prepared nutrient agar plates and confirmed by Gram staining and coagulase tests with rabbit plasma. Colonies on mannitol salt agar that were Gram positive and coagulase-positive were taken as *Staphylococcus aureus* [26].

Enumeration and isolation of Salmonella

The bacteriological examination for *Salmonella* followed the food chain microbiology guidelines, specifically the horizontal method for detection, enumeration, and serotyping of *Salmonella*, as referenced by Gebeyehu et al. (2022). A 25 g of sample food were aseptically mixed with 225 ml of 0.1% buffered peptone water (OXOID, CM059) and incubated at 37 °C for 24 h. In the secondary enrichment phase, a 0.1 ml aliquot was transferred to 10 ml of Rappaport-Vassiliadis with soya (RVS) broth and incubated at 41.5 °C for 24 h. For the selective stage, 10 µl of the enriched sample was plated onto xylose lysine deoxycholate (XLD) agar and incubated at 35 °C for 24 h, after which the plates were examined for *Salmonella* colonies. Typical *Salmonella* colonies appear as pink with or without black centers on XLD agar. Three to five typical colonies were selected and streaked onto tryptone soya agar, then incubated at 37 °C for 18–24 h for further biochemical identification. The biochemical tests followed standard protocols, including indole, methyl red, urease, citrate utilization, triple sugar iron (TSI), lysine decarboxylase, and hydrogen sulfide production tests [4, 25, 27].

Microbial risk assessment

Risk assessment is a process that involves evaluating the health effects of foodborne pathogens, using quantitative or qualitative methods based on available resources and the background of involved parties [28]. For this study, the quantitative microbial risk assessment technique was used following WHO standards, which call for hazard characterization, hazard identification, exposure assessment, and risk characterization [29]. As described by [30] owing to the absence of full data and the multifaceted nature of processing and handling of food items throughout the food chain, it is sometimes possible to focus on the end product to conduct risk assessment. Hence, this research focuses only on processed ready-to-eat food items.

Hazard identification

It is the identification of biological, chemical, and physical agents capable of causing adverse health effects that may be present in a particular food or group of foods [29]. The indicator microorganisms for this research were *Staphylococcus aureus* and *Salmonella* as they are commonly found in street food samples from Ethiopia and other countries [8, 10, 19].

Staphylococcus aureus is one of the major pathogens related to outbreaks of foodborne illness [31]. This gram-positive, catalase, and coagulase-positive coccus can thrive across a wide range of pH values, temperatures, and water activities as low as 0.83 [12]. Due to its adaptability to these diverse conditions, *S. aureus* is commonly found in various foods, particularly ready-to-eat items, making them significant reservoirs of the bacteria. Additionally, S. aureus is a part of the normal skin microbiota in both animals and humans, with a carriage rate of 20 to 30% in healthy individuals [32]. Economically, *S. aureus* is considered one of the most impactful pathogens. It is associated with staphylococcal food poisoning, which typically results in a self-limiting but acutely intense illness. The pathogen is also capable of causing a broad spectrum of infections and foodborne diseases. Its presence in food is often linked to cross-contamination and poor handling practices during food preparation [15, 33].

Salmonella are motile, gram-negative bacilli that can infect or colonize humans. These bacteria produce hydrogen sulfide and are acid-labile, meaning that they are sensitive to acidic environments, and can live both inside and outside cells. *Salmonella* can cause cross-infections between humans and animals, leading to various clinical conditions such as gastroenteritis, enteric fever, bacteremia, and a chronic carrier state. Enteric fever is caused by specifically *Salmonella typhi* and *Salmonella paratyphi*, whereas other strains of *Salmonella* are referred to as non-typhoidal [27, 34, 35].

Exposure assessment

It is the qualitative or quantitative evaluation of the likely intake of biological agents via food and exposure from other sources if relevant [29]. The exposure scenarios were assessed as frequent consumption as consumed daily, average consumption once a week, and occasional consumption once in month [30]. The number of exposure days per year was taken as 365, 52, and 12 days for

frequent, average, and occasional consumers respectively. The average amount of selected food consumed per person per day was weighted, and the other inputs are shown in table one. The dose of the model organisms used for the dose-response assessment was obtained from the exposure assessment via the mathematical relationship [36].

d = q x W.

where: d = quantity of microorganisms consumed per serving,

q = quantity of microorganisms per gram of selected food item (CFU/g).

W = the weight of selected food item consumed per serving.

Hazard characterization (dose response assessment)

It is the qualitative or quantitative evaluation of the nature of the adverse health effects and hazards that may be present in food [29]. *S. aureus* bacteria are responsible for approximately 100,000 infectious disease cases, with an annual mortality rate of 20–30% in the United States and this pathogen has been the cause of 171 outbreaks of foodborne illness in the past decade in Korea [31, 37]. The intoxication dose of *S. aureus* is less than 1000 ng, a level that is reached when it exceeds 100,000 organisms/g in food, indicative of unsanitary conditions. In highly sensitive people, ingestion of 100–200 ng of enterotoxin can cause symptoms of staphylococcal food poisoning [38]. This results in minor skin infections such as boils and a range of food poisoning symptoms. These symptoms, which include nausea, sweating, dizziness, vomiting, hypothermia, stomach cramps, weakness, lethargy, and diarrhea, typically appear within six hours after ingesting contaminated food [11].

Typhoid fever is notably common in South Asia and sub-Saharan Africa, with incidence rates exceeding 100 per 100,000 people each year [34, 35]. In the European Union, *Salmonella* ranks as the second most frequent cause of gastrointestinal outbreaks. In France, *Salmonella* is responsible for nearly half of the 1,500 annual foodborne infections, primarily originating from poultry meat, while usually self-limiting, severe cases in immunocompromised individuals require antibiotics [35, 39]. The exponential dose-response model was used to assess the dose-response rate to predict the probability of *S. aureus* infection. Mathematically, the probability of infection for the exponential model used is given as: [36].

$P = 1 - e^{-r.d}$.

where: P is the probability of infection

d is the dose (CFU) of microorganisms consumed.

r is a dimensionless infectivity constant (the probability for one organism to successfully initiate an infection).

Table 1 Input parameters for quantitative microbial risk assessment, 2024 Ethiopia

Description	Unit	Value	Reference
Average quantity of *Salmonella spps.* per gram of *Sambussa*	CFU/g	6.4	Laboratory result
Average quantity of *S. aureus* per gram of *Sambussa*	CFU/g	3928	Laboratory result
Average quantity of *Salmonella spps.* per gram of *Bonbilino/Biscuit*	CFU/g	15.8	Laboratory result
Average quantity of *S. aureus* per gram of *Bonbilino /Biscuit*	CFU/g	11,126.5	Laboratory result
Average quantity of *Salmonella spps.* per gram of *Ambasha*	CFU/g	12.4	Laboratory result
Average quantity of *S.aureus* per gram of *Ambasha*	CFU/g	10,186.0	Laboratory result
Average weight of *Sambussa*	gm	182.3	Direct measurement
Average weight of *Bonbilino /Biscuit/Kokor*	gm	189.0	Direct measurement
Average weight of *Ambasha*	gm	268.9	Direct measurement
Average weight of the consumer	Kg	59.7	Direct measurement
infectivity constant for *S. aureus*	Unit less	7.64×10^{-8}	[10]
infectivity constant for *Salmonella* species	Unit less	3.97×10^{-6}	[40]

Risk characterization

It is a qualitative or quantitative estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse health effects in a given population on the basis of hazard identification, hazard characterization, and exposure assessment [29].

Risk in this case is defined as the likelihood of the occurrence of an illness and the likely magnitude of its consequences. The risk was assessed on the basis of the identified hazard concentration to which individuals were exposed. The annual probability was calculated using the number of exposure events per year. The annual exposures were analyzed as follows; frequent (365 days), 52 days average, and occasional 12 days. The risk was obtained via the following formula [36], and using the input parameters as described in Table 1.

$P_{(a)} = 1 - (1 - P_{(d)})^{n}$.

$P_{(a)}$ = the annual probability of infection per person per year.

$P_{(d)}$ = the daily probability of infection.

n = the annual exposure frequency (days).

Data collection

Socio-demographic data of the consumers were collected via an interviewer-administered questionnaire (attached as a supplementary file) and the identified food items were also purchased from each street food vendors. From a single vending stall *Sambussa*, *Bobolino*/*biscuit*, and

Ambasha were taken randomly for the analysis. All food samples were collected and stored in labeled sterile polyethylene plastic bags and kept in an icebox, after which they were immediately transported to Hawassa, Jimma, Haramaya Universities, medical laboratory departments, and Ethiopian Public Health Institute Laboratories. On arrival, samples were registered, given a special code, and stored at 4 °C until testing.

Data analysis

The data were entered into SPSS 25.0 for descriptive socio-economic status analysis. For microbial risk assessment, a deterministic quantitative microbial risk assessment was used.

Description of the food items

Sambussa also known as samosa, is a well-known snack in Ethiopia and many other countries around the world that is made up of wheat dough. The dough is prepared flatly and the other ingredients rolled in triangle shape within it and roasted in deep frying oil. The ingredients are wheat dough, salt, oil, chopped onions and red pepper, cooked rice, cooked lentils, *Sambussas* are typically deep-fried until they are golden brown and crispy on the outside, with a deliciously soft and flavorful filling on the inside. They commonly serve as appetizers, snacks, or street food and are enjoyed across Ethiopia and other parts of the world for their delicious taste and portable nature [8, 26, 41].

Table 2 Sociodemographic characteristics of the respondents, 2024, Ethiopia

Variable ($n=175$)	Frequency	Percent
Town		
Addis Ababa	139	79.4
Dire Dawa	12	6.9
Hawassa	15	8.6
Jimma	9	5.1
Types of food		
Sambussa	29	16.6
Kokor/ Biscuit/ Bonbolino	105	60.0
Ambasha	41	23.4
Sex		
Male	136	77.7
Female	39	22.3
Age (mean age is 31.2 ± 6)		
20–29	96	54.9
30–39	55	31.4
≥ 40	24	13.7
Educational status		
Illiterate	6	34
Primary (grade 1–8)	61	34.9
Secondary (grade 9–12)	74	42.3
Higher education	34	19.4
Occupation		
Government employee	63	36.0
Merchant	20	11.4
Farmer	7	4.0
Daily laborer	85	48.6
Frequency of consumption		
Every day	47	26.9
Once a week	92	52.6
Once a month	36	20.5

Bonbolino is a traditional Ethiopian dessert, also known as Ethiopian doughnuts. These delightful treats are typically made from a simple dough consisting of flour, yeast, sugar, and water. The dough is mixed until smooth and then allowed to rise before being shaped into small balls or rings. Once shaped, the dough is deep-fried until it becomes golden brown and crispy on the crust while remaining soft and fluffy on the crumb. Sometimes, after frying, *Bonbolinos* are often dusted with powdered sugar for added sweetness [26, 41].

Ambasha is a well-known Ethiopian traditional flat bread. The fermented wheat dough is shaped into a round, flat disc and baked on a hot plate until it has a golden brown and cooked through. The texture of *Ambasha* is soft and fluffy on the crumb and crust. It is eaten either solely or together with other stews. Besides it can be eaten at any time of the day as a breakfast, lunch, or dinner. It is made up of wheat dough, salt, baking powder, yeast, oil, and small sugar [8, 26].

Results

Sociodemographic characteristics of the respondents

This study involved a total of 175 street food consumers from four Ethiopian towns: Addis Ababa, Dire Dawa, Hawassa, and Jimma. The majority of the respondents were males aged 20 to 29 years. The frequency of street food consumption among these consumers was categorized into three groups: daily or frequent (26.9%), weekly or average (52.6%), and monthly or occasional (20.5%), as shown in Table 2.

Prevalence of *S. aureus*

The mean prevalence of *S. aureus* in this study was 43.4% with the highest occurrence in *Ambasha*. The highest count was 4.88×10^5 CFU/g which was observed in *Bonbolino*. The mean prevalence of *Salmonella* species was 25.7% and the highest count was 4.2×10^2 CFU/g. The highest prevalence of *Salmonella* was observed in *Bonbolino*. As shown in Table 3.

Microbial risk assessment

The probability of infection from *S. aureus* was higher than that of *Salmonella* among street food consumers. Frequent and average consumers of *Ambasha* were at

Table 3 *S. aureus* and *Salmonella* loads of sampled ready-to-eat foods, 2024 Ethiopia

Street food type	Microbial load (CFU/g)					
	S. aureus			Salmonella		
	Mean Prevalence	range	mean	Mean Prevalence	range	mean
Sambussa	40%	$0–1.14\times10^5$	7.6×10^3	20.7%	0–84	6.6
Bonbolino	41.5%	$0–4.88\times10^5$	1.1×10^4	29.5%	0–420	15.9
Ambasha	53.7%	$0–9.80\times10^4$	1.0×10^4	5.9%	0–254	12.4
Total prevalence	43.4%.			25.7%.		

Table 4 *S. aureus* and *Salmonella* exposure assessment of the respondents, 2024 Ethiopia

Type of food items	S. aureus					Salmonella				
	d	*P*(d)	*P*(ann.)			d	*P*(d)	*P*(ann.)		
	CFU/gm	$1\text{-}e^{-rd}$	$1\text{-}(1\text{-}p(d))^n$			CFU/gm	$1\text{-}e^{-rd}$	$1\text{-}(1\text{-}p(d))^n$		
			$n=365$	$n=52$	$n=12$			$n=365$	$n=52$	$n=12$
Sambussa	7.1×10^5	0.41	1	1	0.99	1164.8	0.04	0.81	0.21	0.05
Bonbolino	2.1×10^6	0.14	1	0.99	0.95	2986.2	0.01	0.98	0.46	0.13
Ambasha	2.7×10^6	0.18	1	0.99	0.85	3335.6	0.01	0.99	0.49	0.14

d = quantity of microorganisms consumed per serving, P(d) = probability of infection at dose d; P(ann) = annual probability of infection due to exposure

Table 5 *S. aureus* and *Salmonella* loads of the sample food, 2024 Ethiopia

S. aureus		Salmonella	
Satisfactory $<10^4$CFU/g	Unsatisfactory $\geq 10^4$ CFU/g	Not detected	Detected
118 (67.4%)	57(32.6%)	130 (74.3%)	45 (25.7%)

a slightly higher risk of infection for both *S. aureus* and *Salmonella*. The mean annual risk of *S. aureus* infection of consumers was 100%, 99.3%, and 93% for frequent, average, and occasional consumers respectively as it is shown in Table 4.

The mean annual risk of *S. aureus* infection was 100% for all three ready-to-eat food items. The mean annual risk of *Salmonella* infection was higher in frequent consumers of *Ambasha* than *Bonbolino* and *Sambussa*.

As shown in Tables 5, 32.6% of the sampled ready-to-eat foods were contaminated with *S. aureus* with a count greater than 10^4 CFU/g and were unfit for consumption whereas 25.7% were contaminated with *Salmonella* and unfit for consumption.

Discussion

Foodborne diseases remain a global challenge for public health and economic development, with cases rising worldwide [42]. The prevalence of *S. aureus* in the examined samples in this study was 43.4%. This prevalence was lower than reported in studies performed in different towns of Ethiopia and worldwide. 61% in the world [43], 53.9% [26] in Gondar, 64.4% [8] in Jigjiga, 53.7% [41] in Gondar. This finding was higher than those of studies conducted in Hawassa 9.9% [24], in Arbaminch 31, 9.4% [22], and in Gondar town 35.5% [23], in Iran, Theran 15.4% [37]. This variation could be due to differences in water activity (aw), pH values, and the type of sampled food, as *S. aureus* can grow under various conditions [42]. The use of low-quality, contaminated raw ingredients might also contribute to the high bacterial prevalence in ready-to-eat food [44]. Additionally, transmission might be from infected staff via respiratory passages, skin, and superficial wounds [37, 45] in preparation for smoky fires, and storing food at room temperature for 1–3 h before consumption could lead to contamination and pathogen proliferation [43].

The findings of this study also revealed that the prevalence of *Salmonella* species in the sampled ready-to-eat food items was 25.7%. This percentage was higher than that reported in studies conducted in Hawassa 12.7% [24], Jigjiga 19.7% [8], and Johannesburg 21.8% [46], whereas it was lower than that reported in studies conducted in Gondar 38% [41], and Bahirdar 57.5% [47]. This variation might be due to cross-contamination through the use of contaminated vegetables that are improperly cleaned, the type of sampled food items and environmental factors which might include exposure of the foods to air, the type of water used, the utensils used in the preparation and the personal hygiene of the vendors [45, 48].

The study revealed that the prevalence of *S. aureus* in *Ambasha* was higher than that in *Bonbolino* and *Sambussa*. This finding corroborates the findings of [49], who reported that *Sambussa* had a lower prevalence of *S. aureus* than *Ambasha* and *Bonbolino*. Whereas, a study in Gondar reported the highest incidence of *S. aureus* (66.7%) in *Bonbolino* [41], and a study in Jigjiga reported that the highest incidence (69%) in *Sambussa* [8]. The lower prevalence in *Sambussa* and *Bonbolino* observed in this study could be due to their preparation process, involving frying in boiled oil, and the presence of more oil on the surface of the food items may inhibit

bacterial growth than *Ambasha* does [50]. The presence of *S. aureus* indicates contamination from the skin, mouth, or nose of food handlers through coughing and sneezing, often introduced during handling, processing, or vending [41, 51]. In addition, this might be due to the reuse of improperly washed dishes, open-air distribution, and improperly held temperatures during distribution. Moreover, street foods, which are frequently displayed and sold in unsanitary conditions by the roadside, can be easily contaminated by dust, insects, and consumers' hands [52]. *S. aureus* is a commensal and opportunistic pathogen capable of causing numerous illnesses due to its toxin-mediated pathogenicity, invasiveness, and antimicrobial resistance [11].

Concerning *Salmonella*, the findings of this study revealed that more *Salmonella* species were isolated from *Bonbolino* than from *Sambussa* and *Ambasha*. This finding aligns with another in Gondar town, where the highest incidence of *Salmonella* (16.9%) was observed in *Bonbolino* [23], the differences between our results and those reported elsewhere could also be due to factors like sample source, and geographical origin [52].

The mean difference in *S aureus* and *Salmonella* among the three street food items was not statistically significant ($p > 0.05$) but significant differences were observed in individual food items among the four cities.

In this study, Quantitative Microbiological Risk Assessment (QMRA), which provides information on pathogen presence and growth to aid food safety decisions [15, 16]was used to estimate the risk of unsafe food on consumers. QMRA requires extensive data, and assumptions are made when data are unavailable [53] and uses deterministic and stochastic model [18]. For this study, a deterministic approach was used to estimate the risk. Variables were assigned fixed values, such as means or maximums, and the risk level was calculated using the consumption rate, pathogen dose, and food item weight, then categorized based on the results [54, 55].

In this study, 57 (32.6%) of the sampled ready-to-eat food items contained *S.s aureus* counts of $> 10^4$ and in 45 (25.7%) of the samples *Salmonella* was detected in which these counts were higher than the recommended reference value of the International Commission for Microbiological Specifications for ready-to-eat foods Center for Food Safety (2014). Microbial safety standards for ready to eat foods have been taken from international regulations, like the public health laboratory service guidelines for the microbiological quality of ready to eat foods [56], and the New South Wales (NSW) Food Authority microbiological quality guide for ready-to-eat foods [57]. This study result is similar to that of studies conducted in different developing countries [12, 45, 58].

The findings of this study revealed that consumers who frequently consumed street food were more likely to be infected by both *S. aureus* and *Salmonella* than those who consumed street foods on average or occasionally. Moreover, *S aureus* infection was more prevalent than *Salmonella* infection. This finding corroborates a study conducted by [10]. This might be due to the increase in the dose of the microorganisms. As the dose of the microorganism increases, the probability of infection increases [59]. The mean annual risk of frequent (daily) consumption by *S aureus* infection was similar for all three ready-to-eat food items at 100% of risk of infection. This result is similar to that of the study conducted by [49] where *S aureus* infection was similar for all three consumption frequencies that is daily, weekly, and monthly. The result of this study also revealed that the annual risk of *Salmonella* infection for frequent, average, or occasional consumers was approximately 92.6%, 38.7%, and 10.7%, respectively. *S aureus* and *Salmonella* are among the most common bacteria that cause food borne diseases. The presence of these organisms in ready-to-eat food depicts a deplorable state of poor hygiene and sanitary practices employed in the processing of this food product [60].

According to the public health laboratory service guidelines for the microbiological quality of ready-to-eat street foods and cited by [56], street foods are safe and fit for consumption, if the plate count is $< 10^4$ CFU/g. In this research, *S.aureus* load of some of the food samples was higher than the amount stipulated; hence, their presence above the stipulated amount constituted a health risk. Some of the street food retailed on the roads and streets of the selected towns in Ethiopia, as obtained in this study is not bacteriologically fit for consumption.

Conclusion

This study underscores the significant public health risks posed by foodborne pathogens, particularly *S aureus* and *Salmonella*, in ready-to-eat street foods. The prevalence of these pathogens varies widely across different locations and food types and is, influenced by factors such as food handling practices, environmental conditions, and hygiene standards. The high levels of contamination found in some samples exceeded international street food safety guidelines, indicating poor sanitary practices and potential health risks for consumers. The deterministic quantitative microbiological risk assessment highlighted that frequent consumers of street foods face a high risk of infection, with *S aureus* being more prevalent than *Salmonella*. Overall, these findings call for improved hygiene practices and stricter regulatory measures to ensure the microbiological safety of street foods in Ethiopia. In addition, the respective towns' health and regulatory offices should implement strict monitoring strategies to minimize the risk of contamination of street foods. Moreover, policymakers, public health authorities,

and food vendors can work collaboratively to mitigate the risks associated with foodborne pathogens in street food, enhancing public health and consumer confidence.

Limitations

The use of the deterministic quantitative microbial risk assessment approach to estimate the risk of infection from microbial contaminants in street food in this study relies on fixed values and does not account for variability or randomness in factors such as pathogen concentration and environmental conditions. It assumes specific conditions and inputs, such as the mean pathogen levels, average consumption rates, and typical food handling practices, to calculate the risk of infection. This method provides straightforward risk estimates that are easy to interpret but may overlook the inherent variability in real-world scenarios. Moreover, *S. aureus* bacteria isolated in this study were not further characterized for presence of enterotoxins thus it is possible that the risk of staphylococcal food poisoning may be overestimated.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12879-025-10977-5.

Supplementary Material 1

Acknowledgements

The authors would like to acknowledge, Jimma University, NORPART EXCELL SMART Project, UiO, Oslo Norway and CIH LMU One Health Center for International Health, University Hospital, LMU Munich, Germany for giving scholarship to write the article in Oslo, Norway, and University of Oslo, College of health and society. Moreover Oslo metropolitan University Oslo, Norway to let me to have an office while I am writing this article, Addis Ababa, Dire Dawa, Hawassa and Jimma towns administration offices for facilitating data collection process, Haramaya, Hawassa, and Jimma University laboratory departments and Ethiopian public health institute food and nutrition department microbiology laboratory unit for letting me to conduct laboratory analysis. Professor Jeanette H. Magnus, and Professor Dawit Shawel giving direction and technical advice, Mrs. Ester Mæland for supporting and guiding me in all aspects while I was in Oslo, Data collectors and all street food vendors who were participated in our study. People who are directly or indirectly encouraged us while doing this study.

Author contributions

MM: conceptualization, methodology, validation, formal analysis, investigation, data curation, writing original draft preparation. AA: conceptualization, methodology validation writing, review and editing, and supervision. EKR: Designed the study, reviewed the draft manuscript, and edited the manuscript. All authors reviewed the manuscripts and agreed to the published version.

Funding

Jimma University covered the cost of data collectors.

Data availability

Data is provided within the manuscript.

Declarations

Ethics approval and consent to participate

This study was conducted in agreement with the Declaration of Helsinki, the Ethical principle for medical research involving human subjects. Jimma University's institutional review board has provided ethical clearance (JUIH/IRB/201/22) and Informed consent was obtained from all subjects involved in the study.

Consent for publication

It is not applicable.

Competing interests

The authors declare no competing interests.

Received: 23 August 2024 / Accepted: 15 April 2025
Published online: 22 April 2025

References

1. WHO. Risk Assessment Outputs to Develop Practical Risk Management Strategies: 2006.
2. Kharel N, Palni U, Tamang JP. Microbiological assessment of ethnic street foods of the Himalayas. J Ethn Foods [Internet]. 2016;3(3):235–41. Available from: https://doi.org/10.1016/j.jef.2016.01.001
3. Paul TK, Roy SR, Sarkar PR, Tarafder M, Saha TK. Isolation and identification of bacteria in different street vended foods collected from selected areas of Bangladesh. Asian-Australasian J Food Saf Secur. 2018;2(2):65–70.
4. Birgen BJ, Njue LG, Kaindi DM, Ogutu FO, Owade JO. Determinants of Microbial Contamination of Street-Vended Chicken Products Sold in Nairobi County, Kenya. Int J Food Sci. 2020;2020.
5. Donkor ES, Kayang BB, Quaye J, Akyeh ML. Application of the WHO keys of safer food to improve food handling practices of food vendors in a poor resource community in Ghana. Int J Environ Res Public Health [Internet]. 2009 [cited 2023 May 11];6(11):2833–42. Available from: https://pubmed.ncbi.nlm.nih.gov/20049228/
6. Chauhan N, Uniyal V, Singh Rawat D. Microbial profiling of street foods of different locations at Dehradun city, India [Internet]. Vol. 4, Int.J.Curr.Microbiol. App.Sci. 2015. Available from: http://www.ijcmas.com
7. Esemu SN, Njoh ST, Ndip LM, Keneh NK, Kfusi JA, Njukeng AP. Ready-to-Eat Foods: A Potential Vehicle for the Spread of Coagulase-Positive Staphylococci and Antimicrobial-Resistant Staphylococcus aureus in Buea Municipality, South West Cameroon. Can J Infect Dis Med Microbiol. 2023;2023.
8. Bereda TW, Emerie YM, Reta MA, Asfaw HS. Microbiological safety of street vended foods in Jigjiga City, Eastern Ethiopia. Ethiop J Health Sci. 2016;26(2):161–70.
9. Paiva De Sousa C. The impact of food manufacturing practices on food borne diseases. Brazilian Arch Biol Technol. 2008;51(4):815–23.
10. Sabuj AAM, Haque ZF, Younus MI, Pondit A, Barua N, Hossain MG, et al. Microbial risk assessment of ready-to-eat fast foods from different street-vended restaurants. Int J One Heal. 2020;6(1):41–8.
11. Odetokun IA, Adetona MA, Ade-Yusuf RO, Adewoye AO, Ahmed AN, Ghali-Mohammed I, et al. S Taphylococcus aureus contamination of animal-derived foods in Nigeria: a systematic review, 2002–2022. Food Saf Risk. 2023;10(1):1–18.
12. Nunes MM, Caldas ED. Preliminary Quantitative Microbial Risk Assessment for Staphylococcus enterotoxins in fresh Minas cheese, a popular food in Brazil. Food Control [Internet]. 2017;73:524–31. Available from: https://doi.org/10.1016/j.foodcont.2016.08.046
13. Ahmad-Mansour N, Loubet P, Pouget C, Dunyach-Remy C, Sotto A, Lavigne JP, et al. Staphylococcus aureus toxins: an update on their pathogenic properties and potential treatments. Toxins (Basel). 2021;13(10):1–22.
14. Khalid T, Hdaifeh A, Federighi M, Cummins E. Review of Quantitative Microbial Risk Assessment in Poultry Meat: The Central Position of. 2020.
15. Imathiu S. Quantitative Microbiological risk assessment of two street foods sold in a Kenyan town with regard to Salmonella contamination. Curr Res Nutr Food Sci. 2018;6(1):41–50.
16. Rho MJ, Schaffner DW. Microbial risk assessment of Staphylococcal food poisoning in Korean kimbab. Int J Food Microbiol. 2007;116(3):332–8.
17. Oscar TP. Monte carlo simulation model for predicting salmonella contamination of chicken liver as a function of serving size for use in quantitative

microbial risk assessment. J Food Prot [Internet]. 2021;84(10):1824–35. Available from: https://doi.org/10.4315/JFP-21-018
18. Tesson V, Federighi M, Cummins E, Mota J, de O, Guillou S, Boué G. A systematic review of beef meat quantitative microbial risk assessment models. Int J Environ Res Public Health. 2020;17(3).
19. Tesfaye M. Bacteriological quality of street vended ready to eat legume and vegetable based foods in Bahir Dar, Amhara regional State, North Western Ethiopia. Int J Res Agric Food Sci. 2019;5(8):1–23.
20. Azanaw J, Gebrehiwot M, Dagne H. Factors associated with food safety practices among food handlers: facility-based cross-sectional study. BMC Res Notes [Internet]. 2019 Oct 22 [cited 2023 May 11];12(1). Available from: https://pubmed.ncbi.nlm.nih.gov/31640793/
21. Werkneh AA, Tewelde MA, Gebrehiwet TA, Islam MA, Belew MT. Food safety knowledge, attitude and practices of street food vendors and associated factors in Mekelle city, Northern Ethiopia. Heliyon [Internet]. 2023 Apr 1 [cited 2023 May 12];9(4):e15126. Available from: https://doi.org/10.1016/j.heliyon.2023.e15126
22. Alelign D, Yihune M, Bekele M, Oumer Y, Beyene K, Atnafu K. Bacteriological quality and antimicrobial resistant patterns of foodborne pathogens isolated from commonly vended street foods in Arba minch town, Southern Ethiopia. Infect Drug Resist. 2023;16(May):2883–99.
23. Guadu T, Adimasu A, Mekonnen B, Gizaw Z, Adane T. Bacteriological quality assessment of selected street foods and their public health importance in Gondar town, North West Ethiopia. Glob Vet. 2016;17(3):255–64.
24. Eromo T, Tassew H, Daka D, Kibru G. Bacteriological quality of street foods and antimicrobial resistance of isolates in Hawassa, Ethiopia. Ethiop J Health Sci. 2016;26(6):533–42.
25. Moges M, Rodland EK, Legesse T, Argaw A. Antibiotic resistance patterns of Staphylococcus aureus and Enterobacteriaceae isolated from street foods in selected towns of Ethiopia. BMC Infect Dis. 2024;24(1):1–9.
26. Amare A, Worku T, Ashagirie B, Adugna M, Getaneh A, Dagnew M. Bacteriological profile, antimicrobial susceptibility patterns of the isolates among street vended foods and hygienic practice of vendors in Gondar town, Northwest Ethiopia: A cross sectional study. BMC Microbiol. 2019;19(1):1–9.
27. Gebeyehu A, Taye M, Abebe R. Isolation, molecular detection and antimicrobial susceptibility profile of Salmonella from Raw cow milk collected from dairy farms and households in Southern Ethiopia. BMC Microbiol. 2022;22(1):1–10.
28. Sant'Ana AS, Franco BDGM. Microbial risk analysis. Encycl Food Microbiol Second Ed. 2014;(March):607–13.
29. WHO/FAO. Draft guidance of Microbiological risk assessment for food. 2020;(July).
30. Mataragas M, Zwietering MH, Skandamis PN, Drosinos EH. Quantitative microbiological risk assessment as a tool to obtain useful information for risk managers - Specific application to Listeria monocytogenes and ready-to-eat meat products. Int J Food Microbiol [Internet]. 2010;141(SUPPL.):S170–9. Available from: https://doi.org/10.1016/j.ijfoodmicro.2010.01.005
31. Lee H, Kim K, Choi KH, Yoon Y. Quantitative microbial risk assessment for Staphylococcus aureus in natural and processed cheese in Korea. J Dairy Sci [Internet]. 2015;98(9):5931–45. Available from: https://doi.org/10.3168/jds.2015-9611
32. Hanselman BA, Kruth SA, Rousseau J, Weese JS. Coagulase positive Staphylococcal colonization of humans and their household pets. Can Vet J. 2009;50(9):954–8.
33. Liao F, Gu W, Yang Z, Mo Z, Fan L, Guo Y, et al. Molecular characteristics of Staphylococcus aureus isolates from food surveillance in Southwest China. BMC Microbiol. 2018;18(1):1–9.
34. Noguer NP. Detection of Salmonella in food matrices, from. Foods. 2019;8(371):1–36.
35. Gunasegaran T, Rathinam X, Kasi M, Sathasivam K, Sreenivasan S, Subramaniam S. Isolation and identification of Salmonella from curry samples and its sensitivity to commercial antibiotics and aqueous extracts of Camelia sinensis (L.) and Trachyspermum ammi (L). Asian Pac J Trop Biomed. 2011;1(4):266–9.
36. Haas CN, Rycroft T, Bibby K, Casson L. Risks from ebolavirus discharge from hospitals to sewer workers. Water Environ Res. 2017;89(4):357–68.
37. Mesbah A, Mashak Z, Abdolmaleki Z. A survey of prevalence and phenotypic and genotypic assessment of antibiotic resistance in Staphylococcus aureus bacteria isolated from ready-to-eat food samples collected from Tehran Province, Iran. Trop Med Health [Internet]. 2021;49(1). Available from: https://doi.org/10.1186/s41182-021-00366-4
38. FDA. Bad bug book, foodborne pathogenic microorganisms and natural toxins. Second 2012. 846–51 p.
39. Ashrafudoulla M, Na KW, Byun KH, Kim DH, Yoon JW, Mizan MFR et al. Isolation and characterization of Salmonella spp. from food and food contact surfaces in a chicken processing factory. Poult Sci [Internet]. 2021;100(8):101234. Available from: https://doi.org/10.1016/j.psj.2021.101234
40. Havelaar AH, Kirk MD, Torgerson PR, Gibb HJ, Hald T, Lake RJ, et al. World health organization global estimates and regional comparisons of the burden of foodborne disease in 2010. PLoS Med. 2015;12(12):1–23.
41. Endris M, Derbew G, Sahle S. Bacteriological Assessment of Some Street Vended Foods in Gondar, Ethiopia. Internet J Food Saf [Internet]. 2013;15(June):33–8. Available from: https://www.researchgate.net/publication/258553377
42. Zeaki N, Johler S, Skandamis PN, Schelin J. The role of regulatory mechanisms and environmental parameters in Staphylococcal food poisoning and resulting challenges to risk assessment. Front Microbiol. 2019;10(JUN):1–13.
43. Taulo S, Wetlesen A, Abrahamsen R, Kululanga G, Mkakosya R, Grimason A. Microbiological hazard identification and exposure assessment of food prepared and served in rural households of Lungwena, Malawi. Int J Food Microbiol. 2008;125(2):111–6.
44. Mahros MA, Abd-Elghany SM, Sallam KI. Multidrug-, methicillin-, and vancomycin-resistant Staphylococcus aureus isolated from ready-to-eat meat sandwiches: An ongoing food and public health concern. Int J Food Microbiol [Internet]. 2021;346(February):109165. Available from: https://doi.org/10.1016/j.ijfoodmicro.2021.109165
45. Henry P, Edward MJ, Ogbonna OE, Emmanuel IC. Microbiological assessment of some cooked ready-to-eat street foods sold in Calabar and its environs. J Food Secur. 2017;5(3):100–6.
46. Asiegbu CV, Lebelo SL, Tabit FT. Microbial quality of ready-to-eat street vended food groups sold in the Johannesburg Metropolis, South Africa. J Food Qual Hazards Control. 2020;7(1):18–26.
47. Kibret M, Tadesse M. The bacteriological safety and antimicrobial susceptibility of bacteria isolated from street-vended white lupin (Lupinus albus) in Bahir Dar, Ethiopia. Ethiop J Health Sci. 2013;23(1):19–26.
48. Sudershan RV, Naveen Kumar R, Kashinath L, Bhaskar V, Polasa K. Microbiological hazard identification and exposure assessment of poultry products sold in various localities of Hyderabad, India. Sci World J. 2012;2012.
49. Sabuj AAM, Haque ZF, Barua N, Islam MA, Saha S. Assessment of bacteriological quality of street vended fast foods and their antimicrobial resistance. Int J Curr Microbiol Appl Sci. 2018;7(11):3049–59.
50. Mahmud N, Islam J, Oyom W, Adrah K, Adegoke SC, Tahergorabi R. A review of different frying oils and oleogels as alternative frying media for fat-uptake reduction in deep-fat fried foods. Heliyon [Internet]. 2023;9(11):e21500. Available from: https://doi.org/10.1016/j.heliyon.2023.e21500
51. Madueke SN, Awe S, Jonah AI. Microbiological analysis of street foods along Lokoja- Abuja express way, Lokoja. Am J Res Commun. 2014;2(1):196–211.
52. Sina H, Baba-Moussa F, Kayodé A, Noumavo P, Sezan A, Hounhouigan J et al. Characterization of Staphylococcus aureus isolated fromstreet foods: Toxin profile and prevalence of antibioticresistance. J Appl Biosci [Internet]. 2011;(September):3133–43. Available from: http://www.sfm.asso.fr/
53. Delhalle L, Saegerman C, Messens W, Farnir F, Korsak N, Van Der Stede Y, et al. Assessing interventions by quantitative risk assessment tools to reduce the risk of human salmonellosis from fresh minced pork meat in Belgium. J Food Prot. 2009;72(11):2252–63.
54. McKinlay R, Plant JA, Bell JNB, Voulvoulis N. Calculating human exposure to endocrine disrupting pesticides via agricultural and non-agricultural exposure routes. Sci Total Environ. 2008;398(1–3):1–12.
55. Kammoun R, McQuaid N, Lessard V, Prévost M, Bichai F, Dorner S. Comparative study of deterministic and probabilistic assessments of microbial risk associated with combined sewer overflows upstream of drinking water intakes. Environ Challenges. 2023;12(May).
56. Gilbert R, Louvois J, Donovan T, Little C, Nye K, Ribeiro C, et al. Guidelines for the Microbiological quality of some ready-to-eat foods sampled at the point of sale. Commun Dis Public Health. 2000;3(3):163–7.
57. NSW. Microbiological quality guide for ready-to-eat foods. A guide to interpreting Microbiological results. NSW Food Auth. 2009;(July):1–9.
58. Mesfin A, Mulugeta K. BA. Microbiological quality and safety of Sambusa and fried fish in Bahir Dar, Microbiological quality and safety of Sambusa and fried fish in. 2021;(March):96–108.
59. Buchanan RL, Havelaar AH, Smith MA, Whiting RC, Julien E. The key events dose-response framework: its potential for application to foodborne pathogenic microorganisms. Crit Rev Food Sci Nutr. 2009;49(8):718–28.

60. Khater FD, Heikal EG, Shehata AA, El-Hofy IF. The Microbiological assessment of ready-to-eat-food (liver and Kofta sandwiches) in Tanta City. Egypt. 2013;25(2):187–97.

Publisher's note