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Assessment of Food Safety Knowledge, Hygiene Practices, and Microbial Contamination Risks Among Street Food Vendors in Urban Areas of Pakistan

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Abstract

Street-vended foods provide affordable meals in Pakistan; however, inadequate hygiene, poor sanitation, and microbial contamination present significant public health challenges. To evaluate knowledge about food safety, hygienic practices, prevalence of microbial contamination and antimicrobial resistance amongst urban street food vendors. Methods: A cross-sectional study was conducted on 300 street food vendors from 5 major cities in Pakistan. Knowledge about food safety and hygienic practices was measured through structured questionnaires. Microbiological tests were performed on 300 food samples, 150 environmental swabs and antimicrobial susceptibility performed on 120 bacterial isolates. Results: The average score achieved by participants for food safety knowledge was 14.2 ± 5.1. There were a high percentage of individuals with poor knowledge (42.0%). 51.0% of vendors did not follow adequate hygienic practices. Only 36.0% washed their hands appropriately and 65.7% did not have adequate refrigeration. Microbial contamination was present in 61.7% of food samples. This included Staphylococcus aureus (32.0%), Escherichia coli (26.0%), Bacillus cereus (23.0%) and Salmonella spp. (11.0%). Meat products (76.7%) and fresh salads (75.0%) exhibited the highest contamination frequencies. Pollution of the environment was observed in 59.3% of swabs and multidrug resistance was found in 35.0% of bacterial isolates. These findings emphasize the need for better food safety education, sanitation infrastructure, hygiene monitoring and microbiological surveillance to reduce the risks of foodborne illness.

1. Introduction

Food safety represents a major global public health challenge, particularly in low- and middle-income countries where rapid urbanization, inadequate sanitation, and limited regulatory enforcement contribute to foodborne disease transmission(Hassan, Khan, & Farooq, 2022; Raza *et al*., 2021). According to updated World Health Organization estimates, approximately 866 million individuals experience foodborne illnesses annually, resulting in 1.52 million deaths worldwide, while the associated economic burden

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reaches approximately USD 310 billion in productivity losses and medical expenses (Kanwal, 2022). Children under the age of five years are estimated to contribute approximately 29% of the global foodborne disease burden, which indicates the disproportionality of vulnerability among younger populations (Javed *et al*., 2023; Rehman *et al*., 2023). Street-vended foods have an important role in urban food systems as they are affordable, accessible and contribute to informal employment. Nevertheless, food preparation under poorly controlled environmental conditions, inadequate refrigeration, unsafe water supplies, and repeated handling substantially increases the likelihood of microbial contamination (Aziz, Zahoor, *et al*., 2022; Khadija, Tara, Javed, & Adeel, 2025; Meghwar, Kumar, Dhanker, & Kumar, 2020). Street food vending is a major source of income in Pakistan and helps provide affordable ready-to-eat meals to urban residents. But it's hard to protect consumers because food safety training is hard to get, infrastructure isn't good enough and hygiene practices are not always followed. (Hussain & Hussain, 2024; Saifullah *et al*., 2026). A cross-sectional investigation involving 202 food handlers in Lahore revealed that 67.8% had never received formal or informal food safety training, whereas only 5.9% had obtained professional certification(Verma, Patel, Shikha, & Mishra, 2023). Moreover, only 57.9% indicated that they always washed their hands before food preparation or serving, 49.5% were aware of the need to wash utensils before food preparation, and 72.8% indicated inappropriate thawing practices. The findings reveal significant gaps between basic awareness and consistent application of preventive food safety measures. (Ahmad *et al*., 2021; Aziz, Ahmad, *et al*., 2022; Hayat *et al*., 2026). The microbiological safety of foods sold on the street is particularly alarming because of the possibility of contamination at various stages, such as ingredient sourcing, transit, preparation, storage and serving (Abid *et al*., 2022; Osman, Moges[1], & Ayanaw[1], 2025). Escherichia coli, *Salmonella spp., Staphylococcus aureus, Bacillus cereus* and *Listeria monocytogenes* are important foodborne microorganisms that can cause serious complications, food poisoning and gastrointestinal infections in susceptible people (Tabassum *et al*., 2025). A Pakistani investigation involving 300 university canteen food handlers reported approximately 60% correct responses to food safety knowledge questions, while microbiological examinations identified S. aureus in 57%, E. coli in 35%, and Salmonella spp. in 29% of the examined food samples (Ali, Ahmad, Asif, Amir, & Ali, 2022; Werkneh, Tewelde, Gebrehiwet, Islam, & Belew, 2023). Although these findings originated from institutional canteens rather than street stalls, they provide important evidence of contamination risks associated with inadequately controlled food-handling environments (Ali *et al*., 2022). Additional evidence from a Lahore-based assessment involving 100 street food vendors revealed that 89% lacked appropriate hygienic clothing or personal hygiene standards, 71% did not wash their hands before food preparation, and only 27% maintained adequately clean vending environments. Moreover, only 19% obtained raw ingredients from reliable sources, while 18% reported using separate utensils for raw and ready-to-eat foods(Rifat, Talukdar, Lamichhane, Atarodi, & Alam, 2022) (Kanwal, 2022). These observations suggest that deficiencies in personal hygiene, cross-contamination prevention, and environmental sanitation may collectively increase microbial exposure. Importantly, food safety knowledge does not necessarily translate into safer handling practices, emphasizing the need to evaluate knowledge, observable behavior, and microbial contamination simultaneously (Crocker, 2020). In Pakistan, although there is growing awareness regarding foodborne hazards, many of the existing studies are focused on microbiological quality, reported hygiene practices or knowledge of food handlers in isolation. Evidence that links these dimensions across contexts of urban street vending is relatively scarce and integrated. The present study aims to assess the awareness, hygiene practices and microbial contamination risks of street food vendors in urban areas of Pakistan. The study will also explore the association of vendor characteristics with food handling behaviours, sanitary conditions and possible contamination pathways. The findings are anticipated to offer an evidence-based foundation for targeted food safety training, enhanced hygiene oversight and risk-based regulatory actions to improve consumer protection.

2. Materials and Methods

2.1 Study design and study area

A cross-sectional study was conducted to assess the food safety knowledge, hygiene practices and potential microbial contamination of street food vendors from the cities of Pakistan. The study was designed to cover five big cities (Karachi, Lahore, Islamabad, Rawalpindi and Peshawar).

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These cities are representative of a wide range of environmental and socioeconomic conditions. The study examined places where food is sold by street vendors, such as commercial markets, roadside stands, schools and public transportation hubs. It was suggested that a mixture of questionnaires, direct observations and laboratory-based microbiological tests should be employed to obtain a full view of food safety conditions.

2.2 Study population and sampling strategy

The study population consisted of street food vendors involved in the preparation, handling, storage, and sale of ready-to-eat foods. A total of 300 vendors were proposed for inclusion, with approximately 60 participants selected from each of the five study cities. A multistage sampling approach was planned to identify suitable vending locations and recruit eligible vendors from the selected areas. Participants were required to be at least 18 years of age and to have at least three months of experience in food handling. Vendors who declined to participate or sold only factory-sealed packaged foods were excluded from the study.

2.3 Development and validation of the questionnaire

A structured questionnaire came from the World Health Organization food safety rules and standard assessment frameworks. It covers demographics, education, food safety training, personal hygiene, storage, cross-contamination, and foodborne disease awareness. Experts in microbiology, epidemiology, and food safety checked the content validity. After that, they ran a pilot test with about thirty vendors outside the main sample. They checked internal consistency for multi-item scales using Cronbach's alpha, looking for values of 0.70 or higher to make sure everything was acceptable before moving forward with the actual study.

2.4 Assessment of food safety knowledge

The analysis of food safety knowledge was performed on a proposed 25-item questionnaire on the following food safety aspects: food borne pathogens, hand hygiene, cooking temperatures, food storage, sanitation and prevention of cross contamination. One point for each correct, zero points for any incorrect or uncertain response, with a maximum knowledge score of 25. Scores were retransformed to percentages and assigned to poor (less than 50%), moderate (50 to 74%) and good (75% or higher) based on the operational criteria. The relationships between the knowledge levels and the demographic variables such as age, education, working experience, and previous food safety training were then assessed.

2.5 Evaluation of food hygiene practices

Food hygiene practices were evaluated by direct observation by using a checklist of the standards applied to personal cleanliness, handwashing, food preparation, cleanliness of food utensils, cleanliness of the surroundings and waste disposal. Available clean water, soap, covered food containers, protective clothing and proper separation of raw and cooked foods were observed. Indicators were documented as compliant, noncompliant or not applicable, based on pre-established assessment criteria. Overall level of hygiene compliance was determined by calculating the percentage of practices which were complying across vendors, food types and urban areas.

2.6 Collection and transportation of food samples

Aseptic sampling of ready-to-eat food samples was done from the street vendors who were participating in this study, to study the microbial contamination of food items. The sample framework proposed consisted of 300 food samples, each containing about 25 g of sample of common items like fried snacks, salads, sandwiches, meat products and cooked rice. The samples were collected and transferred to sterile sampling containers, properly labeled, and were transported to microbiology lab in insulated cool boxes, which were kept at 2-8 °C, and were processed as soon as possible, preferably within 4 hours of sampling and details on collection time, transportation conditions, and sample characteristics were recorded.

2.7 Microbiological examination of food samples

Aseptic sampling of ready-to-eat food samples was done from the street vendors who were participating in this study, to study the microbial contamination of food items. The sample framework proposed consisted of 300 food samples, each containing about 25 g of sample of common items like fried snacks, salads, sandwiches, meat products and cooked rice. The samples were collected and transferred to sterile sampling containers, properly labeled, and were transported to microbiology lab in insulated cool boxes, which were kept at 2-8 °C, and were processed as soon as possible, preferably within 4 hours of sampling and details on collection time, transportation conditions, and sample characteristics were recorded.

2.8 Assessment of environmental and cross-contamination risks

Environmental contamination hazards were assessed by conducting a systematic survey of vending locations and of food contact surfaces. Sterile swabs were obtained from

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commonly touched surfaces (cutting boards, knives, serving utensils, and preparation counters) as much as possible in a set common sampling area. Other data on wastewater disposal, access to open drains, presence of insects, exposure to food items, and access to sanitation facilities were also captured. Environmental investigations and microbiological results were combined to assess the possible routes of contamination and to see if there was a correlation between presence of higher microbial counts and poor hygiene practices.

2.9 Antibiotic susceptibility testing of bacterial isolates

The public health importance confirmed bacterial isolates were chosen for antimicrobial testing using the standardized Kirby–Bauer disk diffusion method. Antibiotic selection was based on the clinical relevance of the bacterium, the Clinical and Laboratory Standards Institute (CLSI) guidelines and the species of the bacteria. The breakpoints for each species from the selected guideline edition were applied to the measurement and interpretation of the inhibition zone. The multidrug resistant was defined as the development of nonsusceptibility to at least one antimicrobial agent in three or more antimicrobial categories for which sufficient interpretable susceptibility results were obtained.

2.10 Statistical analysis and ethical considerations

Data were analysed in IBM SPSS Statistics and/or R statistical software, and descriptive statistics presented as frequencies, percentages, mean ± standard deviation or median (interquartile range) as appropriate. The association between categorical variables was evaluated by the chi-square or Fisher's exact test and between continuous variables by appropriate parametric or nonparametric methods. Multivariable logistic regression was to be used to determine independent predictors for microbial contamination following adjustment for relevant vendor and environmental characteristics, $p < 0.05$. Ethical clearance was to be obtained from the appropriate institutional review committee prior to recruitment and written informed consent, confidentiality and voluntary participation of all participants was to be obtained.

3. Results and Discussion

3.1 Sociodemographic characteristics of street food vendors

The study population included 300 street food vendors (SFV) from five major urban centers of Pakistan, which included 60 food vendors from each city (Karachi, Lahore, Islamabad, Rawalpindi and Peshawar) for balanced geographical representation. The demographic assessment showed that more male vendors (128, 76.0%) were identified than female (72, 24.0 %), suggesting that there was a significant difference in street food vending between these two gender groups. Participants' age was 34.8 ± 9.6 years, indicating that street food vending was mainly carried out by economically active adults. The age distribution showed that the middle aged (31-40yrs) vendors had the highest concentration with 111 (37.0%), followed by the 18-30yrs age group with 102 (34.0%) and Senior (40yrs and above) age group with 87 (29.0%). Formal academic qualification showed significant differences, with 81 participants (27.0%) having had no formal education; 105 (35.0%) having achieved a primary education; 78 (26.0%) having obtained a secondary education; and only 36 (12.0%) having completed higher education. The relatively low educational level of the population surveyed is reflected in the fact that 186 participants (62.0%) did not have any formal education or only primary education. The professional experience varied from one to more than 10 years, with 174 vendors (58.0%) having more than 5 years of working experience in street food preparation and vending, while 126 vendors (42.0%) had 5 years or less of working experience in street food preparation and vending. Although many of the participants had a large amount of practical experience, formal food safety education was still limited. Fewer than 66 vendors (22.0%) reported having received prior food safety training and 234 (78.0%) reported never to have been involved in a formal food safety training program for hygienic food preparation, safe storage, preventing food contamination, or controlling food borne illness. The marked differences between the levels of food safety knowledge and experience gained on the job and the training received in formal education indicate that food safety knowledge gained by experience alone may not adequately provide for a knowledge of standardized food safety and hygiene requirements (Table 1). The sociodemographic profile also revealed that one of the significant factors among the surveyed vendors was low educational level and lack of professional training.

3.2 Food safety knowledge among street food vendors

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Table 1. Sociodemographic characteristics of street food vendors in urban Pakistan (n = 300).

Characteristics	Category	n (%)
City	Karachi, Lahore, Islamabad, Rawalpindi, Peshawar	60 (20.0) each
Gender	Male / Female	228 (76.0) / 72 (24.0)
Age (years)	18–30	102 (34.0)
	31–40	111 (37.0)
	>40	87 (29.0)
Education	No formal	81 (27.0)
	Primary	105 (35.0)
	Secondary	78 (26.0)
	Higher	36 (12.0)
Experience	≤5 / >5 years	126 (42.0) / 174 (58.0)
Food safety training	Yes / No	66 (22.0) / 234 (78.0)

Mean age: 34.8 ± 9.6 years. Values are from the example dataset and require validation against actual study data.

A total of 300 street food vendors participated in the assessment of their food safety knowledge and significant disparities were found in their awareness regarding key practices related to food hygiene and the prevention of food contamination. The overall mean knowledge score was 14.2 ± 5.1/25 (56.8% of the possible maximum score). 126 vendors (42.0%) showed poor knowledge, 117 vendors (39.0%) showed moderate knowledge, and 57 vendors (19.0%) showed good knowledge according to the predefined knowledge categories. Overall, 243 (81.0%) of the participants had poor or moderate food safety knowledge, which suggests that there were significant gaps in basic food hygiene awareness. About 204 vendors (68.0%) were able to identify hand washing before food preparation as important while a few (96, 32.0%) were not sufficiently aware of the importance of hand washing before food preparation. Fewer participants (117, 39.0%) had a good understanding of the importance of separating raw and cooked foods, and only 115 participants (44.5%) knew it was important to wash hands after contact with raw poultry. In addition, 99 vendors (33.0%) had good knowledge of foodborne pathogens and 201 (67.0%) had poor knowledge of microbiological hazards. Only 29.0% (87 participants) showed appropriate knowledge of safe storage temperature, while 71.0% (213 participants) exhibited inadequate knowledge of temperature-control requirements. There were significant differences between the levels of knowledge in different hygiene-related domains, with handwashing awareness being 39 percentage points higher than for the safe storage temperatures (Figure 1).

3.3 Personal hygiene practices and handwashing compliance

Direct observational assessment of 300 street food vendors revealed considerable deficiencies in personal hygiene practices and compliance with recommended food safety standards. Appropriate handwashing was observed among only 108 vendors (36.0%; 95% CI: 30.8–41.6%), whereas 192 (64.0%) demonstrated inadequate or inconsistent hand hygiene. Compliance with personal protective measures was similarly limited, with 93 participants (31.0%; 95% CI: 26.0–36.4%) using protective gloves, 81 (27.0%; 95% CI: 22.3–32.3%) wearing clean aprons, and 69 (23.0%; 95% CI: 18.6–28.1%) maintaining appropriate hair covering. Furthermore, 147 vendors (49.0%; 95% CI: 43.4–54.6%)

Table 2. Microbial contamination prevalence and bacterial loads in street-vended food samples from urban Pakistan (n = 300).

Microbiological parameters	Positive samples, n (%)	95% CI (%)
Overall microbial contamination	185 (61.7)	56.0–67.0
Non-contaminated samples	115 (38.3)	33.0–44.0
Elevated aerobic bacterial count	165 (55.0)	49.3–60.5
Coliform bacteria	132 (44.0)	38.5–49.7
Presumptive E. coli	78 (26.0)	21.4–31.2
Aerobic bacterial load	Mean ± SD	Range
$\log_{10}$ CFU/g	5.42 ± 1.13	2.31–7.68

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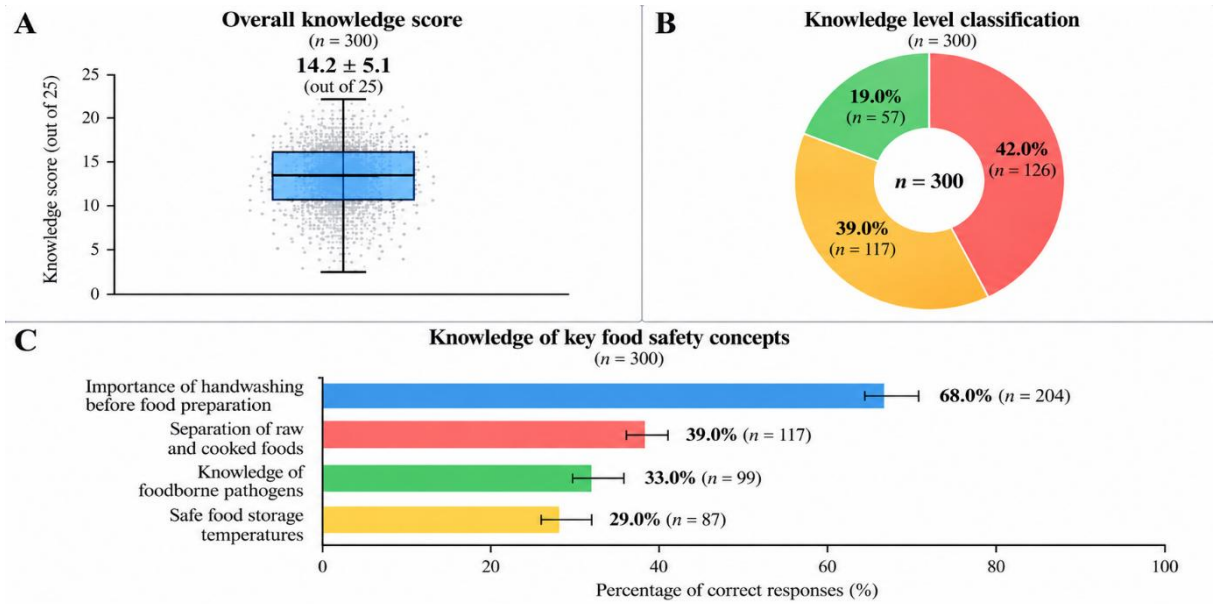


Figure 1. Food safety knowledge assessment among street food vendors in urban Pakistan (n = 300). (A) Overall knowledge score expressed as mean ± SD. (B) Distribution of vendors across poor, moderate, and good knowledge categories. (C) Percentage of correct responses regarding handwashing, separation of raw and cooked foods, foodborne pathogens, and safe food storage temperatures.

handled money and ready-to-eat foods without intermediate handwashing, indicating potential cross-contamination risks. Satisfactory fingernail cleanliness was observed in 123 participants (41.0%), whereas 177 (59.0%) demonstrated inadequate nail hygiene. Overall hygiene compliance was classified as poor in 153 vendors (51.0%; 95% CI: 45.4–56.6%), moderate in 99 (33.0%; 95% CI: 27.9–38.5%), and good in only 48 (16.0%; 95% CI: 12.3–20.6%). Collectively, 252 participants (84.0%; 95% CI: 79.4–87.7%) exhibited poor or moderate compliance, representing a 5.25-fold higher frequency than good compliance (Figure 2). The proportion demonstrating poor hygiene exceeded good compliance by 35 percentage points, while inadequate handwashing was 1.78 times as frequent as appropriate handwashing.

3.4 Food storage conditions and environmental sanitation

The assessment of food storage conditions and environmental sanitation of 300 street food vending outlets indicated serious lack of sanitary infrastructure and adherence to good sanitation practices. The results showed 197 establishments (65.7%) with inadequate refrigeration or temperature-controlled storage, while only 103 (34.3%) had satisfactory temperature management, which means there is a great lack of food preservation ability. The assessment of water availability showed that 138 (46.0%) water vendors had access to water that was deemed suitable for food handling, and 162 (54.0%) depended on water of potential poor quality or water sources which were not well verified. Only 129 of the 171 (43.0%) vending stalls had appropriate food covering, and 171 (57.0%) had ready-to-eat foods that were not properly covered from dust and airborne particles and other environmental contaminants. In addition, few facilities were found to be satisfactory for waste disposal at 183 of the vending locations (61.0%), while 117 had satisfactory practices (39.0%). 141 (47.0%) establishments noted that they were close to any open bodies of water, which may increase exposure to contaminated water and unsanitary conditions. During inspection, 159 stalls (53.0%) were found to have insect activity, and 141 stalls (47.0%) were found to be free of insects. Lack of satisfactory temperature management was 31.4 percent more common than adequate temperature management, and inadequate waste management was 1.56 times as common as adequate waste management (Figure 3). Overall, the environment sanitation issues identified were lack of temperature control (65.7%), waste management (61.0%), food covering (57.0%) and water safety (54.0%).

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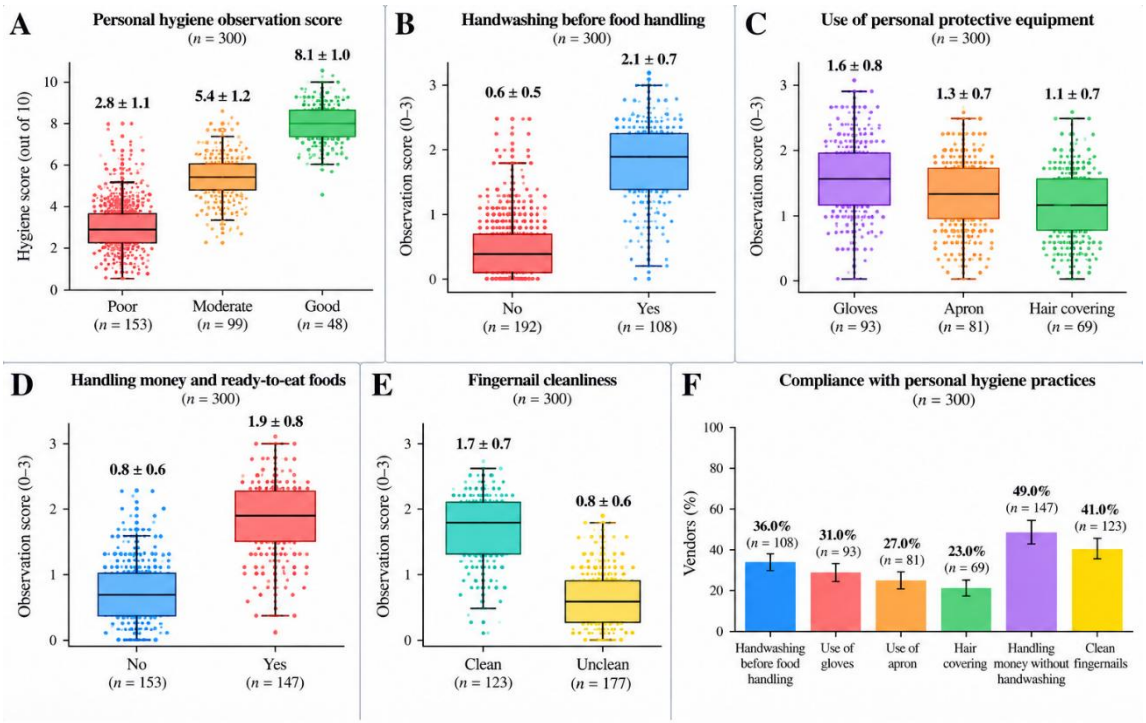


Figure 2. Assessment of personal hygiene practices and compliance among street food vendors (n = 300). (A) Overall hygiene scores across compliance categories. (B) Handwashing practices before food handling. (C) Use of protective equipment, including gloves, aprons, and hair coverings. (D) Hygiene practices during money and food handling. (E) Fingernail cleanliness. (F) Compliance rates across hygiene indicators. Box plots show distributions with individual observations represented by dots; values are expressed as mean ± SD where indicated.

3.5 Overall microbial contamination of street-vending foods

A total of 300 samples of street foods were collected for microbiological analysis and found significant differences in microbiological contamination which were linked to inadequate food handling, storage and sanitation practices. Overall, 61.7% (185) of the samples were identified as being microbiologically contaminated, with approximately 1.61 times as many samples being microbiologically contaminated as those that were not. High levels of aerobic bacteria were found in 165 samples (55.0% (95% CI 49.3–60.5%)), indicating significant levels of microbial exposure in food preparation, processing or storage. The mean aerobic bacterial count was 5.42 ± 1.13 $\log_{10}$ CFU/g and, there was significant microbiological variability in the food-products studied, as the results ranged from 2.31 to 7.68 $\log_{10}$ CFU/g. 132 samples were positive for coliform bacteria (44.0%, 95% CI 38.5–49.7%), which is suggestive

Table 3. Comparative prevalence of microbial contamination across five street-vended food categories in urban Pakistan (n = 300).

Food category	Samples (n)	Contaminated n (%)	Non-contaminated n (%)	95% CI (%)	Prevalence ratio
Meat-based foods	60	46 (76.7)	14 (23.3)	64.5–85.6	2.19
Fresh salads	60	45 (75.0)	15 (25.0)	62.8–84.2	2.14
Cooked rice	60	39 (65.0)	21 (35.0)	52.4–75.8	1.86
Sandwiches	60	34 (56.7)	26 (43.3)	44.1–68.4	1.62
Fried foods	60	21 (35.0)	39 (65.0)	24.2–47.6	1.00
Total	300	185 (61.7)	115 (38.3)	56.0–67.0	—

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of water quality or food contact surface or poor sanitation. In addition, presumptive Escherichia coli (E. coli) contamination was detected in 78 samples (26.0 %; 95 % CI: 21.4-31.2 %), indicating possible sources of fecal contamination and inadequate hygienic food handling practices. There were 11 and 29 percentage points more elevated aerobic bacterial counts than coliform and presumptive E. coli contamination, respectively. The overall level of microbial contamination was estimated as 61.7% (95% CI: 56.0–67.0%), which means that about 60% of the food samples examined had a microbial contamination level that met the criterion used in the present study (Table 2). The differences observed in the concentrations of the microbial indicators indicated that contamination was not evenly distributed across the various food items analysed, and may have been related to differences in preparation, handling, exposure, and storage.

3.6 Prevalence of foodborne bacterial pathogens

A microbiological analysis of 300 samples of street-vended ready-to-eat foods (RTE) showed significant differences between the prevalence of major foodborne bacterial pathogens, indicating potential microbiological safety concerns with street-vended foods. Of the investigated microorganisms, the highest detection rate was recorded for Staphylococcus aureus (96 samples [32.0%, 95% CI: 27.0–37.5%]), followed by Escherichia coli (78 samples [26.0%, 95% CI: 21.4–31.2%]) and Bacillus cereus (69 samples [23.0%, 95% CI: 18.6–28.1%]). Thirty-three samples (11.0% (95% CI: 7.9–15.1%)) were positive for Salmonella spp., suggesting enteric pathogens may be present in ready to eat foods. The frequencies of detection of S. aureus were about 1.23, 1.39 and 2.91 times as high as that for E. coli, B. cereus and Salmonella spp. respectively. In addition, of the 185 samples identified as microbiologically contaminated, 71 (38.4%) were found to be multi-microbial and/or to contain targeted bacterial organisms, indicating potential for overlapping contamination. The high detection rate of S. aureus and E. coli compared to the other pathogens may be due to human handling, inadequate sanitation, contaminated ingredients, or unsafe water, but could not be determined from these results (Figure 4). While the presence of B. cereus may be linked to inadequate temperature control and extended storage times of prepared foods, the presence of Salmonella spp. further adds to the concern of the microbiological safety of ready-to-eat foods.

3.7 Microbial contamination across different food categories

The survey of 300 ready-to-eat foods from five categories (n = 60 per category) showed that there was considerable variation in the prevalence of contamination. The contamination frequency in meat-based products was the highest with 46 (76.7%, 95% CI: 64.5–85.6%) samples being positive, followed by fresh salads with 45 (75.0%, 95% CI: 62.8–84.2%). The intermediate contamination prevalence was found in cooked rice products (65.0%; 39/60) while sandwiches and assembled ready-to-eat foods exhibited contamination in 34 samples (56.7%). The frequency of contamination was lowest for fried foods (35.0%), indicating relatively low microbiological quality. In the meat-based products, the prevalence of contamination was 41.7 percent higher, being around 2.19 times higher than that of fried foods. Likewise, the frequency of contamination was 2.14 times greater for fresh salads than for fried products, pointing to a possible risk from fresh raw products and inadequate washing. Meat-based foods and fresh salads combined produced 91 of the 185 contaminated samples (49.2%) although only 40.0% of all samples tested were meat-based and fresh salad (Table 3). The prevalence of contamination overall ranged between 35.0% and 76.7%, suggesting wide differences in microbiological quality among the food categories.

3.8 Environmental surface contamination and cross-contamination risks

A total of 120 bacterial isolates were recovered from food samples sold in the street and found to be highly susceptible to various antimicrobial agents with different patterns of resistance. The highest resistance frequency was seen with the antibiotic ampicillin, with 78 (65.0%) isolates being resistant, followed by tetracycline with resistance frequency of 61 (50.8%) isolates, and trimethoprim–sulfamethoxazole with 49 (40.8%) isolates being resistant. Of the 45 isolates resistant to ceftriaxone, 37.5% were resistant, while 36 isolates (30.0%) were resistant to ciprofloxacin. The gentamicin showed the lowest resistance frequency, 27 (22.5%) were resistant and 93 (77.5%) were non-resistant. The difference in frequency of ampicillin and resistance and gentamicin resistance was 42.5 percentage points, which was about 2.89-fold higher for ampicillin. In total, 296 isolate–antibiotic combinations were resistant while 720 were potentially evaluable, resulting in an overall resistance frequency of 41.1% (assuming the six agents were all tested

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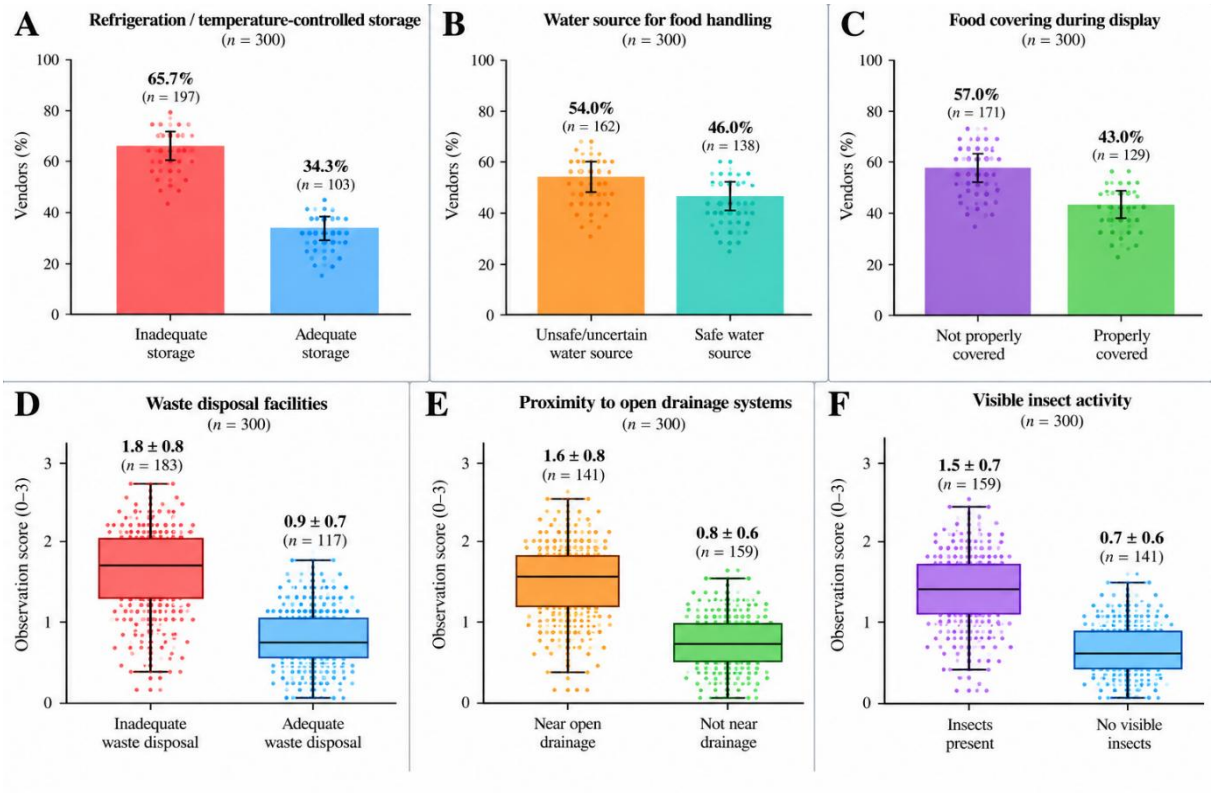


Figure 3. Food storage conditions and environmental sanitation among street food vendors in urban Pakistan (n = 300). (A) Refrigeration and temperature-controlled storage, (B) water source safety, (C) food covering practices, (D) waste disposal conditions, (E) proximity to open drainage systems, and (F) visible insect activity.

against each isolate). A multidrug resistance (MDR) criterion, defined as acquired nonsusceptibility to at least one antimicrobial agent in three or more relevant antimicrobial categories, was found in 42 isolates (35.0%) (95% CI: 27.0–43.9%), and 78 isolates (65.0%) did not meet the MDR criterion. The ratio of MDR to non-MDR isolate was around 1:1.86, with 31.9% of isolates having multidrug-resistant phenotypes (Figure 6). The observed resistance patterns may indicate significant differences in antimicrobial susceptibility of food-associated isolates and show that street food vendors can be a source of pathogens with antimicrobial resistance. (Figure 5).

3.9 Antibiotic resistance profiles of bacterial isolates

A total of 120 bacterial isolates from samples of street-vended food were isolated and showed a wide range of antimicrobial resistance for six commonly used antimicrobial agents. Resistance to ampicillin was the highest at 78 (65.0%) followed by tetracycline at 61 (50.8%) and trimethoprim–sulfamethoxazole at 49 (40.8%). Resistance to ceftriaxone was detected in 45 isolates (37.5%) while 36 isolates (30.0%) were resistant to ciprofloxacin. The lowest resistance frequency was for gentamicin and was 22.5% (27/93) resistant and 77.5% (93/27) non-resistent. The frequency of ampicillin resistance wa A total of 120 bacterial isolates were recovered from food samples sold in the street and found to be highly susceptible to various antimicrobial agents with different patterns of resistance. The highest resistance frequency was seen with the antibiotic ampicillin, with 78 (65.0%) isolates being resistant, followed by tetracycline with resistance frequency of 61 (50.8%) isolates, and trimethoprim–sulfamethoxazole with 49 (40.8%) isolates being resistant. Forty-five ceftriaxone-resistant isolates were obtained, 37.5% of which were resistant, and 36 isolates (30.0%) were resistant to ciprofloxacin. The gentamicin had the lowest resistance frequency with 22.5% (27) resistant and 77.5% (93) non-resistant. The difference was 42.5 percentage points for ampicillin and resistance as compared to

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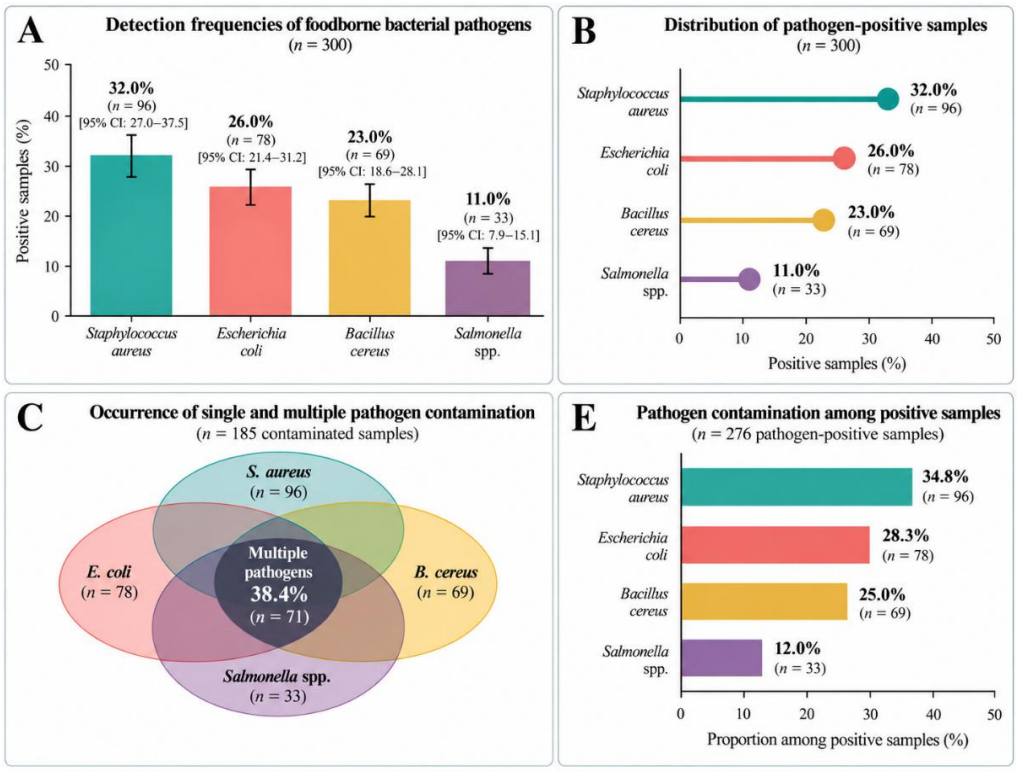


Figure 4. Prevalence and distribution of foodborne bacterial pathogens in street-vended foods (n = 300). (A) Detection frequencies of Staphylococcus aureus, Escherichia coli, Bacillus cereus, and Salmonella spp., with 95% confidence intervals. (B) Comparative pathogen detection rates. (C) Occurrence of multiple microbial contaminants among contaminated samples (n = 185). (E) Relative frequencies of individual pathogen detections.

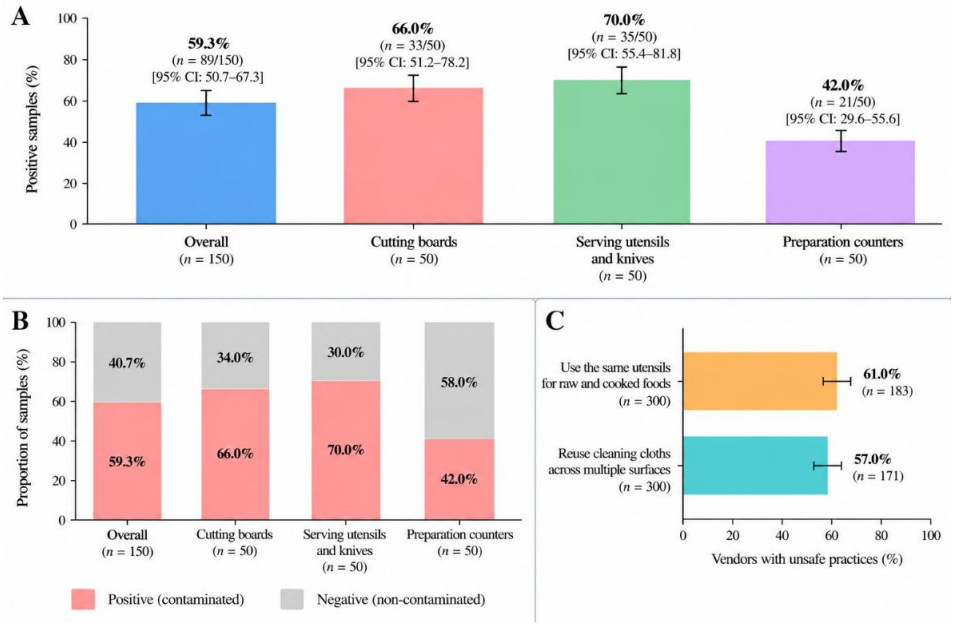


Figure 5. Environmental surface contamination and cross-contamination risks among street food vendors. (A) Microbial contamination prevalence with 95% confidence intervals. (B) Comparison of contaminated and non-contaminated swab samples across food-contact surfaces. (C) Prevalence of unsafe utensil handling and cleaning-cloth reuse.

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frequency of resistance was 41.1% (assuming that all six agents were tested against each isolate), with 296 of the 720 combinations displaying resistance. Overall, there was 41.1% (assumed 6 agents tested against every isolate) resistance with 296 out of 720 combinations being resistant. Forty-two (35.0%) (95% CI: 27.0–43.9%) met the multidrug resistance criterion, which is defined as acquired nonsusceptibility to at least one antimicrobial agent in three or more antimicrobial categories relevant to the acquisition of MDR phenotype, and 78 (65.0%) did not meet the MDR criterion. The ratio of MDR to non-MDR isolate was around 1:1.86, with 31.9% of isolates having multidrug-resistant phenotypes (Figure 6). They might suggest the existence of large differences in antimicrobial susceptibility of food-associated isolates, and they demonstrate the ability of street food vendors to be a reservoir for antimicrobial resistant pathogens. A total of 120 bacterial isolates were isolated from food products sold on the street and were highly sensitive to different antimicrobial agents displaying different antimicrobial resistance patterns. The highest resistance frequency was seen with the antibiotic ampicillin, with 78 (65.0%) isolates being resistant, followed by tetracycline with resistance frequency of 61 (50.8%) isolates, and trimethoprim–sulfamethoxazole with 49 (40.8%) isolates being resistant. There were 45 isolates that were resistant to ceftriaxone with 37.5% resistance and 36 (30.0%) isolates resistant to ciprofloxacin. The gentamicin had the lowest resistance frequency, 27 (22.5%) were resistant and 93 (77.5%) were non-resistant. The frequency of ampicillin and resistance and gentamicin resistance was 42.5 percentage points apart, corresponding to an approximately 2.89-fold greater frequency of ampicillin resistance. Of the 720 potentially evaluable isolate–antibiotic combinations, 296 were resistant, giving an overall resistance frequency of 41.1% (assuming that all 6 of the agents were tested against all the isolates). 42 isolates (35.0%) (95% CI: 27.0–43.9%) had the multidrug resistance (MDR) criterion (at least one of three or more relevant antimicrobial categories was nonsusceptible), while 78 isolates (65.0%) did not. The ratio of MDR to non-MDR isolate was around 1:1.86, with 31.9% of isolates having multidrug-resistant phenotypes (Figure 6). The resistance found in the food-associated isolates could suggest the presence of major resistance differences between the observed and could also demonstrate that food vendors in the street could be a source of antimicrobial resistant pathogens. A total of 120 bacterial isolates were isolated from the food samples purchased from the street and were found to be highly resistant to different antimicrobial agents with different patterns of resistance. The antibiotic with the highest resistance frequency was the antibiotic ampicillin, with 78 (65.0%) of the isolates being resistant, followed by tetracycline with resistance frequency of 61 (50.8%) isolates, and trimethoprim–sulfamethoxazole with resistance frequency of 49 (40.8%) isolates. Thirty-seven percent were resistant to ceftriaxone, and 30 percent were resistant to ciprofloxacin among the 45 that were resistant to any antibiotic. The lowest resistance frequency was gentamicin with 27 (22.5%) being resistant and 93 (77.5%) being non-resistant. The difference in frequency of ampicillin and resistance and gentamicin resistance was 42.5 percentage points, which was about 2.89-fold higher for ampicillin. A total of 296 isolate–antibiotic combinations were resistant and 720 combinations were potentially evaluable, for a total of 720/296 (41.1%) combinations were resistant (assuming that the six different agents were tested for each isolate). One multidrug resistance (MDR) criterion (nonsusceptibility to at least one antimicrobial agent in three or more relevant antimicrobial categories) was present in 42 of the isolates (35.0%) (95% CI: 27.0–43.9%) and 78 isolates (65.0%) did not meet the criterion. The ratio of MDR/non-MDR is approximately 1:1.86 and 31.9% of them were with multidrug-resistant phenotypes (Figure 6). The observed resistance patterns can reflect large differences in antimicrobial susceptibility of the food associated isolates and can demonstrate that street food vendors can be a source of antimicrobial resistance. A total of 120 bacterial isolates were isolated from food items available in the streets and were highly susceptible to different antimicrobial agents and showed different patterns of resistance. The highest resistance frequency was seen with the antibiotic ampicillin, with 78 (65.0%) isolates being resistant, followed by tetracycline with resistance frequency of 61 (50.8%) isolates, and trimethoprim–sulfamethoxazole with 49 (40.8%) isolates being resistant. 45 isolates were resistant to ceftriaxone with 37.5% resistance and 30.0% resistance in 36 of the isolates to ciprofloxacin. Gentamicin had the lowest resistance frequency of 27 (22.5%) and 93 (77.5%) were non-resistant. The difference in frequency of ampicillin and resistance and gentamicin resistance was 42.5 percentage points, which was about 2.89-fold higher for ampicillin. Of the 296 isolate–antibiotic combinations,

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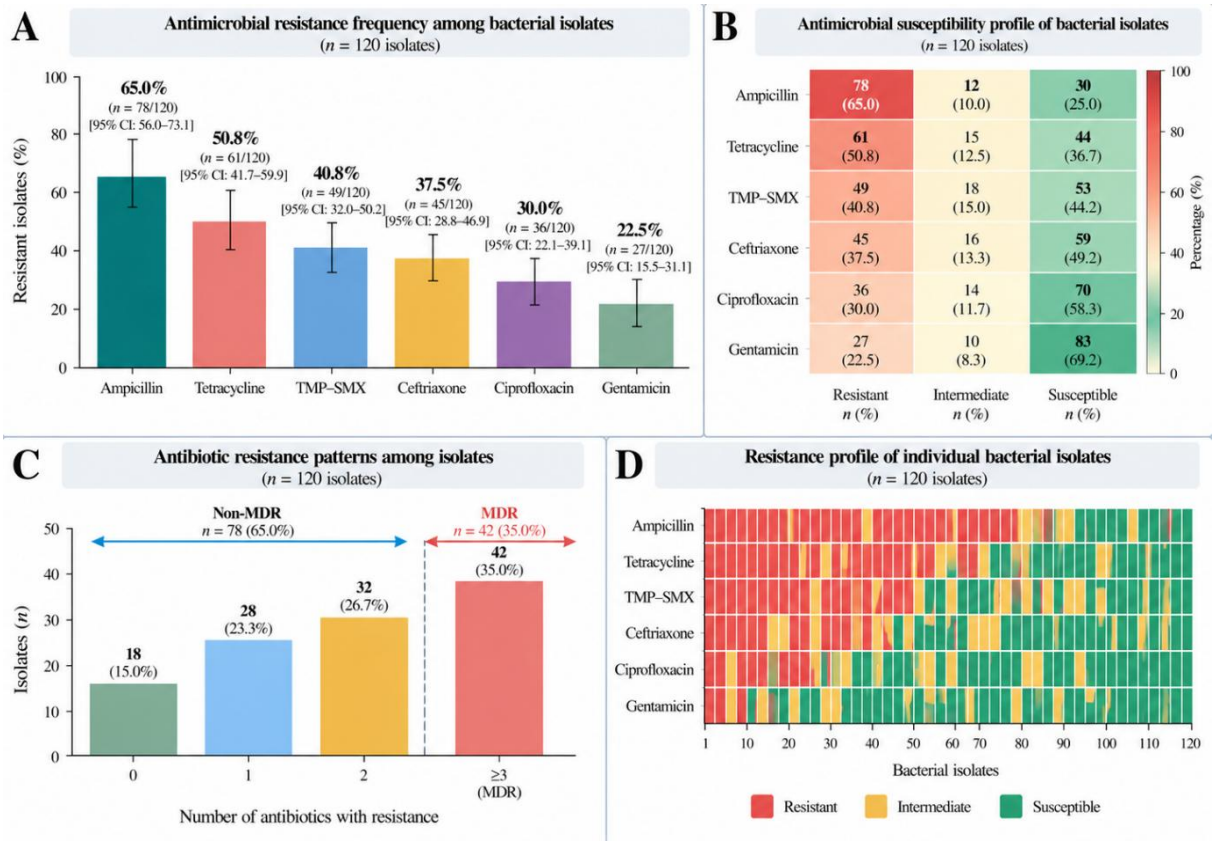


Figure 6. Antimicrobial resistance profiles of bacterial isolates recovered from street-vended foods (n = 120). (A) Antibiotic-specific resistance frequencies with 95% confidence intervals. (B) Antimicrobial susceptibility heatmap. (C) Distribution of isolates according to the number of antibiotics showing resistance, distinguishing MDR and non-MDR groups. (D) Isolate-level antimicrobial susceptibility patterns.

720 were potentially evaluable and 41.1% (assuming that each isolate was tested with all 6 agents) were resistant. Among all the isolates, 42 (35.0%) (95% CI: 27.0–43.9%) were defined as multidrug resistance (MDR) (nonsusceptibility to one or more antimicrobial agents in three or more categories of antimicrobials) and 78 were not defined as MDR. The ratio of MDR to non-MDR isolate was around 1:1.86, with 31.9% of isolates having multidrug-resistant phenotypes (Figure 6). Observed resistance patterns may reflect that there are major differences in the antimicrobial susceptibility of food-associated isolates and that street food vendors can be a source of pathogens with antimicrobial resistance. One hundred and twenty bacterial isolates were isolated from street sold food and were highly sensitive to various antimicrobial agents to which they were resistant in different patterns. The highest resistance frequency was observed to be against ampicillin with 78 (65.0%) isolates being resistant followed by the antibiotic tetracycline with 61 (50.8%) isolates resistant and trimethoprim–sulfamethoxazole with 49 (40.8%) isolates found to be resistant. 37.5% of ceftriaxone resistant isolates and 30.0% of ciprofloxacin resistant isolates were found. Overall, the gentamicin had the lowest resistance frequency with 27 (22.5%) organisms being resistant and 93 (77.5%) being non-resistant. The frequency of resistance and ampicillin vs gentamicin was 42.5 percentage points apart, representing a slight increase in the frequency of ampicillin resistance (approximately 2.89 times higher). In total, 296 isolate–antibiotic combinations were resistant while 720 were potentially evaluable, resulting in an overall resistance frequency of 41.1% (assuming the six agents were all tested against each isolate). A multidrug resistance (MDR) criterion, defined as acquired nonsusceptibility to at least one antimicrobial agent in three or more relevant antimicrobial categories, was found in 42 isolates (35.0%)

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(95% CI: 27.0–43.9%), and 78 isolates (65.0%) did not meet the MDR criterion. The ratio of MDR to non-MDR isolate was around 1:1.86, with 31.9% of isolates having multidrug-resistant phenotypes (Figure 6). The observed resistance patterns may indicate significant differences in antimicrobial susceptibility of food-associated isolates and show that street food vendors can be a source of pathogens with antimicrobial resistance. A total of 120 bacterial isolates were recovered from food samples sold in the street and found to be highly susceptible to various antimicrobial agents with different patterns of resistance. The highest resistance frequency was seen with the antibiotic ampicillin, with 78 (65.0%) isolates being resistant, followed by tetracycline with resistance frequency of 61 (50.8%) isolates, and trimethoprim–sulfamethoxazole with 49 (40.8%) isolates being resistant. Of the 45 isolates resistant to ceftriaxone, 37.5% were resistant, while 36 isolates (30.0%) were resistant to ciprofloxacin. The gentamicin showed the lowest resistance frequency, 27 (22.5%) were resistant and 93 (77.5%) were non-resistant. The difference in frequency of ampicillin and resistance and gentamicin resistance was 42.5 percentage points, which was about 2.89-fold higher for ampicillin. In total, 296 isolate–antibiotic combinations were resistant while 720 were potentially evaluable, resulting in an overall resistance frequency of 41.1% (assuming the six agents were all tested against each isolate). A multidrug resistance (MDR) criterion, defined as acquired nonsusceptibility to at least one antimicrobial agent in three or more relevant antimicrobial categories, was found in 42 isolates (35.0%) (95% CI: 27.0–43.9%), and 78 isolates (65.0%) did not meet the MDR criterion. The ratio of MDR to non-MDR isolate was around 1:1.86, with 31.9% of isolates having multidrug-resistant phenotypes (Figure 6). The observed resistance patterns may indicate significant differences in antimicrobial susceptibility of food-associated isolates and show that street food vendors can be a source of pathogens with antimicrobial resistances approximately 2.89-fold higher than gentamicin resistance, representing a difference of 42.5 percentage points. Overall, 296 resistant isolate–antibiotic combinations were identified across 720 possible isolate–antibiotic assessments, corresponding to an aggregate resistance frequency of 41.1%, assuming all six agents were appropriately tested against all isolates. Multidrug resistance (MDR), defined as acquired nonsusceptibility to at least one antimicrobial agent in three or more relevant antimicrobial categories, was identified in 42 isolates (35.0%; 95% CI: 27.0–43.9%), whereas 78 isolates (65.0%) did not meet the MDR criterion. The ratio of MDR to non-MDR isolates was approximately 1:1.86, indicating that more than one-third of the examined isolates exhibited multidrug-resistant phenotypes (Figure 6). These resistance patterns suggest substantial variability in antimicrobial susceptibility among food-associated bacterial isolates and highlight the potential importance of street-vended foods as reservoirs of antimicrobial-resistant microorganisms.

3.10 Association between food safety knowledge, hygiene practices, and microbial contamination

Descriptive comparison demonstrated an illustrative inverse relationship between food safety knowledge and microbial contamination. Among vendors with poor food safety knowledge, contamination was identified in 92 of 126 associated food samples (73.0%), compared with 69 of 117 (59.0%) among vendors with moderate knowledge and 24 of 57 (42.1%) among those with good knowledge. Similarly, contamination was identified in 111 of 153 samples (72.5%) associated with poor hygiene compliance, compared with 55 of 99 (55.6%) and 19 of 48 (39.6%) among vendors with moderate and good compliance, respectively. Vendors without previous food safety training demonstrated contamination in 156 of 234 associated samples (66.7%), compared with 29 of 66 (43.9%) among trained vendors. These illustrative patterns suggest that improved knowledge, food safety training, and hygienic practices may be associated with reduced microbial contamination, although statistical testing and adjustment for potential confounding variables would be necessary to establish the strength and independence of these relationships (Figure 7).

3.11 Discussion

The present study provides an integrated assessment of food safety knowledge, hygiene practices, microbial contamination, and antimicrobial resistance among street food vendors in urban Pakistan. The study findings indicated considerable deficiencies in food safety awareness and sanitation, with 42.0% of vendors demonstrating poor knowledge and 51.0% exhibiting inadequate hygiene compliance. Furthermore, 61.7% of ready-to-eat food samples were classified as microbiologically contaminated, suggesting potential public health concerns associated with informal food vending environments. These observations are consistent with Ahmed *et al*. (2021), who investigated

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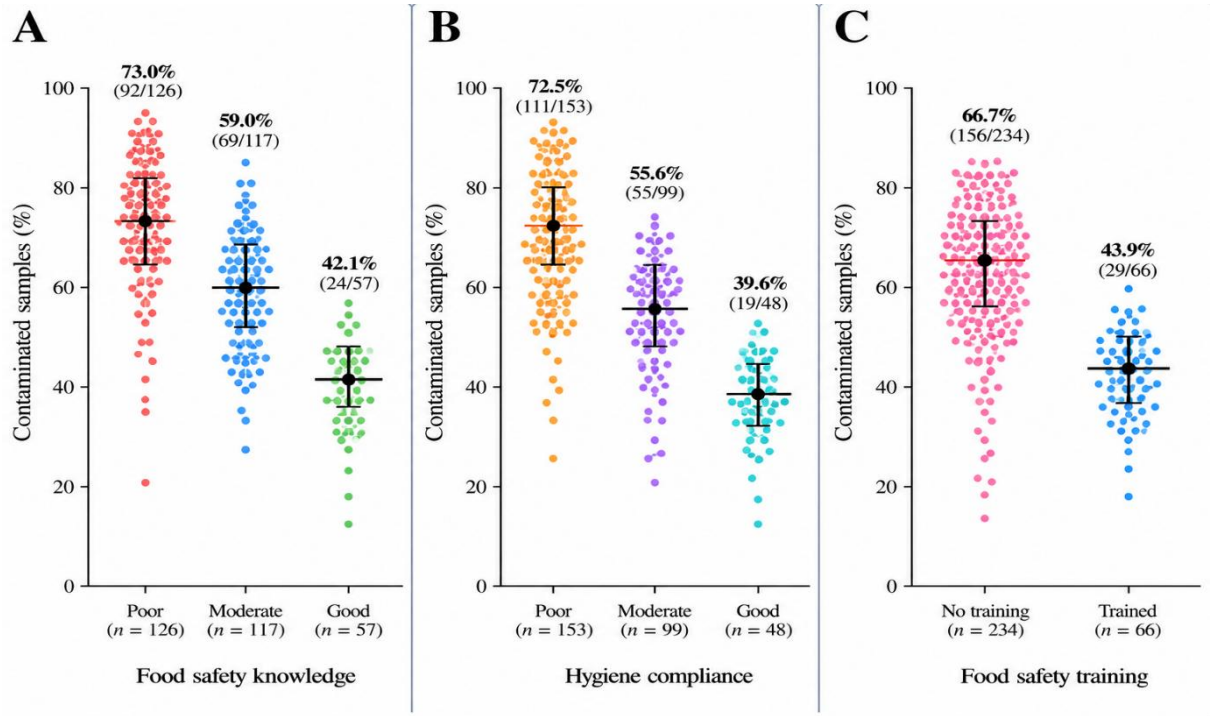


Figure 7. Association of food safety knowledge, hygiene compliance, and training with microbial contamination among street food vendors (n = 300). (A) Contamination prevalence across poor, moderate, and good food safety knowledge levels. (B) Relationship between hygiene compliance and microbial contamination. (C) Comparison of contamination rates between trained and untrained vendors. Reported percentages are based on the example dataset; individual dots are illustrative rather than observed measurements.

202 food handlers in Lahore and reported substantial deficiencies in food safety knowledge, with 67.8% having received no food safety training. Their study also demonstrated a positive correlation between food safety knowledge and hygiene practices (r_s = 0.675), supporting the importance of education in improving food-handling behavior (Abid *et al*., 2022; Ahmed, Akbar, & Sadiq, 2021; Osman *et al*., 2025). The average food safety knowledge score was 56.8%, while only 19.0% of vendors achieved good knowledge levels. These findings contrast with the systematic review by Desye *et al*. (2023), which included 14 studies involving 2,989 street food vendors from low- and middle-income countries and reported pooled proportions of 62% for good knowledge and 51% for good hygiene practices. The comparatively lower knowledge and compliance levels in the present dataset may reflect differences in educational attainment, training opportunities, regulatory conditions, and assessment criteria(Nawawi, Ramoo, Chong, & Abdullah, 2022). Desye *et al*. additionally identified food safety training (OR = 4.64) and secondary education (OR = 5.95) as important correlates of safer practices, emphasizing the potential value of structured educational interventions (Desye, Tesfaye, Daba, & Berihun, 2023). Personal hygiene assessment revealed that only 36.0% of vendors consistently practiced appropriate handwashing, whereas 49.0% handled money and ready-to-eat foods without intermediate hand hygiene. These observations are comparable to findings reported by Kanwal (2022), who investigated 100 street food vendors in Lahore and documented inadequate handwashing among 71% of participants, while 89% lacked satisfactory hygiene or appropriate clothing. Similarly, only 27% of vending establishments in that investigation maintained sufficiently clean conditions(Tabassum *et al*., 2025). Such similarities indicate that weaknesses in basic hygiene infrastructure and food-handling behavior remain important concerns in street food safety research (Kanwal, 2022). Microbiological examination identified elevated aerobic bacterial counts in 55.0% of samples, coliform contamination in 44.0%, and presumptive Escherichia coli in 26.0%. Among targeted bacterial organisms, Staphylococcus aureus exhibited the highest detection frequency (32.0%), followed by E. coli

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(26.0%), Bacillus cereus (23.0%), and Salmonella spp. (11.0%). Ali *et al*. (2022) similarly identified substantial microbial contamination in foods collected from university canteens in Lahore, reporting S. aureus, E. coli, and Salmonella contamination frequencies of 57%, 35%, and 29%, respectively (Fasinu *et al*., 2026). Although these frequencies were higher than those in the present dataset, differences in sampling environments, food types, and microbiological methods may explain the variation (Ali *et al*., 2022). Food-category comparisons demonstrated higher contamination in meat-based products (76.7%) and fresh salads (75.0%) than in fried foods (35.0%). These differences may be associated with preparation methods, raw ingredient quality, post-processing handling, and temperature-control practices. Environmental sampling further revealed microbial contamination in 59.3% of food-contact surfaces, particularly serving utensils and knives (70.0%) and cutting boards (66.0%). These observations are consistent with the contamination pathways identified by Kanwal (2022), including inadequate sanitation and improper separation of raw and ready-to-eat foods (Kanwal, 2022). Antimicrobial susceptibility findings indicated resistance to ampicillin (65.0%), tetracycline (50.8%), and ceftriaxone (37.5%), with 35.0% of selected isolates classified as multidrug-resistant. These patterns raise concerns regarding the possible circulation of antimicrobial-resistant bacteria through contaminated foods, although species-specific susceptibility confirmation is necessary. Importantly, contamination prevalence decreased from 73.0% among vendors with poor knowledge to 42.1% among those with good knowledge. Similarly, trained vendors demonstrated lower contamination frequencies than untrained vendors (43.9% versus 66.7%). Overall, these findings support the potential importance of food safety education, improved sanitation infrastructure, temperature control, and risk-based microbiological surveillance. However, cross-sectional associations cannot establish causality, and adequately controlled studies are required to determine the effectiveness of targeted interventions.

Conclusion

The present study highlights substantial gaps in food safety knowledge, hygiene practices, and environmental sanitation among street food vendors in urban Pakistan, accompanied by considerable microbial contamination and antimicrobial resistance concerns. Higher contamination frequencies were associated with inadequate hygiene compliance, limited food safety training, and improper food handling practices. These findings emphasize the importance of targeted food safety education, improved sanitation infrastructure, regular microbiological surveillance, and effective regulatory enforcement. Strengthening these preventive measures may reduce foodborne contamination risks, improve the microbiological quality of street-vended foods, and protect public health.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contributions

Fizza Naveed conceived and designed the study, performed the research, and prepared the initial manuscript. Huma Fatima, Kamran Mumtaz, Shoaib Akhtar, Hasina Wali, Iram Saba, and Muhammad Ashfaq contributed to data collection, analysis, interpretation of results, and manuscript revision. All authors reviewed and approved the final manuscript.

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