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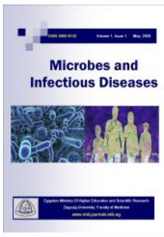

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Review article

Emergence of antimicrobial resistance in street vendor food: A global perspective on bacterial contamination, resistance mechanisms, and mitigation strategies

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ABSTRACT

Background: The emergence of antibiotic-resistant bacteria poses a critical threat to global health, significantly contributing to morbidity and mortality. Environmental surveillance has pointed out that street-vended food is a reservoir and vector for the spread of multidrug-resistant (MDR) pathogens, but its involvement in the dissemination of infectious diseases remains underappreciated. This review brings together national and international studies on the bacteriological quality of street food and its link with antimicrobial resistance (AMR). The most commonly identified foodborne pathogens are *Staphylococcus aureus*, *Escherichia coli*, *Salmonella* spp., and *Klebsiella pneumoniae*, which cause vomiting, diarrhea, and severe infections of the gut. As high as 60% of street foods contain ESBL and MBL-producing bacteria and are resistant to more than 70% of first-line antibiotics. Contamination relates to poor hygiene, including low handwashing abilities (73.3% of vendors), use of untreated water sources (40%), and poor hygiene in food handling (60% of vendors do not trim their nails). External environmental exposure in the form of flies, rodents, and birds increases the transmission of bacteria. Horizontal gene transfer, efflux pumps, and plasmid-mediated resistance mechanisms add complexities to the problems. The first cause is poor awareness and measures of sanitation at the level of the vendors. Weak food safety regulations, poor waste management, and low surveillance of microbes heighten the risk. This review calls for the urgent implementation of food safety policies, better sanitation infrastructure, regular microbial monitoring, and hygiene training of vendors. Moreover, affordable kits for testing microbes can be used for the early detection of MDR pathogens.

Introduction

Street food plays an essential role in the social and cultural fabric of cities worldwide, offering an affordable, convenient, and flavourful food option, particularly in urban areas where time constraints and economic factors make it a popular choice **(Figure 1)**. These foods are widely consumed due to their low cost, accessibility, and the unique tastes they provide, often deeply rooted in local traditions and culinary practices. Street food vendors, particularly in developing countries, cater to the growing demand for quick and affordable

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meals. The consumption of street food is also driven by socio-economic factors such as poor pay, increasing joblessness, limited job opportunities, and the rapid population growth in urban areas, which compel many people to depend on street food for daily meals [1]. However, while street food has clear advantages, the unhygienic conditions in which it is prepared and sold present significant public health risks.

The unhygienic practices and environments where street food is prepared create an ideal breeding ground for microbial contamination. Vendors often operate in open-air environments with inadequate sanitation facilities, lacking access to clean water, proper waste management, and basic hygiene practices. Street food is typically handled in unsanitary conditions, with raw materials stored improperly, utensils washed without soap or disinfectant, and vendors often handling food without washing their hands. Additionally, food is exposed to contaminants like dust, dirt, insects, and rodents, which further exacerbate the risk of contamination. This lack of hygiene is compounded by the fact that food is frequently prepared on open carts, trays, and mats, increasing the chances of cross-microbial contamination [2]. Poor handling, improper storage, reheating, and the use of untreated water further contribute to the spread of foodborne pathogens, such as *Salmonella Typhi*, *Escherichia coli*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and yeast, which are commonly found in street food [3,4]. The unsanitary practices include vendors wearing dirty clothes, handling food with unpolished nails, and chewing tobacco while preparing food. In fact, it was found that 13.4% of street vendors wore dirty clothes, 60% had unpolished nails, 40% chewed tobacco during food preparation, and 73.3% did not wash their hands after serving food [3].

These factors contribute to the prevalence of foodborne illnesses, which are a leading cause of morbidity and mortality worldwide. Foodborne diseases not only affect individuals' health but also result in significant economic losses, including reduced productivity and increased healthcare costs. The growing prevalence of antibiotic resistance among foodborne pathogens, particularly in street food, poses an additional public health challenge. Over the years, there has been a significant rise in the occurrence of antibiotic-resistant bacteria, primarily due to the overuse and misuse of antibiotics, self-medication, and the lack of awareness about the consequences of improper antibiotic use in many underdeveloped countries [5]. This surge in antimicrobial resistance (AMR) is further exacerbated by the absence of proper food safety practices among street food vendors, who often lack formal education or training in safe food handling [6].

Recent studies have reported the presence of multidrug-resistant (MDR) bacteria in street food, including *Salmonella* spp., *E. coli*, *S. aureus*, and *K. pneumoniae*, all of which are known to harbour resistance to multiple antibiotics [3,7]. In addition, strains of *Enterobacteriaceae* producing Extended-Spectrum Beta-Lactamases (ESBL) and Metallo-β-Lactamases (MBL) have been isolated from street food in several countries, further contributing to the global AMR crisis [7]. These antibiotic-resistant pathogens present a significant risk to public health, as they are more difficult to treat and can lead to severe infections, higher mortality rates, and prolonged hospital stays.

The presence of antibiotic-resistant bacteria in street food highlights the urgent need for greater regulation, food safety education for vendors, and improved sanitation practices [5]. While AMR in street food is a growing concern globally, its prevalence varies across regions, with poorer regions facing higher risks due to inadequate infrastructure, limited access to healthcare, and the widespread use of antibiotics in both humans and animals. To mitigate the spread of AMR through street food, it is crucial to implement control strategies such as increasing vendor awareness of food safety, improving hygiene practices, enforcing regulatory measures, and monitoring antibiotic use in food production [8]. Addressing these challenges is essential for reducing the burden of foodborne diseases, protecting public health, and curbing the rise of AMR worldwide.

This review critically examines the role of street food in the emergence and dissemination of AMR, discussing bacterial contamination, resistance mechanisms, and potential control strategies to reduce the public health threat posed by foodborne pathogens and antibiotic resistance. By understanding the risks associated with street food and developing effective mitigation strategies, we can work toward safer food practices that protect consumers and limit the spread of resistant bacteria.

2. Street vendor and street vending:

2.1 Street Vendors:

Vendors on streets include hawkers, peddlers, squatters, and all other synonymous terms that may be local or region specific while selling items, goods, wares, food items of everyday use to the general public in a road, lane, side walk, footpath, pavement, public park, or any other public place or private area from a temporary built-up structure or by moving from place to place [6].

2.2. Street vending:

Measure, schedule, location, pay, labor, and the kinds of goods and services offered vary according to their street vending. It might be a full-time job, a temporary position, a seasonal job, or an occasional job. It may vary from a single person to a franchise of a bigger street business, which can be a means of survival. As a result, street sellers earn very greatly. At the same time, street vendors frequently sell agricultural and manufactured goods produced at home that are difficult to market elsewhere, therefore vital for the economy. Street sellers frequently serve the urban slum because they provide cheaper goods [6].

The existence of urban open space, such as sidewalks, roads, parks, and beaches, are together related to street vending. Many of the challenges faced by them, including the general negative perception received from general public, are also related to the way that these areas are handled by the authorities. Therefore, there is a "complex combination of oppression, control, tolerance, and promotion" for street sellers [9].

The most accessible job available to the poor is street selling, which has the potential to help people escape poverty. However, it also ranks the worst in terms of urban zone competition, as seen by the sellers confronting the police and the local government's fury. It is impossible to dispute that the urban poor, who are frequently of rural origin, are only acceptable as service providers, ideally unseen, to the city elite. As a result, street vending has emerged as a significant source of both sustenance and dispute among numerous vendors and hawkers and the municipal administrators [10].

2.3 Problem faced by street food vendors:

2.3.1 Poor pay:

Despite working about 14–18 hours every day, street sellers receive very poor pay. Therefore, it seems accurate to say that, as compared to their colleagues in the official sector of the economy, the majority of street sellers are excruciatingly poor [10].

2.3.2 Weekly hafta payments:

The majority of street sellers in Indian cities operate without a license and are thus considered as breaking the law. According to estimations, between 20% and 30% of street vendors' revenue is taken as bribes by the governing bodies. The hafta, or weekly bribe, paid by hawkers at illegal locations totals around 3240 million rupees every year [10].

2.3.3 Displacement or seizure of commodities:

Police officers carry out eviction campaigns and seize or destroy the items & products of the street sellers. Action may be taken against sellers and others under Section 283 of the Indian Penal Code (IPC) who hinder pedestrian movement on footpaths or restrict the movement of vehicles [10].

2.3.4 Hostile atmosphere/brutal police action:

Street sellers work in an extremely hostile environment. They are treated horribly by the cops. A police officer splashing boiling oil on a seller after he refused to accept an offer of bribery is a recent incident [10].

2.3.5 Lack of legal sanction and ineffective selling regulation:

The majority of street sellers run their businesses illegally. As a result, they are considered unlawful. Every vendor must receive a license under the new Act [10].

2.3.6 Lack of knowledge of their rights:

Because the majority of them are uneducated, people have no understanding of their rights. They are unwilling to become involved in difficult legal processes because they lack knowledge of the law [10].

2.3.7 Labor in extremely unfavourable conditions due to a lack of basic amenities:

They lack access to adequate lighting, restrooms, drinking water, workspace, etc. One may say that the working conditions for street sellers lack decent jobs [10].

2.4 Food poisoning due to bacteria:

Foodborne illnesses are caused by specific microorganisms. The identity of the sickness usually allows one to determine the features of microbes producing foodborne illnesses. These symptoms are typically caused by the synthesis of poisonous substances by the causative agents. Exotoxins and endotoxins are two different categories of poisonous compounds. Exotoxins, also referred to as enterotoxins, are the main reason for digestive issues [11]. *Clostridium botulinum* and *S. aureus* are the two major types of bacteria that induce food poisoning. While *S. aureus* causes staphylococcal poisoning, *C. botulinum* causes botulism. *Bacillus cereus* and *Clostridium perfringens* are also recognized as food-poisoning microbes [12,13].

2.4.1 Botulism food poisoning:

When an individual ingests foods contaminated with this strain of *C. botulinum*, the toxin-producing organism causes botulism illness in the host. This bacterium produces spores and is anaerobic in nature [14].

The most prevalent signs of botulism include vomiting, diarrhea, trouble urinating, stomach ache, and constipation. These symptoms may together related to other neurological symptoms, according to experts. Three symptoms—lack of pupillary response to various cues, notably dry tongue, and onset of respiratory paralysis—are unique for botulism. The mortality rate from botulism is significant, and failure of the breathing system results in mortality. The best way to confirm the diagnosis is to perform an antibody test on a patient's blood who is exhibiting signs of botulism [14].

2.4.2 Staphylococcal food poisoning:

Dack's (1956) manual on staphylococcal is a reliable study reference. A particular coagulase-positive species type of *S. aureus* causes the typical vomiting, diarrhea, and sadness that happen 3 to 30 hours after consuming toxic food. In recent years, the two kinds of enteric toxins (type A and type B) have been identified [15].

Type A is common and primarily responsible for food poisoning in North America. Various types of food poisoning exist based on various causative factors. These include mycotoxicosis, phycotoxicosis, and viral food poisoning [15].

3. Bacterial Contamination and Resistance in Street Food

Street food plays a vital role in urban communities, providing affordable meals and preserving cultural traditions. However, the microbiological safety of such food is a growing concern worldwide due to poor hygiene during preparation and sale [3]. Studies have shown that street foods are often contaminated with faecal indicator bacteria and foodborne pathogens like *Salmonella enterica*, *Listeria monocytogenes*, and *E. coli* [16] **(Table 1)**. In Bangladesh, popular street food like Chotpoti exhibited high total viable and coliform counts, with gram-negative bacteria such as *E. coli* being prevalent [17]. Similarly, street foods in Porto, Portugal, showed poor microbiological quality, with contamination from antibiotic-resistant *E. coli* strains and clinically relevant *L. monocytogenes* [16]. These findings underscore the potential of street food to act as a vehicle for transmitting harmful bacteria, which could cause public health hazards **(Table 2)**.

Antibiotic resistance among bacteria isolated from street foods poses a significant health challenge. For instance, *E. coli* and *S. enterica* detected in ready-to-eat meats and street food samples were resistant to multiple antibiotics. Bacteria from cooked street foods demonstrated high resistance to commonly used antibiotics like Augmentin, ceftazidime, and cefuroxime, although resistance was lower to ciprofloxacin and nitrofurantoin [18]. These MDR bacteria raise concerns about the potential spread of AMR through the food chain [7]. Improved food safety knowledge and hygiene practices among vendors and consumers, along with regular monitoring and stricter sanitary measures, are crucial to reduce contamination and prevent the transmission of resistant pathogens.

3.1 The Beginnings of "Lactamases"

A class of enzymes called lactamases is found in some bacterial species and is in charge of utilizing the lactam ring to hydrolyze and inactivate antibiotics. Beginning in the 1940s, the discovery of lactamases in bacteria was made; ESBL and carbapenemases were among them. These enzyme-containing bacterial infections are seen as a new public health issue. However, being found in Gram-positive as well as Gram-negative bacteria, β-lactamases are one of the primary methods by which Gram-negative bacteria resist β-lactams [19].

E. coli's synthesis of cephalosporinase AmpC was used to describe the initial discovery of ESBL-producing Enterobacterales in 1940. *K. pneumoniae* isolates were used to explain the initial occurrence of ESBL-producing Enterobacterales in Europe in 1983 after tigecycline was used in clinical studies [7,20]. Since then, strains that produce ESBL have been discovered on practically every continent. The CDC estimates that ESBLs are responsible for around 26,000 HAI cases and 1700 fatalities annually [21].

Between 1980 and 1990, hospital and hospital-acquired epidemic of *K. pneumoniae* isolates manufacturing ESBL (Temorina *E. coli* mutant-1, Temorina *E. coli* mutant2, and Sulfhydryl variant -1) occurred as a result of genetic alterations in classical β-lactamases (TEM-1, TEM-2, and SHV-1). These bacteria are known to cause nosocomial infections that have a high risk of death. Only in the United States in 2017, infections brought on by ESBL strains resulted in 9100 fatalities [21]. The majority of antibiotics frequently used as a last option are said to be ineffective against ESBL-producing types of bacteria. Carbapenems are the only remaining therapeutic choice in such circumstances. Before the emergence and proliferation of carbapenemase-producing bacteria, carbapenems were one of the medications in the treatment of MDR infections due to their broad range of bactericidal activity and stability against most β-lactamases [20].

The three groups of enzymes that make up the ESBL are called TEM, SHV, and CTX-M. These enzymes are spread by clonal proliferation and transmission of resistance genes ($bla_{\text{CTX-M}}$, bla_{SHV}, bla_{TEM}, and their variations) via plasmids, which causes outbreaks to spread quickly [22]. The majority of TEM-type ESBLs are found in *E. coli* and *K. pneumoniae*, but they can also be found in other members of the Enterobacterales family and other Gram-negative bacteria. They are developed from TEM-1 and TEM-2 (non-ESBL). They come in more than 130 varieties and can hydrolyse monobactams, 1st, 2nd, 3rd generation cephalosporins, ampicillin& other antibiotics. The SHV-type ESBLs, which are mostly seen in Enterobacterales which share their hydrolysis activity with the TEM-type ESBLs. SHV-type includes over 50 different kinds of ESBLs developed from SHV-1 (a non-ESBL) [22]. Cefotaxime can be hydrolysed by ESBLs of the Cefotaximase-Munich type, as well as cephalosporins, penicillins, and monobactams. They have about 40 different varieties, are widespread around the world, and are mostly found in the family Enterobacterales. Furthermore, they are separated into five subgroups based on their shared amino acid sequences: CTX-M-1, CTX-M2, CTX-M-8, CTX-M-9, and CTX-M-2 **(Figure 2)** [17].

3.2 Common MDR Pathogens in Street Food:

Several studies have identified MDR pathogens in street food **(Table 3)**, including the following AMR bacteria.

3.2.1 *E. coli* (ESBL-producing):

Since the 2000s, MDR *E. coli*, resistant to oxyimino-cephalosporins and fluoroquinolones, has become a global concern, affecting both clinical settings and healthy individuals. These strains commonly produce ESBL and exhibit quinolone resistance through chromosomal mutations and plasmid-mediated determinants. High fecal carriage rates of ESBL-producing *E. coli* have been particularly noted in Asia and South America, with their rapid spread linked to diverse factors such as livestock, food, pets, and environmental sources. This highlights the complexity of AMR and underscores the need for global awareness and further investigation [22]. ESBL-producing *E. coli* accounts for 6.6% of community-acquired and 26.8% of hospital-acquired bacteraemias, demonstrating high resistance to cephalosporins, ciprofloxacin, and trimethoprim. Mortality rates are significantly higher in patients with ESBL infections (60.8%) compared to those with non-ESBL infections (23.7%), with delayed antibiotic treatment contributing to increased mortality **(Table 3)**. However, no significant difference has been observed in time to death or hospital stay duration between patients with ESBL and non-ESBL infections. The ongoing rise in ESBL variants, plasmids, and international clones underscores the urgent need for improved antimicrobial stewardship and intervention strategies [23].

3.2.2 *K. pneumoniae* (Carbapenem-resistant):

The rise of carbapenem-resistant *K. pneumoniae* (CRKP) presents a significant public health challenge, as carbapenems are considered the last-line treatment for life-threatening infections **(Table 3).** Resistance is primarily mediated by plasmid-encoded carbapenemases, such as KPC, and other enzymes like metallo-β-lactamases, leading to the rapid global dissemination of CRKP. This pathogen is associated with severe healthcare-related infections, including pneumonia and bloodstream infections, with notably high mortality rates. Common risk factors for CRKP infections include Intensive Care Units (ICU) admission, use of certain antibiotics (e.g., β-lactams, cephalosporins, fluoroquinolones), and the presence of indwelling devices like urethral catheters.

Mortality is further exacerbated by factors such as advanced age, comorbidities, and aminoglycoside use [24,25]. To manage CRKP infections, experts recommend combination therapy over monotherapy due to the limited efficacy and potential toxicity of alternative treatments. However, the optimal combination regimen, the role of carbapenems in therapy, and the timing for initiating combination therapy remain uncertain [40]. Infection control strategies, including stringent hand hygiene, contact precautions, antimicrobial stewardship, and active surveillance, are crucial to limit the spread of CRKP. Early identification of CRKP and measures to protect immune function are essential for reducing morbidity and mortality in healthcare settings [25].

3.2.3 *P. aeruginosa* (Efflux pump-mediated resistance)

Efflux pump-mediated resistance (EPO) plays a crucial role in *P. aeruginosa's* fluoroquinolone resistance and MDR **(Table 3).** Overexpression of efflux pumps reduces susceptibility to fluoroquinolones like levofloxacin, ciprofloxacin, and moxifloxacin. Notably, levofloxacin-resistant strains show a higher prevalence of EPO, often coupled with resistance to piperacillin-tazobactam, ceftazidime, and imipenem. The use of efflux pump inhibitors (EPIs), such as MC-04,124, significantly decreases the minimum inhibitory concentration (MIC) of levofloxacin, underscoring the potential of EPIs in combating MDR in *P. aeruginosa* [26]. Resistance mechanisms can also arise from target mutations in topoisomerase genes or increased expression of multidrug efflux pumps, which expel antimicrobial agents. Ciprofloxacin resistance studies have shown that the EPI PAβN significantly reduces resistance by lowering MIC values. Efflux pump overexpression was identified in 35% of ciprofloxacin-resistant isolates, occurring at varying frequencies in isolates resistant to gentamicin, ceftazidime, and imipenem. These findings highlight the impact of fluoroquinolone overuse and the potential of EPIs in restoring susceptibility to multiple antipseudomonal agents [26,27]. *P. aeruginosa's* intrinsic resistome, low membrane permeability, and biofilm formation further reduce antibiotic susceptibility. Its resistance mechanisms prominently feature multidrug efflux pumps, including *MexAB-OprM*, *MexXY*, *MexCD-OprJ*, and *MexEF-OprN*, all members of the RND superfamily. These pumps expel antibiotics, contributing to MDR. *MexAB-OprM*, a key contributor to resistance against quinolones and β-lactams, is regulated by genes like *mexR*, *nalC*, and *nalD*. *MexXY* is associated with aminoglycoside resistance and is often overexpressed in cystic fibrosis isolates. *MexCD-OprJ* is linked to fluoroquinolone resistance, while *MexEF-OprN*, though typically inactive, can enhance resistance when overexpressed. Understanding efflux pump overexpression is vital for developing new antibiotics to counter MDR in *P. aeruginosa* [27].

3.2.4 *S. aureus* (Methicillin-resistant)

Methicillin-resistant *S. aureus* (MRSA) has become a major concern in clinical settings due to its diverse virulence factors and resistance to β-lactams, as well as its often MDR **(Table 3)**. The clinical presentations of MRSA infections range from asymptomatic nasal colonization to severe invasive diseases with high mortality rates. The emergence of MRSA was first noted in the early 1960s, with a moderate increase in resistance between 1960 and 1963, followed by a significant rise from 1968 onwards. This resistance is largely attributed to the widespread use of penicillins and related antibiotics, which have facilitated the selection and survival of resistant strains. Despite limited treatment options, ongoing research is focused on the development of novel antimicrobials and vaccine candidates. A comprehensive understanding of MRSA's colonization dynamics, transmission pathways, and risk factors for infection, along with factors driving resistance, is critical for improving prevention and control strategies [28,29].

3.3 Resistance Mechanisms

MDR bacteria in street food exhibit diverse resistance mechanisms, and an examination of AMR in *Salmonella* isolates from 300 meat products (raw beef, chicken, and street foods) revealed significant resistance patterns, with tetracycline (73.8%) and sulfonamide (63.6%) being the most common. A total of 88 non-duplicate *Salmonella* isolates, including 11 serovars, showed high MDR (67%), with resistance genes such as bla_{TEM-1}, *str*A, *strB*, *sulI*, and *tetA* being identified. Plasmid-mediated resistance genes, including bla_{TEM} and bla_{CTX-M}, facilitate the rapid dissemination of resistance [30]. *Salmonella* from street food and retail meats may transfer resistance to humans through food consumption, especially with the presence of mobile genetic elements, such as integrons, which enable horizontal gene transfer (HGT) and further resistance spread. Efflux pumps, which expel antibiotics from bacterial cells, and biofilm formation enhance bacterial survival on surfaces, increasing the potential for contamination. Additionally, an investigation into the microbiological safety of Ready-to-eat (RTE) street foods in Porto found that food samples and food handlers carried *Enterobacteriaceae*, *E. coli*, and *L. monocytogenes*, with some *E. coli* strains showing multidrug resistance, including to clinically relevant antibiotics [16]. This underscores the critical role of food handlers as a risk factor in the contamination of food with antimicrobial-resistant pathogens. The study highlights that street food can serve as a vehicle for the spread of antibiotic-resistant bacteria and pathogens, reinforcing the need for better hygiene practices and safety measures in this growing food sector **(Figure 3)** [30,16].

3.3.1 Plasmid-mediated resistance:

Plasmid-mediated resistance plays a critical role in the dissemination of antibiotic resistance, particularly in *E. coli* and *K. pneumoniae*, which are common producers of ESBLs. Studies have shown that mobile genetic elements, such as the $bla_{CTX\text{-}M}$, bla_{TEM}, and bla_{SHV} genes, facilitate the rapid spread of resistance across bacterial populations. In a study conducted from December 2016 to November 2017, 276 clinical isolates from patients with wound and urinary tract infections were analyzed for the presence of ESBL genes. The results revealed a high prevalence of ESBL-producing *E. coli* (68.2%) and *K. pneumoniae* (31.8%), with the bla_{TEM}, bla_{SHV}, and $bla_{CTX\text{-}M}$ genes detected in 55%, 35%, and 45% of the isolates, respectively [31]. The mobile nature of these resistance genes, often carried on plasmids, enables them to be transferred between bacteria, exacerbating the global threat of antibiotic resistance. This ability to share resistance genes is facilitated through various mechanisms, including HGT via plasmids, which can carry multiple resistance genes simultaneously. This process significantly contributes to the rapid spread of antibiotic resistance, particularly against β-lactams, in clinical settings. Understanding these molecular mechanisms is crucial for developing strategies to combat the rise of resistant bacteria [32].

3.3.2 Efflux pumps:

Efflux pumps play a crucial role in the antibiotic resistance mechanisms of many bacterial pathogens, particularly in Gram-negative species, by expelling antibiotics before they can reach their intended targets within the bacterial cells. These transport proteins are found in both Gram-positive and Gram-negative bacteria and contribute significantly to MDR, making antibiotic treatments ineffective. For example, the *AcrAB-TolC* system in *E. coli* and the *MexAB-OprM* system in *P. aeruginosa* can extrude a wide variety of antibiotics, including fluoroquinolones, β-lactams, and chloramphenicol [33]. The expression of these efflux pumps is often regulated by specific genes, and their overexpression can occur due to mutations or stress conditions, leading to cross-resistance to different antibiotics. This over-expression results in reduced drug accumulation within bacterial cells, contributing to resistance against a broad spectrum of antimicrobial agents [34]. EPIs have been developed as a potential solution to counteract this resistance by restoring the effectiveness of antibiotics. When used alongside antibiotics, these inhibitors have been shown to lower resistance levels in clinical isolates, offering a promising approach to combating MDR pathogens [31].

3.3.3 Biofilm formation:

Biofilms are microbial communities that adhere to surfaces in various environments, including food processing areas, where they pose significant health and safety risks. These surface-attached communities are encased in extracellular polymeric substances, which provide protection against antimicrobial agents, sanitizers, and other hostile conditions, contributing to their persistence in food processing environments [35]. Biofilm formation is a complex process influenced by genetic mechanisms and factors such as the properties of bacterial surfaces and the substratum [36]. In the food industry, biofilms can harbor spoilage and pathogenic bacteria, increasing the risk of post-processing contamination and foodborne diseases. Bacteria within biofilms exhibit enhanced resistance to cleaning and disinfection processes, complicating efforts to maintain food hygiene. Biofilms are also a concern in medical settings, where they can form on implants and human tissues, contributing to chronic infections and antibiotic resistance [35,36]. Understanding the mechanisms behind biofilm formation, including their growth requirements and resistance strategies, is crucial for developing effective control methods to mitigate their impact on food safety and medical contexts. Research on bacterial biofilms is vital for improving food safety, developing biofilm-free food processing systems, and implementing effective biofilm removal strategies to protect public health [37].

3.3.4 Horizontal Gene Transfer (HGT):

HGT is a vital mechanism by which bacteria acquire new genetic material, significantly contributing to their evolution and the spread of beneficial traits. Three primary mechanisms of HGT—conjugation, transformation, and transduction—allow bacteria to share genes, including those responsible for antibiotic resistance. Conjugation, a direct exchange of genetic material between bacterial cells, often involves the transfer of plasmids containing resistance genes, which can rapidly spread antibiotic resistance within bacterial populations. Transformation occurs when bacteria take up free DNA from their environment and incorporate it into their genome, contributing to adaptability and microbial diversity. This process plays an essential role in both laboratory settings and natural environments, where bacteria exchange genetic material to survive changing conditions [38]. Transduction, the transfer of genetic material via bacteriophages, also contributes to the spread of resistance genes by moving them between bacterial species [39]. The significance of HGT in the context of AMR is profound, as the acquisition and dissemination of resistance genes via these mechanisms accelerate the emergence of resistant pathogens. The review emphasizes the urgent need to better understand HGT mechanisms and their implications for combating AMR [38].

4. Environmental Factors Contributing to Contamination

Street food trading provides affordable, ready-made meals and employment opportunities in developing countries, but is often associated with unregulated practices, leading to significant food safety risks. One critical factor contributing to contamination is the poor hygiene and safety practices followed by food vendors, particularly in informal settings. For example, a study on ESBL-producing *E. coli* in foods of animal origin found high contamination rates in raw foods, environmental samples, and RTE foods, with a large number of the isolates being MDR [40]. Additionally, vendors' use of untreated or contaminated water, such as municipal water with high total bacterial count, has been identified as a major source of microbial contamination in fruit juices sold in urban markets. *E. coli*, *Salmonella*, and *Vibrio* contamination levels were particularly high in sugarcane and mixed fruit juices. The informal nature of street food businesses, coupled with inadequate agricultural practices, hazard analysis, and critical control point strategies, exacerbates the risk of foodborne diseases. Thus, addressing these environmental factors through proper hygiene practices and stricter regulation can significantly reduce contamination risks and enhance food safety [41].

4.1 Hygiene and Sanitation Deficiencies

Street vendors often lack access to clean water, adequate waste disposal, and proper hand hygiene facilities **(Figure 4)**. A study in India found that 73.3% of vendors did not wash their hands after handling food, and 40% chewed tobacco while preparing meals. In many developing countries, hygiene and sanitation deficiencies pose significant risks to public health, especially concerning food safety. These deficiencies are often exacerbated by inadequate technology, equipment, and infrastructure for testing product quality, which are prevalent in food-exporting nations. Studies have shown that poor hygiene practices in exporting countries contribute to contamination of imported foods, with foodborne pathogens being transmitted via human excreta, improper sanitation, contaminated water, insects, and soil. The lack of regulatory frameworks around street food trading also contributes to poor hygiene, with vendors often not adhering to recommended safety standards. This leads to considerable health risks for both vendors and consumers [42]. Similarly, sanitation and hygiene practices in rural areas, such as in Nepal, have direct associations with undernutrition, parasitic infections, and diarrhoea in children. A study on water, sanitation, and hygiene (WASH) conditions revealed that children living in households with inadequate hygiene were more likely to suffer from nutritional deficiencies and diarrhoea, linked to factors such as intermittent water supply, unhygienic environments, and poor handwashing practices [43]. In street food markets, poor sanitation practices often lead to contamination of food items, raising concerns about foodborne illnesses and the overall safety of the food supply chain. The adoption of improved sanitation practices, hygiene education, and stricter enforcement of public health policies are essential steps toward mitigating the risks associated with hygiene and sanitation deficiencies [41].

4.2 Contaminated Water Sources:

Many vendors use untreated water for food preparation and utensil washing, facilitating microbial persistence and contamination. The contamination of food in street food vending is often linked to the use of unsafe water sources. In markets, studies have shown that access to a toilet facility and running water plays a crucial role in reducing the risk of food contamination. Vendors with access to running water around their toilet facilities and for food preparation exhibited significantly lower rates of food contamination, highlighting the importance of clean water for hygiene practices. However, vendors who lacked access to these facilities experienced higher contamination risks, especially those who reported the presence of pests and rodents, further exacerbating the problem [44]. Similarly, in Southeast Asia, many street food vendors still use non-tap water, such as bucket water, which significantly contributes to foodborne illnesses due to contamination. A systematic review of water hygiene practices among street vendors in the region found that the reliance on unhygienic water sources increases the likelihood of contamination, emphasizing the need for better water management and hygiene systems in the street food sector [44]. Moreover, various studies have linked poor water quality to food safety issues in street food vending, identifying microorganisms such as *Bacillus*, *Staphylococcus*, and *Salmonella* as common contaminants, underscoring the importance of proper water hygiene in preventing foodborne diseases [45].

4.3 Seasonal Influence on Bacterial Proliferation:

Hot and humid conditions favor bacterial growth, increasing contamination risks during peak summer months. The microbial safety of street foods can be heavily influenced by the seasonal conditions in which the food is prepared, stored, and sold. A study in India examined the food safety practices of street-food vendors in Hyderabad and Delhi and found that vendors in high-income areas with better education and resources were more likely to follow safety standards. However, despite regulations, vendors across various socioeconomic groups still failed to implement basic food safety practices such as proper sanitation, use of soap, access to tap water, and refrigeration for food storage [46]. This inconsistency in food safety adherence, particularly during warmer seasons, contributes to higher bacterial proliferation. Similarly, a study focused on the microbial quality of popular street foods highlighted the influence of improper handling, personal cleanliness, and lack of awareness about foodborne illnesses, resulting in high bacterial counts in street foods such as grilled chicken and fried fish. The total viable counts of these foods exceeded acceptable limits, showing how the warm weather and improper food handling during peak street vending seasons exacerbate bacterial growth, leading to an increased risk of foodborne infections [47]. These findings emphasize the need for improved hygiene practices among street-food vendors, particularly during seasons conducive to bacterial growth.

5. Choice of effective antibiotics:

The frequency of hospital-borne MRSA and, until recently, VRE was reduced because of a combined interhospital infection management plan. According to a care-bundle strategy has been developed, which includes a list of requirements for adequate hand washing and sanitary procedure during invasive procedures [48]. Despite the absence of peer-reviewed data, Singapore now seems to be reducing infections caused by central lines in accordance with global trends. When colonized patients' medical records were electronically tagged, enhanced environmental cleaning, active patient monitoring of high-risk patients, and identified individuals were isolated [49].

Unlike several regions of Europe, where the baseline prevalence of MRSA is low, comprehensive decontamination and elimination of MRSA is necessary. The medical facilities are still an unreachable objective. Although isolation of Gram-negative MDR organisms' carriers is intended to minimize infection transfer, control will be challenging due to the already existing local burden and the impact of community epidemics from neighbouring nations in which these microorganisms are being found in external sources [49].

In Asia, the management of antibiotics is still in its early stages. Although Singapore uses more broad-spectrum antibiotics than the majority of wealthy nations, AMR is also greater. It is challenging to separate cause from effect. In Singaporean hospitals, up to 38% of the prescribed antibiotics might be deemed inappropriate (mainly due to failing to de-escalate when culture results were revealed) [50]. All of the main hospitals in Singapore currently exercise antimicrobial management, which has been shown to reduce readmissions for infections and shorten hospital stays. The impact on AMR has not yet been demonstrated. There are no recent statistics on community prescribing. Antibiotics need a prescription in the Singaporean population, unlike most other Asian nations [51].

Most Asian nations still lack robust surveillance systems. Singapore has increased monitoring to show leadership in the area and aid in the detection of new forms of resistance. In addition to levels of broad-spectrum antibiotic usage, every hospital must report rates to the Ministry of Health for MRSA, VRE, carbapenem-resistant *Acinetobacter baumannii.* and *P. aeruginosa*, third-generation cephalosporin-resistant and carbapenem-resistant *E. coli*, and *K. pneumoniae*. The response against antibiotic resistance within medical centers and residential care homes is coordinated by a National Antibiotic Task Force. In order to better prepare for upcoming difficulties, this effort attempts to formalize channels of communication between healthcare facilities and track clinical and molecular epidemiology [51]. Future resistant species are likely to spread swiftly across national lines, as expected. Containment necessitates a planned, worldwide strategy.

6. Epidemiological Data and Global Trends

Foodborne illness is considered a major public health, economic, and social concern that comprises a broad spectrum of diseases and is a major cause of morbidity and mortality in the present scenario [52]. Foodborne diseases are caused by to consumption of contaminated food, and this contamination is caused by bacteria, viruses, parasites, poisonous chemicals, or may be biological toxins [53]. The result of this foodborne illness mainly manifests as gastrointestinal illness, which affects about 1 out of 10 people suffering from it due to food contaminated with microbial and chemical contaminants. It is estimated that 600 million illnesses, 420000 deaths, and 3.3 million healthy lives were lost globally, and about 2 million deaths worldwide in 2005 [52].

More than 250 different foodborne illnesses are caused due to different pathogens or toxins. Specifically, norovirus (a total of 120 million cases) & different kinds of *Campylobacter* (96 million cases) were responsible for a total of 550 million of the anticipated 600 million reported cases of sickness, of the 4,20,000 fatalities attributed to foodborne dangers, 2,30,000 were also caused by agents that cause diarrheal diseases. Of these, 26,000 fatalities were brought on by enterotoxigenic *E. coli*, 37,000 by *E. coli* that is enteropathogenic, 35,000 by norovirus, and 59,000 by non-typhoidal *S. enterica* [54].

MDR microbial food poisoning is a global health issue that is getting worse. These strains frequently carry third-generation cephalosporin resistance genes, making them one of the main therapeutic options for treating illnesses brought on by *Enterobacteriaceae* that are immune to first-line drugs. As a result, the World Health Organization (WHO) has advised that intestinal microbes that produce ESBL should be monitored [55]. When the poisonous food is consumed, *Enterobacteriaceae* from the surroundings can enter the human digestive system. Therefore, a healthy society depends on food with excellent microbiological purity. Unlike regulated eateries and hygienically made dinners at home.

A precise diagnosis, along with rapid therapy, is required to ensure the prevention of foodborne diseases. The problem that arises in this process is when the medications used to treat bacterial foodborne diseases stop working. Antibiotic use, which results in the development of AMR, is a main reason for unsuccessful treatment. Antibiotic resistance to MDR is a global issue caused by the emergence of robust bacterial species. These MDR pathogen-caused outbreaks are linked to challenging and limited therapeutic choices, higher mortality, and more hospitalizations [56].

Bacterial strategies for resistance have grown to be an important concern is an outcome to their prevalence in the environment, including in beverages and food. The excess and abuse of antibiotics, which place a selective strain on bacteria, is the epidemiological cause for the development of antibiotic resistance. As a result, robust strains become more varied, and other species can share their resilience. The danger to human health posed by the existence of ESBL-producing microorganisms in food is significant. The epidemiological importance of RTE meals makes it necessary to analyze them [57].

According to the Centers for Disease Control's 2019 Antibiotic Resistance Threats Report, the mortality rate brought on by antibiotic resistance is a serious health issue that accounts for more than 23,000 fatalities annually in the US alone.

Moreover, over 33,000 in Africa [58]. Although estimates are tough to come up with for this subject, the number of fatalities is expected to rise from the current worrying level to more than 10 million by the year 2050. Due to overpopulation, extremely crowded nations like India witness the greatest occurrence of growth of these drug-resistant strains [59].

Three distinct processes, resistance, acceptance, and persistence, are used by bacteria to overcome the antimicrobial effects of antibiotics. Bacterial growth in the presence of elevated levels of antibiotics is referred to as resistance, and it is brought on by hereditary alterations. The drug target, the antibiotic molecule, or the efflux pumps are the mechanisms adapted by bacteria for antibiotic resistance [60]. Water, animals, inanimate objects, people, plants, and food are only a few examples of habitats where resistant populations can be discovered. A considerable increase in the MIC of antibiotics is needed to efficiently kill resistant bacteria because they can grow when antibiotic pressure is applied, their resistance phenotype is inheritable, and they can proliferate under antibiotic pressure [61].

The misuse and overuse of antibiotics leading to an increase in bacterial competition is regarded as the epidemiological cause for the increasing prevalence of antibiotic resistance. That leads to strong strains to diversify and for other species to share the resilience [61].

6.1 Antibiotic Resistance and risk of death globally:

While AMR in street food is a global concern, its prevalence varies across regions. In the European Union, for instance, multi-resistant bacteria contribute to around 25,000 deaths annually, with differing morbidity rates for resistant and susceptible microbes [62] **(Table 4) (Figure 5)**. A notable example is *A. baumannii*, which, once not considered particularly harmful, has emerged as a significant issue, especially in ICU. This bacterium exhibits multiple resistances and can cause a range of illnesses. Between 2003 and 2011, *A. baumannii* caused mortality rates in European nations ranging from 3% to 67% [63]. In the UK, carbapenem resistance in *A. baumannii* rose from 0% in 2000 to 55% in 2006, and patients with carbapenem-resistant strains had a higher mortality rate (16.4%) compared to those with non-resistant strains (5.4%) [64]. A Spanish study found that over 370 individuals were infected with or transmitted *A. baumannii*, with a death rate of 53.8% in comparison to 31.0% in patients infected by a different strain [65].

Similarly, CRKP has emerged as a significant concern. The KPC enzyme found in *K. pneumoniae* can hydrolyze a wide range of beta-lactam antibiotics, contributing to its resistance [40]. This resistance was first observed in a hospital setting in the US in 1996, and by 2003, a point mutation led to the discovery of KPC-2. Studies have shown that patients with CRKP infections have higher mortality rates than those with non-resistant strains. For example, in a Greek study, 42.9% of patients with CRKP died, compared to 18.9% of those with non-resistant *K. pneumoniae* [66]. In Israel, CRKP infections had a mortality rate of 44%, significantly higher than the 12.5% for patients with carbapenem-sensitive *K. pneumoniae*. In Spain, patients infected with or carrying CRKP had a mortality rate of 45.5%, compared to 30.9% for control patients [67].

MRSA continues to be a leading cause of infections in healthcare settings worldwide. MRSA strains were first identified in the UK in 1960 and have spread globally, often causing severe medical issues such as heart infections and septic shock [68]. Studies on MRSA-related mortality in ICU patients have shown a death rate of 29.1% for MRSA infections compared to 20.5% for methicillin-sensitive *S. aureus* (MSSA), with general mortality rates of 36.4% and 27.0%, respectively. In the US, patients with MRSA infections had a significantly higher mortality rate (23.6%) compared to those with MSSA (11.5%) [69].

6.2 Reported cases of microbial-related diseases nationally and internationally:

A reliable indicator of sanitation and control of temperature processes utilized for the production of food is the overall number of germs per gram of food. The probability of contracting foodborne organisms in the food increases with the diversity of bacteria involved. In India, there are hardly any known cases of food illness. Between 1980 and 2009, the cases of bacterial food-related illnesses recorded in India there were 24 outbreaks involving 1,130 people. In these epidemics, antibiotic-resistant *S. aureus*, *Vibrio*, *Salmonella*, *E. coli*, and *Yersinia enterocolitica* were found to be the major bacterial pathogens [53,3,4] **(Table 5)**.

From 2009 to 2018, a total of 2688 foodborne illness incidents, 153,745 illnesses, and 572 fatalities were submitted to IDSP during the tenyear span. A median of 269 breakouts, 15,375 sicknesses, and 57 fatalities were recorded annually. With a peak of 3.2 in 2016, the average yearly incidence of foodborne illness incidents was 2.2 occurrences per 10,000,000 people. Major sickness cases occurred in 2013 and 2016, impacting 22,177 as well as 23,425 people, respectively, and making up 30% of all food-borne illness cases, *Salmonella, E. coli, Vibrio parahaemolyticus, S. aureus,* and *B. cereus* are the most prevalent bacteria to cause food-borne illnesses in India [70] **(Table 6)**.

7. Surveillance and Mitigation Strategies:

The emergence of AMR in street-vendor food has significant public health implications due to widespread bacterial contamination, inappropriate antimicrobial use, and the lack of effective regulatory frameworks [8]. Irrational antimicrobial prescribing contributes to financial and societal burdens, with AMR increasingly recognized as a chronic healthcare sector challenge [71]. WHO has emphasized prevention through the Global Action Plan on AMR, approved in 2015, which focuses on improving WASH practices, especially in food preparation and distribution environments. Contaminated surfaces, food, and water serve as major reservoirs of resistant microbes, necessitating robust interventions to combat AMR. For example, the Swachh Bharat Abhiyan and Kayakalp initiatives in India have effectively promoted hygiene and Infection IPC programs, while Bangladesh's regulated pharmacy system and North Korea’s nationwide sanitation coverage demonstrate the importance of governance in mitigating AMR spread [72, 73]. Furthermore, increasing the use of vaccines targeting pathogens commonly associated with street-vendor foodborne illnesses, such as *Haemophilus influenzae* type B and *Streptococcus pneumoniae*, can reduce reliance on antibiotics [74]. Antimicrobial stewardship programs (ASPs) and educational campaigns aimed at healthcare professionals and the public are critical to improving rational antimicrobial use and fostering behavioural change. Multisectoral collaboration, regulatory enforcement, and innovative measures such as bacteriophage therapy, probiotics, and faecal transplants offer promising alternatives to traditional antibiotics, particularly in resource-constrained settings [75]. These strategies, coupled with targeted surveillance of bacterial contamination in street-vendor food and stringent monitoring of antimicrobial consumption, are essential to countering the growing threat of AMR globally. Legislative and institutional frameworks must prioritize equitable access to effective antimicrobials while enhancing vaccination rates, particularly in low- and middle-income countries (LMICs) where the AMR burden is disproportionately high [45].

7.1 Strengthening Microbial Surveillance:

Routine microbial testing of street food should be implemented to detect and control MDR pathogens. Enhanced microbial surveillance is crucial for detecting pathogens with pandemic potential. Prioritizing symptomatic patients, sick or dead animals, and high-risk locations like markets and abattoirs enables early identification. Techniques such as multiplex nucleic acid amplification, next-generation sequencing, and SISPA increase detection accuracy. Surveillance at the human-animal interface, including high-risk species like bats and pangolins, helps identify zoonotic threats. Testing pathogens in animal and human organoids, along with evaluating their transmissibility and pathogenicity, can guide the development of diagnostics, treatments, and vaccines. Sustained efforts in surveillance and preventive strategies are essential to mitigate future spillover events [76].

7.2 Vendor Training and Awareness:

Foodborne diseases are a significant concern in LMICs, where traditional market vendors face challenges in ensuring food safety due to poor infrastructure, limited resources, and regulatory gaps. Educational programs targeting vendors' knowledge, attitudes, and practices are crucial to improving food safety standards. These programs should focus on proper food handling techniques, emphasizing safe storage and preparation practices, the importance of hand hygiene to prevent contamination, and the use of clean water for washing food, utensils, and hands. Research indicates that while vendors generally have positive attitudes toward food safety, their knowledge and practices often fall short, with unsafe handling and storage practices being common. By involving local government staff and tailoring training to address vendors’ specific needs, these programs can help bridge knowledge gaps, foster compliance with food safety regulations, and promote sustainable improvements in traditional markets [77].

7.3 Policy and Regulatory Recommendations:

Governments must enforce strict hygiene regulations to enhance food safety standards and mitigate public health risks. Key recommendations include:

7.3.1 Licensing Requirements for Street Vendors:

Implement mandatory licensing systems with accessible and affordable preconditions to ensure compliance while considering the economic constraints of informal vendors [78].

7.3.2 Regular Inspection and Penalties for Non-Compliance:

Strengthen regulatory oversight by increasing inspection frequency and imposing penalties for violations to promote adherence to hygiene and safety guidelines, particularly during health crises like the COVID-19 pandemic [79].

7.3.3 Introduction of Affordable Microbial Testing Kits:

Provide cost-effective microbial testing solutions for vendors to encourage regular self-monitoring and compliance with safety standards [80].

These measures, when combined with vendor training, improved communication strategies, and culturally sensitive public awareness campaigns, can drive better food safety practices and protect public health.

8. Future Research Directions

8.1 Development of Rapid Diagnostics:

Point-of-care AMR detection in street food samples. Future research should focus on developing rapid diagnostics for AMR detection in street food samples, addressing a critical gap in food safety monitoring. Leveraging advances in point-of-care (POC) technologies, including CRISPR-based diagnostic tools and biosensors, could enable precise, cost-effective, and portable detection of AMR directly in street food environments. These innovative tools, integrated with amplification technologies and potentially enhanced by AI and machine learning, offer the potential to revolutionize on-site testing. Such advancements would not only improve the surveillance of AMR in high-risk settings but also support better regulatory compliance and public health outcomes by facilitating timely interventions.

8.2 Biofilm Inhibition Strategies:

Exploring novel antimicrobials to prevent bacterial persistence on surfaces. Research on biofilm inhibition strategies is gaining momentum, emphasizing the development of novel antimicrobials to prevent bacterial persistence on surfaces. Current approaches face limitations due to the protective nature of biofilms, which renders them resistant to traditional treatments like antibiotics and mechanical debridement. Novel strategies focus on disrupting the extracellular polymeric substance matrix that shields biofilm-forming bacteria. Promising avenues include molecular dispersal agents capable of inducing microbes to degrade their biofilms, quorum-sensing inhibitors to prevent biofilm formation, and nanotechnology-based solutions to enhance antimicrobial delivery. Combinatorial therapies, which integrate multiple mechanisms of action, show great potential to address recalcitrant biofilm infections and antibiotic resistance. However, translating these innovations from in vitro studies to in vivo applications remains a critical challenge. Advancing biofilm inhibition research through preclinical and clinical trials is essential to develop effective solutions for managing biofilm-associated infections in medical, industrial, and environmental settings.

8.3 Impact of Climate Change on AMR Spread:

The impact of climate change on the spread of AMR is an emerging area of concern, particularly in relation to how rising temperatures influence pathogen survival in food systems. Human activities driving climate change are resulting in rapid shifts that have been observed across various domains, including socioeconomic, environmental, and natural contexts. The increasing global temperatures and changes in precipitation patterns are affecting the survival, reproduction, and spread of pathogens, with significant implications for food safety. For example, the alteration of temperature and humidity can enhance the persistence and virulence of foodborne pathogens, contributing to an increased risk of foodborne diseases. Additionally, climate change influences the behavior and distribution of disease vectors, such as ticks and mosquitoes, which could further complicate food safety in regions where these vectors are common. Pathogens such as those responsible for West Nile virus, Chikungunya, and other vector-borne diseases may proliferate as their vectors expand their range due to climate change. Understanding the complex interactions between rising temperatures, pathogen survival, and AMR in the context of food systems is essential for developing effective strategies to mitigate these risks. Given the critical role of climate change in shaping microbial dynamics, future research must prioritize investigating these linkages to protect public health and food security in a warming world.

Table 1. Bacterial contamination and resistance in different street foods in different places worldwide.

S. No	Study focused	Key finding
1.	Contamination in chutney in Nepal	According to Adhikari *et al.* (2023), *E. coli* was detected in 27.33% of samples, with a MDR rate of 65.85%. Similarly, *Salmonella* was present in 20.67% of samples, exhibiting an MDR rate of 45.16%.
2.	Contamination in fruits/vegetables in Delhi	According to Saksena *et al.* (2020), 97.3% of samples were contaminated, with *E. coli* detected in 17.4% of them. Additionally, the presence of ESBL and MDR isolates was reported.
3.	RTE food contamination in Pakistan	According to Hasan *et al.* (2021), 38% of samples were deemed unfit for consumption, while *Salmonella* spp. was detected in 40% of samples. The isolates exhibited high resistance to erythromycin and amoxicillin.
4.	MDR bacteria in Bangladesh street food	According to El-Sayed (2021), high levels of MDR bacteria were detected, including *E. coli, S. aureus,* and *Enterococcus faecalis*.
5.	Antibiotic resistance in bacteria from cooked food	According to Adeleke *et al.* (2023), 50 isolates exhibited high resistance to Augmentin (96%) and Ceftazidime (96%). Additionally, MDR was associated with plasmid-mediated resistance.

Table 2. Bacterial contamination, resistance, and common MDR pathogens in street food worldwide.

S. No	Region	Sample type	Pathogens Identified	Key Finding
1.	Nepal	Chutney	*E. coli, Salmonella spp.*	According to Adhikari *et al*. (2023), *E. coli* was detected in 27.33% of samples, including seven *E. coli* O157:H7 isolates, while *Salmonella* was present in 20.67% of samples. The MDR rates were 65.85% for E. coli and 45.16% for *Salmonella*.
2.	India	Fresh produce, RET	*E. coli*, coliforms	According to Saksena *et al.* (2020), 97.3% of samples were contaminated, with the presence of ESBL-producing and carbapenem-resistant isolates.
3.	Bangladesh	Phuchka, Chatpati	*E. coli, Klebsiella spp., Salmonella spp.*	According to Hasan *et al.* (2021) and Khan and Saha (2015), a high microbial load and MDR bacteria were detected, with resistance to common antibiotics such as ampicillin.
4.	Algeria	RTE sandwiches, soups, and salads	*E. coli*, *K. pneumoniae*	According to Zaatout *et al*. (2023), ESBL-producing strains were detected, including *bla*$_{CTX\text{-}M\text{-}1}$ and *bla*$_{CTX\text{-}M\text{-}15}$, posing a risk of foodborne transmission.
5.	Pakistan	RTE food	*S. enterica*	According to Thong *et al.* (2011), 40% of unfit samples were contaminated with *Salmonella*, which exhibited high resistance to erythromycin and amoxicillin.
6.	Ghana	Street food (salads, fufu)	*E. coli, Salmonella spp.*	According to Karikari *et al.* (2022), 100% of the isolates were MDR, with a high prevalence of resistance to β-lactams.
7.	Ecuador	RTE street food	*E. coli*	According to Zurita *et al.* (2020), ESBL genes (*bla*$_{CTX\text{-}M\text{-}15}$, *bla*$_{CTX\text{-}M\text{-}55}$) were identified, and epidemic clones such as ST410 and ST131 were detected.
8.	Nigeria	Cooked street foods	Multiple Gram-positive and Gram-negative species	According to El-Sayed (2021), high resistance was observed to Augmentin (96%), Ceftazidime (96%), and cephalosporins. Additionally, MDR plasmid genes were detected.
9.	Taiwan	RTE street foods	*Pseudomonas spp., Acinetobacter spp.*	According to Lin *et al.* (2017), 86.4% of *Acinetobacter* spp. were MDR, with ceftazidime resistance attributed to efflux pumps and ESBL genes.
10.	Netherlands	Poultry and retail chicken meat	*E. coli, Klebsiella spp.*	According to Leverstein *et al.* (2011), SBL genes (*bla*$_{CTX\text{-}M\text{-}1}$, *bla*$_{TEM\text{-}52}$) were shared between human and poultry isolates.

Table 3. Common MDR pathogens in street food (identified MDR pathogens in street food).

S. No	Pathogen	Sample type	Resistance Traits
1.	*E. coli*	Chutney, vegetables, RET	According to Adhikari *et al.* (2023), ESBL-producing (*bla*$_{CTX-M}$) and carbapenem-resistant MDR isolates were detected, with high resistance to β-lactams.
2.	*K. pneumoniae*	RET food (India, Algeria)	According to Giri *et al.* (2021), ESBL-producing (*bla*$_{TEM}$, *bla*$_{CTX}$, *bla*$_{SHV}$) and carbapenemase-producing (*bla*$_{NDM}$) isolates were detected, with MDR.
3.	*S. enterica*	RTE foods, street food	According to Ehuwa *et al.* (2021), MDR to tetracycline, sulfonamide, and ampicillin was observed, and it was associated with invasive infections and outbreaks.
4.	*S. aureus*	Street food	According to Sina *et al.* (2011), toxin-producing strains were detected, including *MRSA* isolates, with MDR observed.
5.	*P. aeruginosa*	Clinical, environmental, and poultry	According to Odoi *et al.* (2021), high resistance to antipseudomonal agents was observed, with β-lactamase production and efflux mechanisms detected.
6.	*Campylobacter jejuni*	Poultry products	According to Munck *et al.* (2020), isolates exhibited resistance to fluoroquinolones (ciprofloxacin) and macrolides (erythromycin), with MDR observed.
7.	*L. monocytogenes*	RTE meat and dairy	According to the European Food Safety Authority (2018), MDR strains exhibited resistance to tetracyclines and erythromycin, along with biofilm-forming capability.
8.	*Vibrio parahaemolyticus*	Seafood	According to Simpson *et al.* (2018), environmental isolates exhibited resistance to ampicillin and penicillin, with MDR traits observed.
9.	*Shigella dysenteriae*	Street food, salads	According to Solomon *et al.* (2018), resistance to quinolones, tetracyclines, and sulfonamides was observed, with ESBL-producing and MDR strains.
10.	*B. cereus*	RTE foods, rice dishes	According to Lin *et al.* (2017), resistance to penicillin and cephalosporins was observed, with MDR strains identified in foodborne outbreaks.
11.	*E. faecalis*	Street food	According to Ehuwa *et al.* (2021), high resistance to vancomycin (*VRE*) was observed, with MDR strains detected.
12.	*Proteus mirabilis*	Meat-based Street foods	According to Zurita *et al.* (2020), MDR was observed against quinolones, β-lactams, and sulfonamides.
13.	*C. perfringens*	Cooked food and meat dishes	According to Karikari *et al.* (2022), resistance to penicillin and clindamycin was observed, along with toxin-producing strains.
14.	*A. baumannii*	RTE foods and hospital settings	According to Hasan *et al.* (2021), high resistance to carbapenems and aminoglycosides was observed, with MDR strains detected.
15.	*Y. enterocolitica*	Pork and dairy products	According to Thong and Modarressi (2011), resistance to ampicillin and cephalosporins was observed, with MDR associated with outbreaks.

Table 4. % of Death rate due to the following bacteria based on the resistant strain and sensitive strain (Bhatnagar *et al.*, 2021).

Bacteria	Death rate (resistant strain) (%)	Death rate (sensitive strain) (%)
E. coli [23]	32	17
A. baumanii[25]	16.4	5.4
A. baumanii[19]	53.8	31.0
K. pneumoniae[26]	42.9(CRKP)	18.9
K. pneumoniae[10]	43.8(CRKP)	12.5
K. pneumoniae [28]	38	12
S. aureus [14]	36.4(MRSA)	27.0
S. aureus[14]	23.6(MRSA)	11.5

Table 5. Reported foodborne disease outbreaks due to bacteria in India during 1980- 2018.

S.No	**Year of outbreak**	**Places**	**Microorganisms found**	**Disease and symptoms**	**Reference**
1	1983	Vellore	*V.paraheamolyticus*	Gastroenteritis, bloody diarrhea, watery diarrhea	[53,3,4]
2	1985	Delhi	*Salmonella welteverden*	Acute watery diarrhoea within 12 hr of taking food	
3	1985	Bihar	*Salmonella bornum*	Salmonellosis	
4	1987	Haryana	*S. aureus*	Gastrointestinal illness, diarrhoea	
5	1990	Pune	*Vibrio fluvialis*	Extra-intestinal infection, food poisoning due to the consumption of raw fish	
6	1993	Army unit	*S. aureus*	Gastrointestinal illness, diarrhoea	
7	1995	Maharashtra	*Salmonella Paratyphi A Var durazoo*	Acute gastro enteritis (salmonellosis)	
8	1997	Tamil Nadu	*Y. enterocolitica*	Yersiniosis due to eating raw or undercooked pork	
9	1998	Western Himalaya	*Salmonella enteritidis*	Gastro enteritidis	
10	2007	Madhya Pradesh	*S. aureus*	Gastrointestinal illness, diarrhoea	
11	2008	Mangalore	*Salmonella wein*	Salmonellosis	
12	2009	Kerala,Mangalore	*Salmonella*	Salmonellosis	[70]
13	2010	Rajasthan	*B. Cereus*	Emetic (vomiting), gastrointestinal illness	
14	2011	Uttar Pradesh	*E. coli*	Diarrhea, stomach cramps	
15	2012	Himachal Pradesh	*V.paraheamolyticus*	Gastroenteritis, bloody diarrhoea, watery diarrhoea	
16	2013	Maharashtra	*Salmonella spp.*	Salmonellosis	
17	2014	Punjab	*S. aureus*	Gastrointestinal illness, diarrhoea	
18	2015	Tamil Nadu	*Vibrio vulnificus*	Watery diarrhoea, stomach cramping, chills, fever	
19	2016	West Bengal	*S aureus*	Gastrointestinal illness, diarrhoea	
20	2017	Odisha	*Salmonella spp.*	Salmonellosis	
21	2018	Assam	*Vibrio spp.*	Cholerae	

Table 6. Food and microbial research work in India.

S. No	Food and microbial research work conducted in India	Places	Year
1	According to Mudey *et al.* (2010), food handlers in the Wardha District of Maharashtra, India, working as food service providers near a rural teaching hospital, were studied for their health status and personal hygiene.	Maharashtra	2010
2	According to Okhuebor *et al.* (2021) and Rane *et al.* (2011), microbial risks and the security of the ready-to-eat food being sold on the sidewalks of Amravati City, India, were studied.	Amaravati	2008
3	According to Sudershan *et al.* (2014), foodborne illnesses and food poisoning in Hyderabad, India, were studied.	Hyderabad	2017
4	According to Sharma *et al.* (2022), the prevalence of water- and food-borne diseases in Ahmedabad City, India, is influenced by sociodemographic heterogeneities.	Ahmedabad	2022
5	According to Malhotra *et al.* (2008), the understanding and perceptions of food handlers involved in a healthcare institute in Delhi, India, regarding health education were analyzed.	Delhi	2008
6	According to Raghupathi *et al.* (2022), the bacteriological state of street-vended foodstuffs and their medical significance were studied in Buldana District, Maharashtra, India, as a case study.	Buldana. MS	2012
7	According to Debnath *et al.* (2018), a *Shigella sonnei* outbreak of foodborne illness was reported in West Bengal, India.	West Bengal	2018
8	According to Sharma *et al.* (2021), a study evaluating food handlers in the cafeterias of multiple medical centers in Solapur City, Maharashtra, identified palm contagion among food handlers.	Maharashtra	2019
9	According to Solanki *et al.* (2019), *B. cereus* isolates were sampled from various chicken shops in and around the market in Anand, Gujarat, India. The study involved cultural and biochemical identification of *B. cereus* extracts and MDR screening of *B. cereus* isolates.	Gujarat	2019

Figure 1. Transmission and resistance mechanisms of MDR bacteria through street food and community interaction.

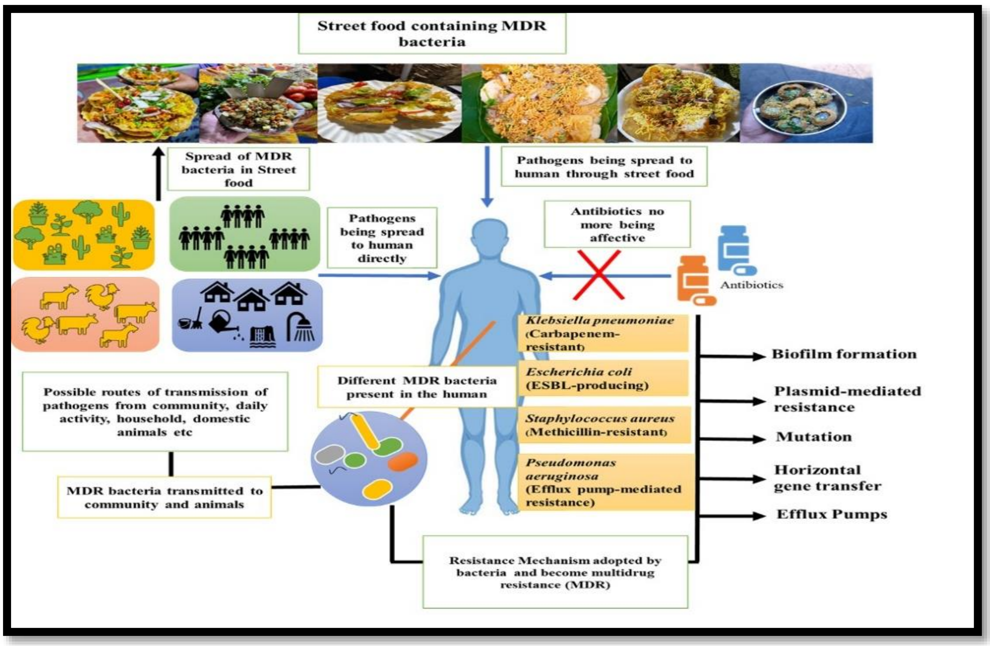


Figure 2. Timeline for the introduction and beginning of antibiotic resistance in Gram-negative bacteria.

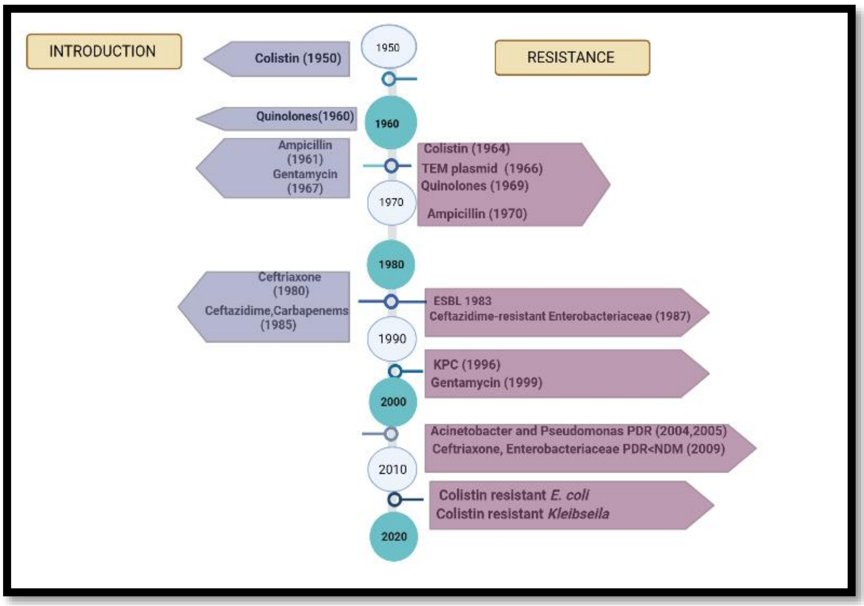


Figure 3. Mechanisms of antibiotic resistance in bacteria.

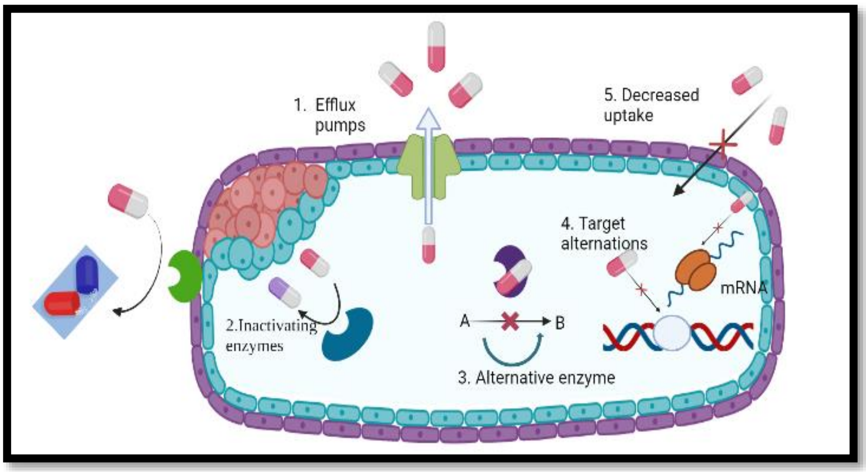
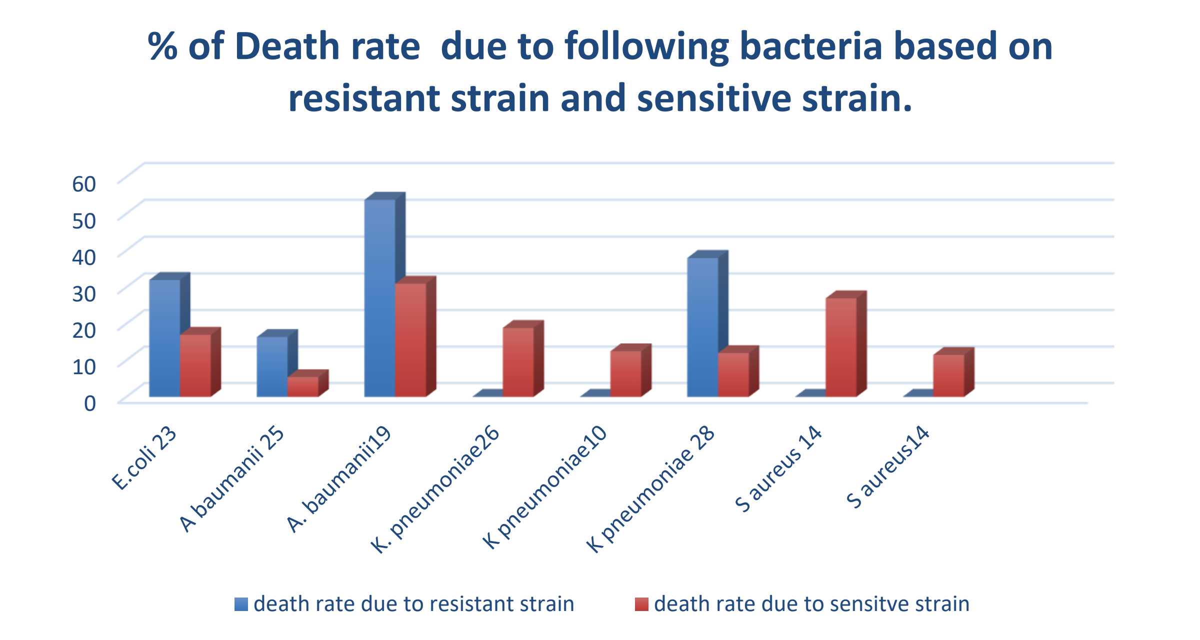


Figure 4. Microbial contamination in street food is due lack of hygiene and sanitation**.**

Figure 5. Death rate due to resistant and sensitive bacterial strains.



Conclusion

The widespread presence of MDR bacteria in street vendor food poses a significant public health challenge, particularly in urban areas where such food is a vital source of nutrition for economically disadvantaged populations. Addressing this issue requires a multifaceted approach that integrates enhanced microbial surveillance, stricter regulatory enforcement, and community-based strategies. Advanced diagnostic tools and systematic monitoring can help identify contamination hotspots and ensure compliance with food safety standards, while educating vendors on hygiene practices and the risks of antibiotic misuse can promote safer food handling. Governments must prioritize stricter hygiene regulations, access to clean water and sanitation for vendors, and the introduction of affordable microbial testing kits to empower self-monitoring. On a global scale, international collaboration is essential to standardize safety protocols, share surveillance data, and foster innovation in alternative antimicrobials, such as bacteriophages and probiotics. By implementing these strategies, we can mitigate the risks of MDR bacteria in street food, reduce foodborne illnesses, and enhance public health outcomes worldwide.

Conflict of interest

There are no conflicts of interest

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